Small Galaxy Groups
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A new catalogue of multiple galaxies in the Local Supercluster

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Abstract.
A new approach is suggested which makes use of the individual properties of galaxies, for the identification of small galaxy groups in the Local Supercluster. The criterion is based on the assumption of closed orbits of the companions around the dominating group member within a zero velocity sphere.

The criterion is applied to a sample of 6321 nearby galaxies with radial velocities $V_0 \leq 3000$ km s^{-1}. These 3472 galaxies have been assigned to 839 groups that include 55% of the sample considered. For the groups identified by the new algorithm (with $k \geq 5$ members) the median velocity dispersion is 86 km s^{-1}, the median harmonic radius is 247 kpc, the median crossing time is $0.08(1/H)$, and the median virial-mass-to-light ratio is 56 $M_\odot/L_\odot$.

1. Grouping criterion

Over the last years the number of galaxies with known radial velocities has grown greatly. This is true for distant volumes as well for the nearby volume of the Local Supercluster. For instance, the Nearby Galaxies Catalog by Tully (1988) contains 2367 galaxies, whereas last version of the LEDA Database (Paturel et al, 1996) collects about 6900 objects in the same volume of the Local Supercluster. The new observational data give us grounds to consider the assignment of nearby groups again.

For the selection of small galaxy groups we apply a new percolation algorithm based on an approach proposed by Karachentsev (1994). Unlike in earlier approaches, where individual properties of galaxies were not fully utilised, we consider pairwise interactions of galaxies and assume the total energy for each physical pair to be negative.

The condition of closed orbits can be expressed as the kinetic and gravitational energy ratio:

$$\frac{\mathrm{T}}{\Omega} = \frac{V^2 R}{2G \sum \mathcal{M}} < 1 \tag{1}$$

where R and V are the linear separation in space and the space velocity difference respectively, $\sum \mathcal{M}$ is the total mass of the pair, and G is the gravitational constant. However, because of projection effects this condition itself does not allow one to distinguish false pairs with small radial velocity difference.

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Therefore, the condition (1) must be adopted with a limitation on the maximum galaxy separation in a pair. Such a natural bound is the "zero-velocity" surface, which separates the collapsing volume against expanding space (Sandage, 1986). In the case of a spherically symmetric expansion it can be expressed as:

$$\frac{\pi^2 R^3 H^2}{8G \sum \mathcal{M}} < 1 \tag{2}$$

where H is the Hubble parameter.

It should be noted that both conditions are conservative with respect to projection factors, i.e. for each real bound pair they remain true. On the other hand, the group catalogue may still be polluted by optical pairs.

Our algorithm for group selection is a kind of percolation method. At the first step it reveals pairs satisfying the conditions (1) and (2). At the second step all pairs with common components link together into a group. Finally, if a galaxy turns out to be a companion of several more massive galaxies, we choose from these combinations the most massive attractor. Particularly, one group can form a subgroup inside more massive one. Therefore, our criterion combines the advantages of a "friends-of-friends" companionship to a hierarchic "dendrogram" approach.

Each galaxy mass can be estimated from its luminosity or amplitude of its rotation curve. We use the first case, because it can be applied to all the galaxies considered. We apply the mass-to-light relation seperately for different galaxy types. The "total" mass has been derived as

$$\mathcal{M} = \kappa \mathcal{M}_{25} \tag{3}$$

where $1/\kappa$ is the mass fraction within a standard galaxy radius. According to numerous data on rotation curves of galaxies we assume as an average $\kappa \approx 3$ (Hoffman et al., 1996; Broeils & Rhee, 1997).

2. Application of the criterion

The described algorithm was applied to a sample of galaxies from the LEDA Database (Paturel et al, 1996), updated by the latest observations.

We selected galaxies with radial velocities less than 3000 $\mathrm{km\,s^{-1}}$ after correction for the Solar motion with respect to the centroid of the Local Group. The "Zone of Avoidance" region due to the Milky Way was excluded:

$$\begin{cases} V_0 < 3000 \ \mathrm{km\,s^{-1}} \\ |b| > 10^\circ \end{cases} \tag{4}$$

We kept the central part of the Virgo cluster in order to check the efficiency of the method in crowded regions. In all, 6321 galaxies were collected for analysis, which is 2.5 times the number in the catalogue by Tully (1988).

Apparent magnitudes of galaxies were corrected for the Galactic extinction using the new IRAS/DERBE map (Schlegel et al, 1998). All other photometric corrections were made following the LEDA manner (Paturel et al, 1996). To correct heliocentric radial velocities we used the apex parameters from Karachentsev & Makarov (1996). A Hubble constant of 70 $\mathrm{km\,s^{-1}\,Mpc^{-1}}$ was adopted.

3. Results

The criterion allows us to identify 839 galaxy groups of different multiplicity. In total these groups contain 3472 galaxies, i.e. 55 percent of the considered galaxy sample. For different parameters of the groups their median values and quartiles are presented in the table.

Table 1. The median parameters of the groups.

k	N	$M_v/\sum L$	σ_V	R_h	$\tau_L H_0$
2	424	18^{+39}_{-14}	24^{+22}_{-13}	170^{+185}_{-114}	$0.21^{+0.45}_{-0.15}$
3	158	32^{+34}_{-22}	41^{+19}_{-18}	191^{+157}_{-88}	$0.15^{+0.16}_{-0.09}$
4	72	28^{+39}_{-13}	52^{+30}_{-18}	187^{+135}_{-77}	$0.10^{+0.10}_{-0.05}$
5	47	42^{+39}_{-24}	57^{+26}_{-14}	230^{+92}_{-99}	$0.10^{+0.12}_{-0.04}$
6	27	50^{+51}_{-31}	87^{+29}_{-32}	176^{+93}_{-70}	$0.06^{+0.06}_{-0.02}$
7	21	52^{+71}_{-12}	96^{+38}_{-24}	189^{+150}_{-45}	$0.06^{+0.03}_{-0.01}$
≥ 5	185	56^{+40}_{-28}	86^{+38}_{-28}	247^{+89}_{-87}	$0.08^{+0.06}_{-0.03}$
≥ 8	90	60^{+38}_{-28}	102^{+26}_{-33}	284^{+83}_{-101}	$0.08^{+0.05}_{-0.03}$
≥ 20	11	80^{+42}_{-39}	159^{+23}_{-74}	298^{+223}_{-10}	$0.08^{+0.03}_{-0.02}$
all	839	29^{+41}_{-20}	40^{+35}_{-20}	194^{+148}_{-106}	$0.14^{+0.22}_{-0.08}$

There is no correlation between the velocity dispersion and the distance to the groups; neither is there a correlation between their virial-mass-to-light ratio and the group distance (see fig. 1). We conclude that our clustering algorithm does not introduce a considerable distance bias to the dynamical parameters of the groups.

The median velocity dispersion in groups increases with group membership. For groups with $k \geq 5$ it is just 86 km s^{-1}, being considerably lower than in the Geller & Huchra (1983) catalog. The maximum value of radial velocity dispersion, 287 km s^{-1}, is comparable to the rotational velocity amplitude in typical giant galaxies. The histogram of group velocity dispersion is shown in fig. 2.

The median harmonic radius (see fig. 3) for galaxy systems (with ≥ 5 members) is 247 kpc.

The median crossing time for the same groups is only $0.08H$, which indicates that most of the galaxy groups are in a virialised state (see fig. 4).

The virial-mass-to-luminosity ratio grows with the number of galaxies in a group, and for rich systems with $k \geq 5$ its median is 56 $M_\odot/L_\odot$. The derived quantity indicates the existence of a moderate amount of dark matter in the groups. The histogram of mass-to-light ratios is presented in fig. 5.

As is seen in fig. 6, there is a tendency of increasing M/L ratio with increasing harmonic radius of the groups.

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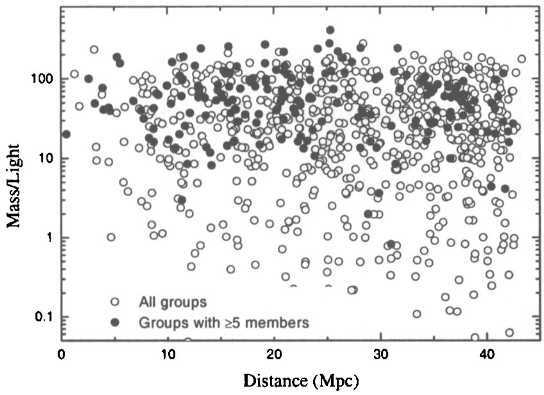

Figure 1. Mass-to-light ratio versus distance to groups.

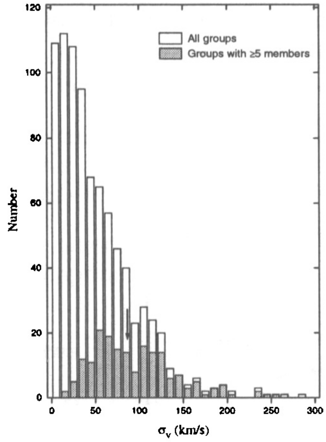

Figure 2. Histogram of velocity dispersion. The arrow indicates the median value of 86 $\mathrm{km\,s^{-1}}$ for groups with ≥ 5 members.

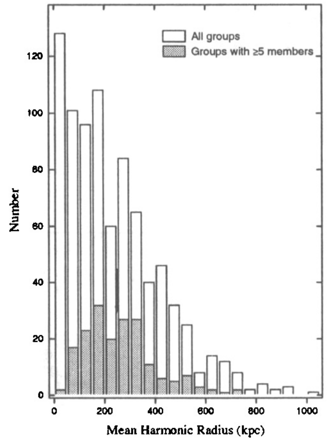

Figure 3. Mean harmonic radius. The arrow point out the median value of R_h = 247 kpc for groups with ≥ 5 members.

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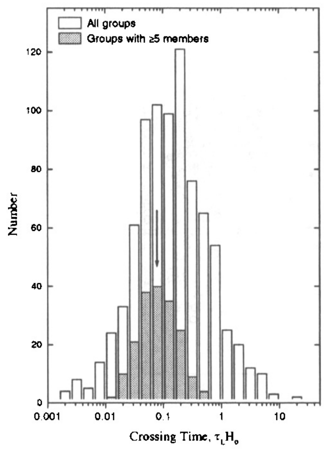

Figure 4. The histogram of crossing time. The median value for the "rich" groups with ≥ 5 members of $\tau_L H_0 = 0.08$ is indicated by the arrow.

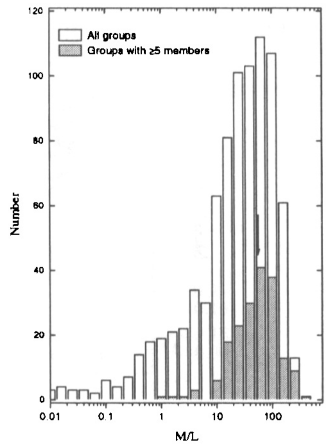

Figure 5. Mass-to-light ratio. The median value of 56 for the large groups with ≥ 5 members is indicated by the arrow.

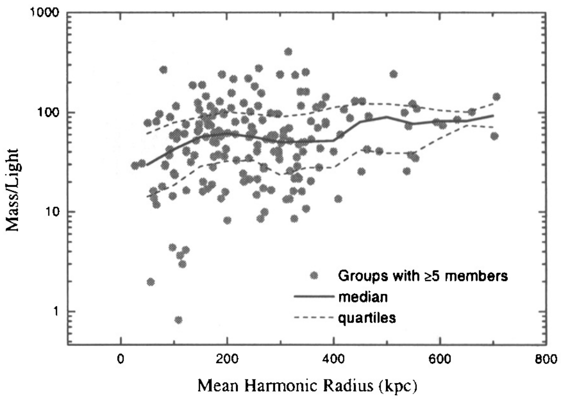

Figure 6. Mass-to-light ratios as a function of harmonic radius of group.

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The proposed algorithm is best suited to low density regions like the Local Group. But, in fact, it allows us also to distinguish some groups in the Virgo cluster. Two groups with populations of about 80 members each were recovered around the giant galaxies NGC 4486 and NGC 4472. These probable subclusters in the Virgo have been also noted by other authors. However, one should be careful with the parameters of groups selected in the central part of rich clusters, because this method needs better physical grounds to be applied to regions of high overdensity.

4. Conclusions

- We propose an algorithm for group selection which takes account of individual galaxy properties in their pairwise interaction and is based on a linkage of galaxies with negative mutual total energy.
- For an assumed value of $\kappa = 3$ (where $1/\kappa$ is the mass fraction within a standard galaxy radius) about 55 % of the galaxies have been grouped.
- The dynamical parameters of the groups show no dependency on their distance.
- In rich groups the velocity dispersion is about 70 to 80 $\mathrm{km\,s^{-1}}$, which differs considerably from the quantity obtained by Geller & Huchra (1983). The maximum velocity dispersion in the groups reaches 287 $\mathrm{km\,s^{-1}}$.
- The median crossing time is about 0.08 of the Hubble time which points to a virialized state in many of the groups.
- The median virial-mass-to-luminosity ratio is about 56 $M_\odot/L_\odot$, which shows a presence of moderate amount of dark matter in small galaxy groups.
- The algorithm is intend for selection of small groups, but probably can be also applied to distinguish substructures in galaxy clusters.

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