Properties of Nearby Groups of Galaxies

© S.-M. Niemi [1,2,3], P. Nurmi [1], P. Heinämäki [1], M. Valtonen [1]

[1] University of Turku, Tuorla Observatory, Finland
[2] Nordic Optical Telescope, Santa Cruz de La Palma, Spain
[3] Email: saniem@utu.fi

Abstract: We have compared numerical simulations to observations for the nearby groups of galaxies (Huchra & Geller and UZC-SSRS2 catalogues). The dynamical properties of groups of galaxies identified from the ΛCDM simulations are within 2σ agreement with the observational catalogues of groups of galaxies. About 20 to 50 per cent of nearby groups of galaxies, identified by the same algorithm as in the case of observations, are not bound, but merely groups in a visual sense. This is significant, because estimations of group masses in observations are often based on an assumption that groups of galaxies identified by the friends-of-friends percolation algorithm are gravitationally bound objects. Our study also shows that discordant redshifts in small galaxy groups arise when these groups are gravitationally unbound and the dominant galaxy of the group is misidentified. Our results indicate that there is no need to introduce any "anomalous" redshift mechanism to explain the redshift excess of Arp.

1. Introduction

Groups of galaxies contain a large fraction of all galaxies in the Universe [e.g. 1, 2, 3, 4, 5, 6]. These density enhancements are important cosmological indicators of the distribution of matter in the Universe, and may provide important clues for galaxy formation. Groups of galaxies are, in general, divided into a large number of different classes, for example, loose groups [e.g. 7, 8, 9], poor groups [e.g. 10, 11], compact groups [e.g. 12, 13, 14, 15] and fossil groups [e.g. 16, 17, 18, 19]. However, from the observational point of view, groups of galaxies and their member galaxies are not extremely well defined.

A variety of grouping algorithms have been developed [e.g. 4, 20, 21, 22] to identify real groups. However, few studies (e.g. [23] and references therein) have argued that these algorithms do not always return true groups, but a significant number of groups can be spurious and contain interlopers. It has been shown [23, hereafter Paper I] that one commonly applied grouping algorithm, namely the Friends-of-Friends algorithm [4, hereafter HG82], produces a significant fraction of groupings which are not gravitationally bound systems, but merely groups in a visual sense.

An excess of higher redshift galaxies, relative to the brightest member in loose groups, was discovered in 1970 [24, 25, and for detailed study see 26]. Since then many authors have found a statistically significant excess of high redshift companions relative to the group centre. The original study [24] was extended [27] to nearby groups of galaxies in which the magnitude difference between the companion and the main galaxy was higher than 0.4. A statistically significant excess of positive redshifts was found [28, hereafter S84] when spiral-dominated groups were studied in the catalogue of galaxy groups by HG82. The redshift excess Z = 0.21 was derived for spiral dominated groups while the E/S0 dominated groups showed a blueshift excess of -0.13 [28]. Discordant redshifts were also found [29] while nearby small groups, identified by Tully [30] in the Nearby Galaxy Catalogue, were studied.

Some possible origins for the observed redshift excess have been listed [28]. It has been argued that this positive excess is mainly due to the unbound expanding members and the fact that the dominant members of these groups are misidentified [31, 32]. It has also been argued that the positive excess may be explained if groups are still collapsing and contain dust in the intra group medium [33]. Monte Carlo simulations have been run to solve this problem and these authors concluded that the random projection could explain discordant redshifts [34]. It has also been found that projection effects alone can account for the high incidence of discordant redshifts [35]. However, these studies [34, 35] dealt only with Hickson's compact groups of galaxies. Catalogue of nearby groups of galaxies has been analyzed and no evidence of redshift asymmetries in galaxy groups was found [36]. However, unlike in earlier work, the reference system was not the brightest group member, but the unweighted average velocity of members.

To solve this enigma we have theoretically studied redshift asymmetries in small groups of galaxies by taking advantage of the largest cosmological N-body simulation conducted so far: the Millennium Run [37]. We have created two 'mock' catalogues of groups of galaxies (called Mock1 and Mock2) from the semi-analytical galaxy catalogue [38] of the Millennium Simulation by mimicking observational methods. For the creation of mock catalogues we applied the Friends-of-Friends (FoF) percolation algorithm developed by HG82.

2. Methods: Group-Finding Algorithm and Virial Ratio

In observations there are generally three basic pieces of information available for the study of the galaxy distribution: the position, the magnitude and the redshift of each galaxy. Although the magnitude is important as a measure of the object's visibility, it is usually a poor criterion for group membership. The method used for creating a group catalogue in HG82 can be summed up in two criteria: the projected separation and the velocity difference. This percolation algorithm essentially finds density enhancements in position and in redshift space above a set threshold factor defined by free parameters separation and velocity difference: D_0 and V_0. The FoF algorithm is described in greater detail by the original authors in HG82.

In general form [39], the kinetic energy of a galaxy group may be written:

$$T_{kin} = (2M)^{-1} \Sigma_{(i<j)} m_i m_j (\mathbf{V}_i - \mathbf{V}_j)^2,$$

and the potential energy:

$$U = G\, \Sigma_{(i<j)} m_i m_j R^{-1}_{i,j},$$

where M is the sum over member galaxy masses, m_i and m_j are the masses of the two galaxies, $\mathbf{V}_i$ and $\mathbf{V}_j$ are their velocities, G is the gravitational constant, and $R_{i,j}$ is the distance between them.

These general equations have been used to get the total kinetic energy of a group and compare it to its total potential energy. If the group does not fulfill the criterion:

$$T_{kin} - U < 0 \ ,$$

it is entered to a list of unbound groups. The above criterion is equal to the virial ratio:

$$T_{kin}U^{-1} < 1.0 \ ,$$

which we have used as a criterion for discriminating between bound and unbound groups.

3. Description of Cosmological Simulations

We present results from five different simulations. Our own simulations have been performed by the cosmological N-body simulation code AMIGA (Adaptive Mesh Investigations of Galaxy Assembly). The former version of AMIGA was known as MLAPM (for details see [40]). For the first two runs we have adopted the currently popular flat low-density cosmological model ΛCDM with h=1.0, Ω_{dm}=0.27, Ω_Λ=0.73 and σ_8=0.83, with two different resolutions. Both simulations were made with 256^3 dark matter particles. The high-resolution simulation began at the initial redshift z_i=47.96 while the low-resolution simulation was initiated at redshift z_i=38.71. The volume employed in the high-resolution simulation was $(40h^{-1}$ Mpc$)^3$ and $(80\ h^{-1}$ Mpc$)^3$ in the low-resolution simulation corresponding to the mass resolutions of 2.86 x $10^8 h^{-1}$ M_{sun} and 2.29 x $10^9 h^{-1}$ M_{sun}, respectively. The force resolution for the high-resolution simulation is $1.8h^{-1}$ kpc and for the low-resolution $7.3h^{-1}$ kpc.

For the third and the fourth simulations we have adopted different cosmological models. These simulations were also performed with 256^3 dark matter particles but with different values of the cosmological constant Λ. The total density of the universe was kept equal to the critical density (Ω=1.0). For the third simulation we adopt h=1.0, Ω_{dm}=0.1, Ω_Λ=0.9 and σ_8=0.83, while for the fourth simulation we adopt h=1.0, Ω_{dm}=1.0, Ω_Λ=0.0 and σ_8=0.84.

The Millennium Simulation [37, hereafter MS] is a cosmological N-body simulation of the ΛCDM model performed by Virgo Consortium. The MS was carried out with a customized version of the GADGET2 code [41]. The MS follows the evolution of 2150^3 particles from redshift z=127 in a box of $500h^{-1}$ Mpc on a side. The cosmological parameters of the MS simulation are: Ω_m=Ω_{dm}+Ω_b=0.25, Ω_b=0.045, h=0.73, Ω_Λ=0.75, n=1, and σ_8=0.9 (for detailed description of the MS see [37]).

The galaxy formation modeling of the MS data is based on merger trees build from 64 individual snapshots. Properties of galaxies in MS data are obtained by using semi-analytic galaxy formation models, where the star formation and its regulation by feedback processes are parameterized in terms of analytical physical models. A detailed description of the MS group catalogue, used in this study, can be found in [38, 42].

The MS galaxy database does not directly give morphology for a galaxy. We have used a method, which takes an advantage of bulge-to-disk ratios to assign morphology to every galaxy. A correlation between the B-band bulge-to-disc ratio, and the Hubble type T of galaxies has been found [43], and the mean relation may be written:

$$\langle \Delta m(T) \rangle = 0.324x(T) - 0.054x(T)^2 + 0.0047x(T)^3 \;,$$

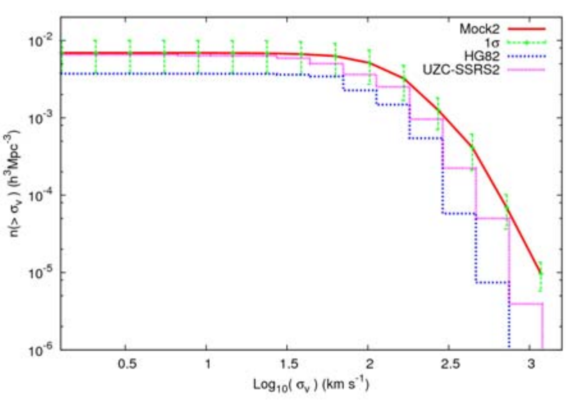
where $\Delta m(T)$ is the difference between the bulge magnitude and the total magnitude and $x(T)=T+5$. We have classified galaxies with $T < -2.5$ as ellipticals, those with $-2.5 < T < 0.92$ as S0s, and those with $T > 0.92$, as spirals and irregulars. Galaxies without any bulge are classified as type $T=9$.

4. Comparison with Observations

We have compared our simulated mock catalogues to observations. The comparison catalogues are HG82 and UZC-SSRS2, which has been derived from magnitude-limited redshift samples of galaxies. A compilation of 6846 galaxies with the apparent magnitude limit $m_{lim} \leq 15.5$ has been used in the creation of UZC-SSRS2 catalogue, which contains, in total, 1168 groups while the HG82 catalogue contains only 92 groups.

We have used five independent volumes from the Millennium Simulation galaxy catalogue for our Mock2 catalogue. The Mock2 catalogue has an apparent magnitude limit of 14.0, and $V_0 = 200$ km s^{-1} and $D_0 = 0.37$ Mpc were adopted for the free parameters of the FoF algorithm, corresponding to the space density enhancement of about 68. Each of the cubes used have the side length of 250h^{-1} Mpc, and they do not overlap each other. The observation point inside every volume was chosen to be in the centre of the particular cube. No additional criteria were applied for the selection of observation points. Reasonable statistical agreement between Mock2 catalogue and observed galaxy group catalogues show that our method of choosing the origin without any further criteria is strict enough in a statistical study of galaxy groups.

To compare abundances of groups in magnitude-limited samples we weight each group according to its distance [44, 45]. This weighting is necessary as there is no 'total' volume of a galaxy sample in magnitude-limited group catalogues. After weighting each group individually we can scale abundances of groups in Figs. 1 and 2 to the comoving volume of the sample. We include all galaxies with cz > 400 km s^{-1}. This lower cutoff avoids including faint objects that are close to the observation point as these groups could contain galaxies fainter than in real magnitude-limited surveys. Therefore we consider only groups with mean radial velocity, <cz>, larger than 400 km s^{-1} in mock, HG82 and UZC-SSRS2 catalogues. Figs. 1 and 2 show that cosmological N-body simulations can produce groups of galaxies whose statistical properties are similar to observed ones and that the agreement is within 2σ. The definitions and equations for velocity dispersion and 'observable' mass of a group can be found in Paper I. We use a statistical Kolmogorov-Smirnov (K-S) test to prove or disprove the null hypothesis that the two distributions are alike and are drawn from the same population distribution function. Results of the K-S tests are presented as significance levels (value of the Q function) for the null hypothesis.



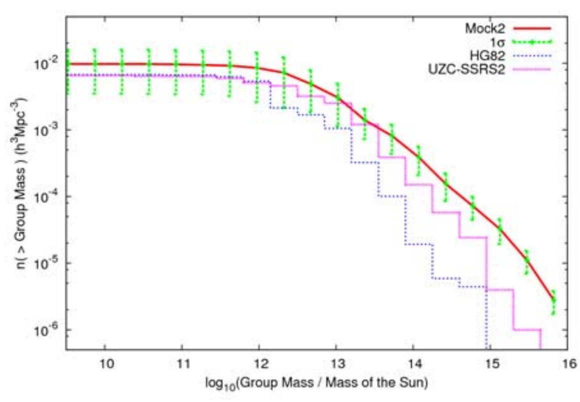


Fig. 1 Fig. 2

The groups of galaxies in our Mock2 catalogue are similar to observed ones in statistical sense (Fig. 1). However, the Mock2 catalogue shows an excess of high velocity dispersion groups compared to observations. The discrepancy is larger when comparison is carried out against the HG82 group catalogue, and the K-S test fails (Q □ $5\text{x}10^{-4}$). A better agreement is observed when the Mock2 catalogue is compared to the UZC-SSRS2 catalogue, and the K-S test approves the null hypothesis (Q □ 0.015). The fractile values of velocity dispersion of Mock2 catalogue groups are 80.5/131.0/213.4 km s^{-1}. These values are closer to observed ones than the values of mock catalogues in Paper I, where our own simulations were used.

From Fig. 2 it is clear that the Mock2 catalogue shows a small excess in light groups, but also a larger excess in the number of heavier groups. Because of these discrepancies the K-S test fails (Q □ 0.001), when the comparison is carried out against the UZC-SSRS2 catalogue. However, when the Mock2 catalogue is compared to the HG82 catalogue the K-S approves the null hypothesis (Q □ 0.02). This result is due to the fact that K-S test takes into account the shapes of the distributions, which are more similar between the Mock2 and HG82 catalogues. Because Figs. 1 and 2 show the cumulative distributions of abundance of galaxy group properties, they do not show the true shape of the actual distributions very sensitively. The fractile values of 'observable' mass of Mock2 catalogue groups are 1.4/3.1/15.8 x 10^{12} M_{sun}, which are close to the observed values (see Table 4 in Paper I for numerical comparison).

5. Gravitationally Bound Groups

Gravitationally bound groups are determined by using the virial ratio. This method of computing the gravitational potential well of a group does assume that the group is isolated. This is not strictly true as each group is embedded in the large-scale matter distribution, which might have an effect to the threshold 1.0 of the virial ratio. However, we believe this effect to be negligible in a statistical study like ours.

We find that □20 per cent of groups generated by the FoF algorithm are not gravitationally bound when the mock catalogue of our own low-resolution ΛCDM simulation has been studied. If we vary the apparent magnitude limit of the search from the original 13.2 to 20.0, even more groups (□37 per cent) are unbound. If the mock catalogues from the MS data are considered, even larger fraction of groups, about □50 per cent, are gravitationally unbound. This is not a negligible fraction considering that one widely accepted and applied method of calculating a group mass, from observations, is based on the assumption that groups found by the FoF algorithm are gravitationally bound systems.

If we change the value of the cosmological constant from the original 0.73 to 0.90, a slightly larger fraction of groups seems to be unbound when the apparent magnitude limit of 13.2 is adopted. This result is intuitively reasonable. If the negative vacuum pressure of space is larger, gravitational force becomes 'weaker' and a smaller number of dark matter haloes are formed and fewer groups are gravitationally bound objects. How does the fraction of gravitationally unbound groups change when the negative vacuum pressure of space is lowered? If the value of the cosmological constant is put to 0.0, about the same fraction of groups (with $m_{lim} = 13.2$) are spurious as in the $\Omega_\Lambda = 0.90$ cosmology. When the apparent magnitude limit is changed to 20.0, □37 per cent of the groups are spurious.

The fractions of gravitationally unbound groups are not highly sensitive to the choices of free parameters. If the values of the free parameters of the FoF algorithm are changed, only small effects are seen. The most noticeable effect is in the total number of groups and in the number of isolated galaxies found from simulations. However, the fractions of gravitationally bound groups remain roughly the same.

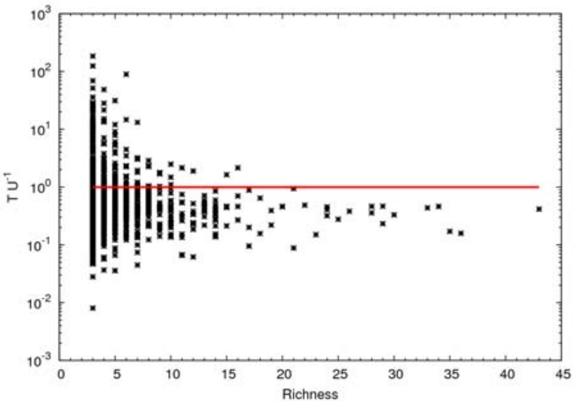


Fig. 3

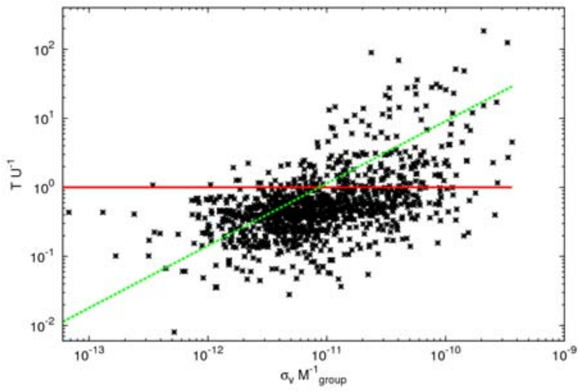


Fig. 4

From Fig. 3 we see that groups with more than 10 members are most likely gravitationally bound and groups with three to five members are quite often unbound. In Fig. 4, the virial ratio is plotted as a function of the velocity dispersion of the group when the latter has been scaled with the total mass of the group. Fig. 4 shows a decent correlation in the sense that groups with large velocity dispersion are more often gravitationally unbound than groups with small velocity dispersion. The linear correlation coefficient of 0.40 suggests that the correlation in Fig. 4 is relatively strong. The rms line plotted in Fig. 4 is of the form $T_{kin}U^{-1} \propto (M_{group}^{-1}\sigma_v)^b$. The value of the parameter b of the rms line is b=0.90±0.03. Data in these images are from our own low-resolution ΛCDM simulation.

6. Redshift Asymmetry in Galaxy Groups

The Mock1 catalogue is generated from the MS data with the same parameters as the original HG82 catalogue, and where S84 found positive redshift excess. There is a clear positive redshift excess in the mock catalogue when spiral-dominated groups are studied, but the excess is not significant when elliptical (E or S0) dominated groups are considered. However, Mock1 catalogue shows a larger number of groups with no excess than S84. By conventional theory, this suggests that groups in Mock1 catalogue could mostly be gravitationally bound. However, we found that ≈48.1 ± 7.9 per cent of our groups in the Mock1 catalogue are unbound.

The Mock1 catalogue does not show a significant difference in positive redshift asymmetry between all groups (number of members ≤ 10) and groups where the elliptical (T<0.92) dominant groups are removed. This result contradicts with S84 who found a large difference between these groups. As our Mock1 catalogue contains more groups than S84 we believe that the large difference in S84 is partly due to the small number of groups of this kind in HG82.

More detailed analysis of the Mock1 catalogue clearly shows that groups, which are gravitationally unbound, show a large positive redshift excess while gravitationally bound groups do not show any significant redshift excess. This may be an indication of dark energy dominated outflows around bound groups, which automatically lead to the redshift effect [46, 47]. The highest positive redshift excess is found in the Mock1 catalogue when groups, which are gravitationally unbound and when at the same time the brightest member galaxy is not the most massive one (i.e. the centre-of-mass is wrongly identified).

The Mock1 catalogue shows a similar negative redshift (i.e. blueshift) excess as S84 found when only gravitationally bound E/S0 (T < 0.92) dominated groups are considered. This negative redshift excess is present in both correctly and wrongly identified subsamples. The subsample of gravitationally bound E/S0 (T < 0.92) dominated groups show the largest blueshift-redshift equality. When we consider groups which are wrongly identified (i.e. the brightest group member is not the most massive galaxy) we found that these groups have the lowest percentage of positive-negative equality. This result is easy to understand in the conventional theory. If the gravitational potential of group is not correctly identified we do not get groups, which are symmetrical in redshift space. However, groups, which are bound, should show this symmetry more often than unbound groups.

Groups, which are gravitationally bound, show larger error limits in redshift asymmetry than groups, which are unbound. This result suggests that there are large differences in the fraction of bound groups between our five observation points. This shows that projection effects can play a significant role when the FoF percolation algorithm is applied, and it can produce groups, which are spurious because of these projection effects. Also the number of galaxies in the above mentioned dark energy outflows may vary a lot from one group to another and this may contribute to the large error limit.

S84 found a redshift excess Z=0.21 for spiral dominated groups. It has been derived from an analytical model that redshift excess ranges from Z=0.1 to Z=0.5 depending on adopted parameters, while the most probable value is 0.2 [31, 32]. The Mock1 catalogue gives a redshift excess Z=0.17 when gravitationally unbound spiral dominated groups are studied. If we consider only spiral-dominated groups, which are unbound and the centre is wrongly identified, we find a redshift excess of 0.35. When only bound groups from the Mock1 catalogue are considered the redshift excess is only 0.07. The good agreement between observations, analytical models and simulations (unbound groups) indicate that most of the membership of HG82's spiral dominated groups is unbound.

For elliptical dominated groups, S84 found a blueshift excess of -0.13. It has been derived from analytical calculations that the blueshift excess of correctly identified, but unbound groups which are dominated by elliptical galaxies ranges from -0.13 to 0.03 depending on values of free parameters [31, 32]. The Mock1 catalogue shows a blueshift excess of -0.05 when gravitationally unbound groups, whose centre galaxies are correctly identified, are studied. The agreement between observations, analytical models and simulations are decent. This points to the possibility that E/S0 galaxies can mark the position of the group centre.

7. Conclusions

We have shown that the ΛCDM cosmology can produce groups of galaxies comparable to observations of groups of galaxies when the FoF algorithm based on that of HG82 is adopted and the dynamical properties of groups are studied. Groups from cosmological simulations are, in general, in a moderate agreement with the HG82 and the UZC-SSRS2 group catalogues. The agreement between simulations and observations is good when the velocity dispersion and the 'observable' mass of groups are considered. The moderate agreement between simulations and observational data suggests that gravitational force alone is sufficient to explain the dynamical properties of groups of galaxies.

We find that about 20 to 50 per cent of the groups generated with the algorithm presented in the HG82 are not gravitationally bound objects. The fraction of gravitationally bound groups varies with different values of the apparent magnitude limits. When the apparent magnitude limit is raised from the original 13.2 to 20.0, a larger number of spurious groups are found. The larger fraction of unbound groups with m_{lim}=20.0 could be explained by the fact that more interlopers are included into groups when the apparent magnitude limit is increased.

A larger number of 'rich' groups are found when the apparent magnitude limit is lowered. This result originates from the fact that more faint galaxies at proximity to massive dark matter haloes become visible and those galaxies are included into the groups. When the magnitude limit is changed from the original value of 13.2 to 12.0, a slightly larger fraction of the groups are found to be gravitationally bound, fewer groups (in absolutely number) are found and these groups are 'poorer'. Also, small differences are found when the fractions of gravitationally bound 'poor' and 'rich' groups are studied. However, in general, 'rich' groups with more than four members are more often gravitationally bound than 'poorer' groups.

When the value of the cosmological constant Ω_Λ is varied, the fractions of unbound groups change only slightly. This is somewhat surprising, as it would be intuitively expected that a larger value of the dark energy would lead to a greater number of groups that are not gravitationally bound. Some variation is observed when the fraction of gravitationally bound groups is studied as a function of the cosmological constant, but a significant number of groups remain unbound in all cases of Ω_Λ.

The cosmological N-body simulations show a similar positive redshift excess as is observed in HG82, however, the excess is not as large as found by S84. Our Mock1 group catalogue shows higher positive redshift excess when gravitationally unbound groups are studied. The positive redshift excess percentage is highest in groups that are gravitationally unbound and in which the visually brightest galaxy is not the most massive galaxy. We conclude that when the group centre is not correctly identified it can cause part of the observed redshift excess alone. If the group is also gravitationally unbound it causes the positive redshift excess observed by S84.

Gravitationally bound groups do not show any significant positive redshift excess. This is in an agreement with the conventional theory, where it is expected that distribution of redshift differentials should be evenly distributed. The subsample of Mock1 catalogue with only gravitationally bound groups has an equal number of members relative to the brightest member within statistical errors. Our results show that there is no need to introduce any 'anomalous' redshift mechanism to explain the redshift excess of Arp [24].

References

1 Holmberg E., Medd. Lunds Obs. Ser. 2, 128, 1950.
2 Humason M.L., Mayall N.U., Sandage A.R., ApJ, 61, 97, 1956.
3 Geller M.J, Huchra J.P., ApJS, 52, 61, 1983.
4 Huchra J.P., Geller M.J., ApJ, 257, 423, 1982 (HG82).
5 Nolthenius R.A., White S.D.M., MNRAS, 235, 505, 1987.
6 Ramella M., Geller M.J., Pisani A., da Costa L.N., AJ, 123, 2976, 2002.
7 Ramella M. et al., AJ, 109, 1469, 1995.
8 Tucker D.L. et al., ApJS, 130, 237, 2000.
9 Einasto M. et al., A&A, 401, 851, 2003.
10 Zabludoff A.I., Mulchaey J.S., ApJ, 496, 39, 1988.
11 Mahdavi A. et al., ApJ, 518, 69, 1999.
12 Shakhbazyan R.K., Afz, 9, 495, 1973.
13 Hickson P., ApJ, 255, 382, 1982.
14 Hickson P. et al., ApJ, 329, L65, 1988.
15 Focardi P., Kelm B., A&A, 391, 35, 2002.
16 Ponman T.J. et al., Nature, 369, 462, 1994.
17 Jones L.R. et al., MNRAS, 343, 627, 2003.
18 D'Onghia E. et al., ApJ, 630, 109, 2005.
19 Santos W.A., Mendes de Oliveira C., Sodré L.Jr., AJ, 134, 1551, 2007.
20 Turner E.L., Gott J.R., ApJS, 32, 409, 1976.
21 Materne J., A&A, 63, 401, 1978.
22 Botzler et al., MNRAS, 349, 425, 1985.
23 Niemi S.-M. et al, MNRAS, 382, 1864, 2007 (Paper I).
24 Arp H., Nature, 225, 103, 1970.
25 Arp H., ApJ, 256, 54, 1982.
26 Jaakkola T., Nature, 234, 534, 1971.
27 Bottinelli L., Gouguenheim L., A&A, 26, 85, 1793.
28 Sulentic J.W., ApJ, 286, 442, 1984 (S84).
29 Girardi M. et al., ApJ, 394, 442, 1992.
30 Tully R.B., Nearby Galaxies Catalogue, Cambridge Univ. Press, 1988.
31 Byrd G.G., Valtonen M.J., ApJ, 289, 535, 1985.
32 Valtonen M.J., Byrd G.G., ApJ, 303, 523, 1986.
33 Girardi M. et al, ApJ, 394, 442, 1992.
34 Hickson P., Kindl E., Huchra J.P., ApJ, 329, L65, 1988.
35 Iovino A., Hickson P., MNRAS, 287, 21, 1997.
36 Tully R.B., ApJ, 321, 280, 1987.
37 Springel V. et al, Nature, 435, 629, 2004.
38 De Lucia G., Blaizot J., MNRAS, 375, 2, 2007.
39 Chernin A.D., Mikkola S., MNRAS, 253, 153, 1991.
40 Knebe A., Green A., Binney J., MNRAS, 325, 845, 2001.
41 Springel V., Yoshida N., White S.D.M, N.Astron., 6, 79, 2001.
42 Croton D.J. et al., MNRAS, 365, 11, 2006.
43 Simien F., De Vaucouleurs G., ApJ, 302, 564, 1986.
44 Moore B., Frenk C.S., White S.D.M., MNRAS, 261, 827, 1993.
45 Diaferio A., Kauffmann G., Colberg J.M., White S.D.M., MNRAS, 307, 537, 1999.
46 Chernin A.D. et al., Astrophysics, 50, 405, 2007.
47 Teerikorpi P. et al., A&A, 2008, in press.