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GROUPS OF DWARF GALAXIES IN THE LOCAL SUPERCLUSTER

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Abstract. We present a project on study of groups composed of dwarf galaxies only. We selected such structures using HyperLEDA and NED databases with visual inspection on SDSS images and on digital copy of POSS. The groups are characterized by size of few tens of kpc and line-of-sight velocity dispersion about 18 km s^{-1}. Our groups similar to associations of nearby dwarfs from Tully et al. (2006). This specific population of multiple dwarf galaxies such as I Zw 18 may contain significant amount of dark matter. It is very likely that we see them at the stage just before merging of its components.

1 Introduction

The modern mass surveys of galaxy redshifts like 2dF (Colless *et al.* 2001), HIPASS (Zwaan *et al.* 2003), 6dF (Jones *et al.* 2004), ALFALFA (Giovanelli *et al.* 2005) and SDSS (Abazajian *et al.* 2009) give us extensive opportunities to refine and improve our knowledge about the structure of our Universe. In the series of papers (Karachentsev & Makarov 2008; Makarov & Karachentsev 2009, 2011) we have studied the distribution and properties of galaxy groups on scale of the Local supercluster. During this work we found surprisingly high fraction of groups consisting of dwarf galaxies. Some very interesting objects happen to be among these groups. It is famous metal deficient galaxy I Zw 18. The pair of extremely metal-poor blue compact dwarf HS 0822+3542 and low surface brightness object SAO 0822+3545 were studied by Chengalur *et al.* (2006). It seems that gas rich galaxies with very low metallicity (Ekta *et al.* 2006) appear quite often among the systems from our sample. On the other hand, Tully *et al.* (2006) pointed out the existence in the Local Volume of associations of galaxies which exclusively consist of dwarfs. That associations were identified based on 3D map of nearby galaxies

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with distances of high precision. These structures can contain big amount of dark matter and the mass-to-light ratios are in the range 100–1000 M/L in solar units. Our systems are related to Tully's association of dwarfs and they also could have very high mass-to-light ratio.

We have started spectroscopic survey of galaxies from our sample on Russian 6-meter telescope of SAO RAS. In this work we describe the selection and analyse the properties of groups of dwarf galaxies in the Local supercluster.

2 The data

We use the HyperLEDA[1] (Paturel *et al.* 2003) and the NED[2] databases as main sources of data on radial velocities, apparent magnitudes, morphological types and other parameters of galaxies. A blind use of database is fraught with false and erroneous data. Both databases contain a significant amount of 'spam': objects with erroneous radial velocities that come from the mass sky surveys such as 2dF etc. Quite common case is a confusion of coordinates and velocities of galaxies located close to each other on the sky. Apparent magnitudes and radial velocities from the SDSS survey often correspond to individual knots and associations in bright galaxies. We have taken into account and corrected different kind of contamination of the databases. As a matter of fact it is most hard and time-consuming part of our work.

Additionally, we made a number of optical identifications of HI sources from the HIPASS survey, specifying their coordinates and determining the apparent magnitudes and morphological types of galaxies (Karachentsev *et al.* 2008). Many dwarf galaxies, especially of low surface brightness, were examined by us on the DSS digital images to determine their magnitudes and morphological types.

We use K-band photometry as indicator of stellar mass of a galaxy because it is weakly affected by a dust and young blue star complexes in the galaxy. Most of near-infrared photometry comes from the all-sky 2MASS survey (Jarrett *et al.* 2000, 2003). In case of lack of K-band photometry we transferred the optical (B, V, R, I) and near infrared (J, H) magnitudes into the K-magnitudes as it described in series of our papers (Karachentsev & Makarov 2008; Makarov & Karachentsev 2009, 2011). Note that because of short exposure the 2MASS survey turned out to be insensitive to the galaxies with low surface brightness and blue colour. Thus we have the direct near-infrared measurements for about 65% of galaxies in our sample and for 35% the K magnitude was estimated from optic.

We collected 10914 galaxies with radial velocities in the Local Group rest frame of $V_{LG} < 3500$ km s^{-1}, located at the galactic latitudes $|b| > 15°$. The sample of such a depth contains the entire the Local supercluster with its distant outskirts, surrounding voids and ridges of the neighbouring clusters.

[1] http://leda.univ-lyon1.fr
[2] http://nedwww.ipac.caltech.edu

3 The algorithm

Our algorithm (Karachentsev 1994; Makarov & Karachentsev 2000) for group selection is based on natural requirement that total energy of physical pair of galaxies has to be negative.

$$\frac{V_{12}^2 R_{12}}{2GM_{12}} < 1, \tag{3.1}$$

where M_{12} is the total mass of the pair, and G is the gravitational constant. However, observations give us only radial velocities and the sky-plane projected distance between the galaxies. Two galaxies with a very small difference in radial velocities but a large separation in the sky can meet the condition (3.1) without being mutually bound. Hence the condition of negative total energy of the pair, expressed in terms of the observables must be added by another restriction on the maximal distance between the components at their fixed mass M_{12}. The condition when the pair components remain within the sphere of 'zero-velocity' (Sandage 1986) takes the form of

$$\frac{\pi H_0^2 R_\perp^3}{8GM_{12}} < 1, \tag{3.2}$$

where H_0 is the Hubble constant.

We determined the masses of galaxies from their integral luminosity in the infrared K_s-band, supposing that they have the same mass-to-luminosity ratio

$$M/L_K = \kappa(M_\odot/L_\odot), \tag{3.3}$$

where κ is taken equal to 6. In the fact, the value of $\kappa = 6$ is only more or less arbitrary parameter of the algorithm. To bound it we 'trained' the clusterization algorithm (3.1–3.3) on detailed three-dimensional distribution of galaxies in the Local Volume (Karachentsev *et al.* 2004), where the membership of galaxies in the groups is known from good quality photometric distances. The choice of $\kappa = 6$ is the compromise between a loss of the real members and an impurity of groups by false members. For the $\kappa \leq 4$ we lose significant number of real members while $\kappa \geq 8$ leads to appearance in the groups suspicious members. Moreover, for $\kappa \geq 10$ galaxies are combined into extended non-virialized aggregates. At the given value of $\kappa = 6$ the dwarf companions in the well-known nearby groups are usually located inside the zero velocity surface around the major galaxies of these groups.

4 Basic properties of the groups of dwarfs

This section contains short description of main properties of groups in the Local supercluster (Makarov & Karachentsev 2011). We gathered 5926 objects of 10914 galaxies in 1082 groups. The 395 groups have a population of $n \geq 4$ members. The dispersion (σ_V) in well populated ($n \geq 4$) groups ranges from 10 to 450 km s^{-1} with the median of 74 km s^{-1}. The mean harmonic radius of the groups is

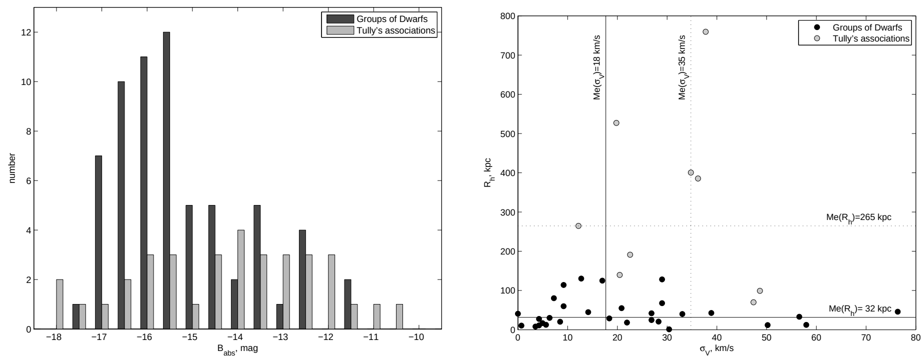

Fig. 1. The left panel shows luminosity function of galaxies in comparison with associations of dwarfs (Tully *et al.* 2006). The distribution of velocity dispersion and harmonic radius of the groups of dwarfs in comparison with Tully's associations is shown on the right panel.

distributed over a wide range from 7 kpc to 750 kpc with a median of 204 kpc. The median crossing time of selected systems is 2.2 Gyr. Only 2% of groups fall have estimation of crossing time higher than age of Universe (13.7 Gyr). Consequently, almost all of the selected by our criterion groups can be considered as dynamically evolved systems. The groups are characterized by median mass corrected for measurement error $M_p^c = 2.3\,10^{12} M_\odot$ and mass-to-luminosity ratio in K-band $M/L = 22\ M_\odot/L_\odot$.

The special interest are drawn by the groups where brightest member has absolute magnitude below $M_K = -19$ (the luminosity of the SMC). Surprisingly, the sample of groups of dwarf galaxies contains 30 such systems. It corresponds to at least 3% of the all groups in the Local supercluster. The distribution of the groups over the sky is highly inhomogeneous. We have found only 2 systems outside of zone of SDSS survey. Our sample of galaxies is subjected to different kind of observation selection. Therefore, it is impossible to estimate the incompleteness of the sample, but it seems that the number of such systems should be quite significant. The dispersion of radial velocities in groups of dwarfs (σ_V) is less than 80 km s^{-1} with the median of 18 km s^{-1}. The projected size of groups is less than 200 kpc. The median values of harmonic radius is 32 kpc. Thus, the groups of dwarfs are much more compact and they have significantly smaller velocity dispersion than normal groups in the Local supercluster.

The luminosity function of the groups of dwarfs is shown on Fig. 1 (left panel). The groups of dwarfs (dark gray bars) occupy the same range of absolute magnitudes as the Tully's associations of dwarf galaxies (light gray bars) (Tully *et al.* 2006). Unlike to nearby galaxies our sample is very incomplete. It explains the sharp drop of the number of galaxies bellow $M_B = -16$ absolute magnitude. The Fig. 1 (right panel) illustrates the relation between sizes and velocity dispersions in the groups and associations. The groups and associations have quite comparable

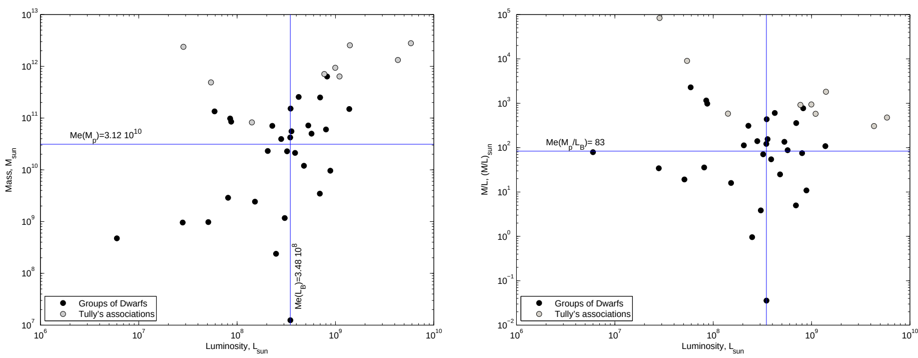

Fig. 2. The mass-luminosity relation for groups under consideration is presented on left panel. The mass-to-light ration versus luminosity for sample of groups of dwarf galaxies is shown on right panel.

velocity dispersion 18 and 35 km s^{-1} respectively, while the size of groups (32 kpc) is significantly smaller than size of associations (265 kpc). This big difference in sizes of groups and associations is explained by different method of system selection. Our algorithm is oriented to find a bounded and virialized groups of galaxies, while the associations of dwarf were selected by correlation in position, velocity and distances of nearby galaxies. The median value of luminosity of the groups is $3.5\,10^8\ L_\odot$ in B-band and median of mass is $3.1\,10^{10}\ M_\odot$. It lead to mass-to-light ratio of 83 in solar units. Despite of mass of the groups is systematically lower then mass of the association, the groups of dwarfs form continuous sequence with Tully's association (see Fig. 2).

5 Conclusion

In the last decade the modern mass redshift survey significantly increase the number of galaxies with known velocity in the Local supercluster. We developed the algorithm of group selection which is base on on natural requirement that total energy of bounded pair of galaxies has to be negative (Karachentsev & Makarov 2008; Makarov & Karachentsev 2009, 2011). Application of our method to new data has allowed us to find interesting kind of groups which consist of only dwarf galaxies. The number of such groups is surprisingly high. They amount at least 3% of the all groups in the Local supercluster.

Most of the galaxies in our sample are blue and show sign of ongoing star formation. The galaxies of very low metallicity like I Zw 18 or HS 0822+3542 appear quite often among of them (Chengalur *et al.* 2006; Ekta *et al.* 2006).

The groups of dwarfs are characterized by size of 32 kpc and velocity dispersion of 18 km s^{-1}. These values are significantly smaller then sizes and inner motion in ordinary groups in the Local supercluster (204 kpc and 74 km s^{-1}, respectively). The groups of dwarfs form continuous sequence with association of dwarfs which were found by Tully *et al.* (2006) using precise distance determination. The groups have about the same luminosity and velocity dispersion as association but associations are significantly wider. The median value of mass-to-light radio of groups of dwarfs is 83 $M_{\odot}/L_{\odot}$. It indicates that such kind of groups contains significant amount of dark matter.

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