New Probable Dwarf Galaxies in Northern Groups of the Local Supercluster

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Abstract. We have searched for nearby dwarf galaxies in 27 northern groups with characteristic distances 8–15 Mpc based on the Second Palomar Sky Survey prints. In a total area of about 2000 square degrees, we have found 90 low-surface-brightness objects, more than 60\% of which are absent from known catalogs and lists. We have classified most of these objects (80\%) as irregular dwarf systems. The first 21-cm line observations of the new objects with the 100-m Effelsberg radio telescope showed that the typical linear diameters (1–2 kpc), internal motions (30 km s\textsuperscript{-1}), and hydrogen masses ($\sim 2 \times 10^7 M_\odot$) galaxies correspond to those expected for the dwarf population of nearby groups.

Keywords: dwarf galaxies, groups of galaxies.

1 INTRODUCTION

A clear definition of galaxy membership in a group is required to analyze the kinematics and dynamics of the groups of galaxies. However, the groups of galaxies are defined in different ways, depending on the adopted selection algorithm and the galaxy sample to which this algorithm is applied.

Supplementing the groups by adding new dwarf galaxies makes it possible to study in more detail the galaxy luminosity function, the morphological segregation in groups, and the dependence of the chemical composition of dwarf galaxies and the star formation rate in them on their immediate environment. The problem of discrepancy between predictions of the Lambda-CDM-model (Klypin et al. 1999) and observational data has not yet been solved: the currently known number of dwarf galaxies in the Local Group is approximately an order of magnitude smaller than the predicted number. Thus, finding new dwarf galaxies in nearby groups remains a very topical problem.

The chance of detecting and identifying dwarf galaxies decreases sharply with distance. The groups selected from (either "optical," CGC (Zwicky et al. (1961–1968), or "infrared," 2MASS (Cutrie and Skrutskie 1998)) flux-limited catalogs contain virtually no dwarf galaxies. At the same time, purposeful thorough searches for putative dwarf members of the Local Volume in the POSS-II and ESO/SERC sky surveys out to distances of 5–6 Mpc proved to be successful (for more detail, see the Catalog of Nearby Galaxies (CNG) by Karachentsev et al. (2004)). These searches doubled the number of confirmed dwarf galaxies in the nearest groups, which made it possible to study in detail the kinematics and dynamics of the Local Volume groups (Karachentsev 2005). Based on the similarity between the functions of the linear
diameters of galaxies in the Local Group and the nearest groups, we undertook independent searches for the dwarf population in the more distant (10.4 Mpc) Leo-I group (Karachentsev and Karachentseva 2004). This required decreasing the limiting angular diameter of the sought-for dwarf members of Leo-I from 0.6–0.5 arcmin to 0.4–0.3 arcmin. We found 36 candidates for dwarf objects in the Leo-I group. HI 21-cm line observations with the 300-m Arecibo radio telescope confirmed the membership of most of them in the group (Stierwalt et al. 2005). This encouraging result allowed us to undertake searches for new probable dwarf members in other nearby groups of the Local Supercluster.

As we see from Table 1, the number of detected candidates for new group members depends weakly on the distance to the group (in the interval under consideration) and on its population. Note, however, that we found the largest number of new objects in groups where the brightest member is an early-type galaxy (NGC 1023, NGC 3607).

2 RESULTS OF OUR SEARCHES

As the initial sample, we took the 2004 version of the Catalog of Groups of Galaxies of the Local Supercluster with radial velocities $V_{LG} < 3100$ km s$^{-1}$ (Makarov and Karachentsev 2000). We selected the groups that satisfied the following three conditions from this catalog: (1) the number of galaxies in the group $N \geq 4$; (2) the mean radial velocity reduced to the Local Group centroid $< V_{LG} >= 550 – 1100$ km s$^{-1}$; and (3) a positive declination of the group center. There were 43 such groups. Subsequently, we excluded the groups located in the Virgo cluster from our searches, because of the complex dynamical pattern and the difficulty of clearly separating its subsystems. Table 1 gives a list of groups studied. Its columns present the following characteristics:

- name of the dominating galaxy in the group;
- mean radial velocity in km s$^{-1}$;
- number of group members with known radial velocities; the number of elliptical galaxies among them is given in parentheses;
- morphological type of the dominating galaxy on the RC3 scale (de Vaucouleurs et al. 1991);
- numbers of the POSS-II fields in which the searches were constructed;
- number of detected presumed dwarf members of the group without radial velocities; the number of new objects is given in parentheses.

We carried out our searches on the blue (B) and red (R) POSS-II prints to a limiting angular size of 0.4–0.3 arcmin. We examined wide neighborhoods of the groups in order that the radius of the search region be twice the harmonic mean radius of the group. The results of our searches are summarized in Table 2, where the following data are presented:

- object name, where ”d” stands for ”dwarf,” followed by two four-digit sequences indicating the hours and minutes in right ascension and the degrees and minutes in declination;
- right ascension and declination for epoch J2000.0;
- type of dwarf galaxy: Ir–irregular, Sph–spheroidal, dE–elliptical;
- major and minor axes measured on the blue print;
- name of the group to which the object presumably belongs;
- notes and identification with known lists made using the NED database.

All of the objects found have a low surface brightness. In the notes, VLSB and ELSB stand for very low ($\sim 25^{m}$ arcsec$^{-2}$) and extremely low ($\sim 26^{m}$ arcsec$^{-2}$) surface brightness,
Table 1: Groups in which dwarf galaxies were searched for

| Group          | $< V_{LG} >$ | $N(N_E)$ | Type | POSS-II field numbers | Number of objects |
|----------------|--------------|----------|------|-----------------------|------------------|
| (1)            | (2)          | (3)      | (4)  | (5)                   | (6)              |
| NGC 1023       | 824          | 17 (1)   | −3   | 299; 355; 356         | 12 (12)          |
| NGC 2681       | 752          | 6 (2)    | 0    | 211                   | 0 (0)            |
| NGC 2841       | 653          | 8 (2)    | 3    | 212                   | 1 (0)            |
| NGC 3180       | 565          | 4 (0)    | 6    | 316; 317              | 1 (1)            |
| NGC 3486       | 621          | 4 (0)    | 5    | 438                   | 0 (0)            |
| NGC 3507       | 957          | 18 (2)   | 3    | 569; 570; 640         | 1 (0)            |
| NGC 3607       | 854          | 11 (7)   | −2   | 570                   | 21 (17)          |
| NGC 3627       | 705          | 6 (0)    | 4    | 641; 642; 713; 714    | 4 (3)            |
| NGC 3686       | 1038         | 7 (0)    | 4    | 641; 642              | 1 (0)            |
| NGC 3726       | 926          | 20 (3)   | 5    | 216; 217; 266         | 0 (0)            |
| NGC 3938       | 805          | 8 (2)    | 5    | 266; 267              | 0 (0)            |
| NGC 3953       | 1092         | 18 (4)   | 4    | 170; 171; 216; 217    | 4 (2)            |
| NGC 3972       | 871          | 4 (0)    | 4    | 171                   | 0 (0)            |
| NGC 4062       | 728          | 4 (0)    | 5    | 440; 379              | 1 (1)            |
| NGC 4088       | 826          | 8 (0)    | 5    | 216; 217; 266; 277    | 0 (0)            |
| NGC 4151       | 1051         | 10 (0)   | 2    | 321; 322; 379; 380    | 0 (0)            |
| NGC 4183       | 972          | 4 (2)    | 6    | 217; 218; 267         | 2 (1)            |
| NGC 4258       | 561          | 9 (0)    | 4    | 216; 217; 267         | 5 (2)            |
| NGC 4274       | 957          | 8 (1)    | 2    | 441                   | 12 (3)           |
| NGC 4278       | 609          | 10 (3)   | −5   | 441; 442              | 6 (3)            |
| NGC 4346       | 793          | 5 (1)    | −2   | 218; 267; 268         | 1 (0)            |
| NGC 4490       | 602          | 9 (0)    | 7    | 268; 322              | 3 (2)            |
| NGC 4559       | 740          | 13 (4)   | 6    | 380; 381; 442         | 5 (2)            |
| NGC 5033       | 996          | 15 (1)   | 5    | 323; 324; 382         | 3 (2)            |
| NGC 5194       | 611          | 7 (1)    | 5    | 220; 269; 270; 323    | 2 (0)            |
| NGC 5248       | 1087         | 6 (0)    | 4    | 720                   | 1 (1)            |
| NGC 5906       | 913          | 13 (4)   | 5    | 176; 177              | 2 (2)            |

respectively.

Our independent searches revealed objects that either were found previously (Karachentseva and Karachentsev 1998 (KK); Karachentsev et al. 2001 (KKH) or were included in the lists of other authors (Binggeli et al. 1990 (BST); Shombert et al. 1997 (D); Trentham and Tully 2002 (ComaI); Cabanela 1999 (MAPS); Trentham et al. 2001 (TTV)). Table 2 includes those of them that have no measured radial velocities. The object d1223+2935, whose radial velocity was determined with a large error, was left in Table 2 for further observations. In addition, we included the object d1243+4127, a possible member of the NGC 4736 group missed when the lists of presumed dwarf members of the Local Volume were published, in the list. Several objects, to be described in more detail below, stand out among those found.

(1) d0226+3325. This is an object of extremely low surface brightness located 13 arcmin SW of the galaxy NGC 925. This galaxy lies on the periphery of the NGC 1023 group and was included in the catalog of isolated galaxies (Karachentseva 1973) as CIG 105. HI mapping of
the spiral NGC 925 and its neighborhood revealed a hydrogen satellite connected with NGC 925 by a "bar" (Briggs 1980; Gottesman 1980). Pisano et al. (1998) pointed out that there is a hydrogen cloud with a radial velocity of $V_h = 524$ km s$^{-1}$ and a line FWHM $W_{50} \sim 40$ km s$^{-1}$ at 10 arcmin SW of NGC 925. Note that the mean measured velocity of NGC 925 is $V_h = 553$ km s$^{-1}$. The hydrogen mass of the cloud was estimated to be $10^7 M_\odot$. The cloud is invisible on a deep R-band image obtained by these authors with the WINM telescope. The object we found is probably an extremely low surface brightness object and is the optical counterpart of the "hydrogen cloud."

(2) A close "triplet" in the NGC 1023 group. Our observations (see Table 3) show that the dwarf galaxies d0245+3955, d0245+3957, and d0246+3952 are members of a single group.

(3) d1228+4358. This object appears as a partially destroyed "tail" pointing away from the galaxy NGC 4449 southward. It is similar in size, low surface brightness, and diffuse structure to the dwarf system KK 208 with an old stellar population near NGC 5236 (Karachentsev et al. 2002). This may be an example of the formation of the so-called tidal dwarfs or, conversely, the capture of a dwarf system by a bright galaxy just like the Sagittarius dSph phenomenon around the Milky Way. The figure presents the images of the six new dwarf galaxies mentioned above from the Digital Sky Survey. Each image corresponds to the blue POSS-II prints. As we see from Table 2, more than 60% of the objects are absent from known catalogs and lists. The median of the distribution of new objects in angular diameter is 0.4 arcmin, which is half that for the known objects. At a characteristic distance to the groups of 12 Mpc, the median linear diameter of the new galaxies is about 1.5 kpc, which is typical of the dwarf population of the Local Group and other nearby groups. According to our estimates, about 80% of the objects in Table 2 are irregular dwarf galaxies. In such systems, a significant fraction of the mass is usually accounted for by neutral hydrogen (HI), which makes their 21-cm line observations promising.

3 21-cm LINE OBSERVATIONS

The objects from Table 2 were observed in 2005–2006 with the 100-m Effelsberg radio telescope. At a beam width (FWHM) of the radio telescope equal to 9.3 arcmin, the angular sizes of the objects we found occupy only a small fraction of its aperture. Therefore, a considerable accumulation time is required to detect the HI flux from them. Small angular separations between group galaxies are another problem, which occasionally causes confusion of the signals from several objects that fell within the aperture of the radio telescope.

Table 3 presents the results of our observations for several detected galaxies where no confusion arose because of close neighbors. Its columns present the following: 1, equatorial coordinates of the galaxy; 2, HI flux in Jy km s$^{-1}$; 3, maximum emission and (or) its rms error in mJy; 4, heliocentric radial velocity and its error in km s$^{-1}$; 5, line full width at half maximum; 6, total apparent magnitude of the galaxy that we estimated on the blue POSS-II print compared to other galaxies of similar morphology; 7, absolute magnitude of the galaxy corrected for the Galactic extinction as derived by Schlegel et al. (1998) for an assumed distance to the galaxy of $D = V_{LG}/H$, where $H = 72$ km s$^{-1}$Mpc$^{-1}$; 8, HI mass-to-light ratio in solar units, where the hydrogen mass was determined from the HI flux $F$ as log $M_{HI} = \log F + 2 \log D + 5.37$. Judging by their low radial velocities, weak HI fluxes, and small line widths, these objects are actually dwarf galaxies with a typical hydrogen masses of $\sim 2 \times 10^7 M_\odot$. The HI survey of the galaxies listed in Table 2 is not yet complete. We are
| Name        | RA (2000.0) | DEC      | Type | \((a \times b)'\) | Group | Notes                        |
|-------------|-------------|----------|------|---------------------|-------|------------------------------|
| d0224+4102  | 022420.7+410212 | Ir | 0.50x0.30 | N1023         |       |                              |
| d0226+3325  | 022652.8+332537 | Sph | 1.30x1.20 | N1023         | ELSB at 13’ SW of 925 |
| d0237+4136  | 023718.8+413607 | Ir | 0.40x0.35 | N1023         | LSB   |                              |
| d0238+4052  | 023851.2+405247 | Ir | 0.70x0.40 | N1023         | VLSB  |                              |
| d0241+3653  | 024131.5+365327 | Ir | 0.70x0.40 | N1023         | Wedge-shaped |                      |
| d0243+3759  | 024302.0+375926 | Sph | 0.60x0.50 | N1023         |       |                              |
| d0245+3955  | 024530.8+395347 | Ir | 0.35x0.30 | N1023         |       |                              |
| d0245+3957  | 024555.7+395711 | Ir | 0.90x0.75 | N1023         |       |                              |
| d0246+3952  | 024600.6+395238 | Ir | 0.70x0.50 | N1023         |       |                              |
| d0246+3910  | 024612.4+391055 | Ir | 0.75x0.50 | N1023         | Distant spiral? |                      |
| d0246+3249  | 024621.8+324945 | Ir | 0.65x0.35 | N1023         | VLSB  |                              |
| d0246+3832  | 024649.0+383251 | Ir | 0.40x0.25 | N1023         |       |                              |
| d0921+5016  | 092157.1+501621 | Sph | 1.10x0.90 | N2841         | KKH 49 |                      |
| d1018+4109  | 101822.6+410958 | Ir | 0.60x0.40 | N3180         | LSB, blueish |                      |
| d1106+1250  | 110610.5+125042 | Ir | 0.50x0.25 | N3507         | D 640-9 |                      |
| d1110+1932  | 111037.6+193217 | Ir | 0.35x0.30 | N3607         |       |                              |
| d1112+1845  | 111257.5+184540 | dE | 0.70x0.40 | N3607         | F 570-4, distant? |                      |
| d1114+1802  | 111422.9+180235 | Ir | 0.40x0.30 | N3607         | Sph?  |                              |
| d1115+1756  | 111507.1+175815 | Ir | 0.25x0.25 | N3607         | dE?   |                              |
| d1115+1755  | 111513.0+175545 | dE | 0.30x0.25 | N3607         |       |                              |
| d1115+1756  | 111524.5+175635 | Ir | 0.50x0.40 | N3607         | dE? 19.5” (MAPS) |                      |
| d1115+1801  | 111536.4+180108 | Ir | 0.45x0.40 | N3607         | Sph? ELSB |                      |
| d1115+1804  | 111548.1+180438 | Ir | 0.25x0.25 | N3607         | VLSB  |                              |
| d1115+1756  | 111558.0+175620 | Ir | 0.40x0.30 | N3607         |       |                              |
| d1116+1757  | 111611.7+175700 | Ir | 0.35x0.30 | N3607         | D 570-5 |                      |
| d1116+1713  | 111621.0+171347 | Sph | 0.25x0.25 | N3607         | ELSB  |                              |
| d1117+1818  | 111702.0+181807 | Ir | 0.45x0.35 | N3607         |       |                              |
| d1117+1719  | 111708.1+171909 | Ir | 0.30x0.25 | N3607         |       |                              |
| d1117+1759  | 111722.7+175945 | Ir | 0.30x0.25 | N3607         | VLSB  |                              |
| d1117+1815  | 111748.2+181500 | Ir | 0.60x0.50 | N3607         | distant spiral? |                      |
| d1117+1737  | 111756.9+173726 | dE | 0.70x0.30 | N3607         | Sph?, 18.8” (MAPS) |                      |
| d1119+1157  | 111914.6+115709 | Ir | 1.00x0.35 | N3627         | 17.9” (MAPS) |                      |
| d1119+1404  | 111921.5+140434 | Ir | 0.65x0.45 | N3627         |       |                              |
| d1119+1732  | 111921.9+173214 | Ir | 0.40x0.35 | N3607         | Sph?  |                              |
| d1120+1332  | 112016.1+133249 | Ir | 0.60x0.35 | N3627         | Satellite of N 3628 |                      |
| d1121+1830  | 112153.8+183008 | Ir | 0.35x0.30 | N3607         |       |                              |
| d1123+1916  | 112341.8+191615 | Ir | 0.55x0.45 | N3607         |       |                              |
| d1123+1816  | 112355.0+181657 | Ir | 0.40x0.30 | N3607         |       |                              |
| d1124+1125  | 112410.9+112514 | dE | 0.40x0.30 | N3627         | distant? |                      |
| d1134+1709  | 113416.2+170946 | Sm | 0.70x0.40 | N3686         | KKH 107 |                      |
Table 2: continued

| RA      | DEC     | IR      | Size   | Notes                  |
|---------|---------|---------|--------|------------------------|
| d1142+5210 | 114230.1+521036 | Ir? | 0.30x0.25 | N3953       |
| d1148+5555 | 114843.8+555545 | Ir | 0.60x0.45 | N3953       |
| d1150+5546 | 115006.3+554657 | Ir | 1.00x0.70 | N3953       |
| d1154+3635 | 115423.9+363504 | Ir | 0.70x0.60 | N4062       |
| d1156+5548 | 115601.2+554846 | Ir | 0.45x0.30 | N3953       |
| d1205+4342 | 120525.0+434227 | Ir | 0.80x0.50 | N4183       |
| d1212+4237 | 121218.0+423732 | Ir | 0.50x0.45 | N4183       |
| d1214+2749 | 121442.3+274955 | Ir | 0.35x0.30 | N4274       |
| d1214+2915 | 121443.4+291511 | Ir? | 0.30x0.30 | N4274       |
| d1215+2813 | 121541.2+281315 | Ir? | 0.40x0.30 | N4274       |
| d1215+2917 | 121546.7+291728 | Ir | 0.30x0.30 | N3953 KK     |
| d1216+2838 | 121639.2+283846 | Ir | 0.30x0.25 | N4062       |
| d1217+4703 | 121710.1+470349 | Ir | 0.35x0.25 | N4258 BTS    |
| d1217+2914 | 121747.2+291436 | Ir | 0.40x0.40 | N4274 ComaI  |
| d1217+2828 | 121748.6+282827 | dE | 0.70x0.45 | N4274 ComaI  |
| d1218+2933 | 121829.4+293312 | dE | 1.10x0.60 | N4274 ComaI  |
| d1219+4734 | 121906.5+473451 | Ir | 0.60x0.50 | N4258 BTS    |
| d1219+4727 | 121933.8+472706 | dE | 0.30x0.30 | N4258 BTS    |
| d1219+4705 | 121936.8+470533 | Sph | 0.25x0.25 | N4274       |
| d1221+4739 | 122143.8+473933 | dE | 0.60x0.40 | N4274 BTS    |
| d1221+4700 | 122140.6+470003 | dE | 0.30x0.30 | N4258 BTS    |
| d1222+4649 | 122205.0+464945 | Sph | 0.30x0.25 | N4258 ELSB   |
| d1222+4729 | 122210.8+472926 | Ir | 0.45x0.35 | N4278 ComaI  |
| d1222+2905 | 122215.8+290502 | Ir? | 0.35x0.30 | N4278 VLSB   |
| d1223+2832 | 122309.5+283235 | Ir? | 0.30x0.30 | N4278 VLSB   |
| d1223+2935 | 122357.7+293547 | dE | 0.70x0.65 | N4278 Vh     |
| d1224+4707 | 122412.0+470724 | dE | 0.40x0.35 | N4346 BTS    |
| d1228+4358 | 122844.9+435818 | Ir | 4: x 1: | N4490 VLSB   |
| d1229+3056 | 122941.2+305641 | Ir | 0.40x0.30 | N4278 Sph?    |
| d1230+3002 | 123025.8+300224 | Ir | 0.55x0.40 | N4278 VLSB, KDG |
| d1233+3806 | 123307.4+380658 | Ir | 0.50x0.40 | N4490 BTS    |
| d1238+3512 | 123854.6+351218 | Ir | 0.40x0.35 | N4559 VLSB   |
| d1242+4115 | 124212.3+411509 | Sph | 0.60x0.60 | N4490 VLSB   |
| d1243+3228 | 124325.2+322855 | dE | 1.10x0.60 | N4559 BTS    |
| d1243+2956 | 124344.2+295603 | Ir | 0.60x0.40 | N4559 BTS    |
| d1243+3232 | 124345.3+323201 | Ir? | 0.35x0.30 | N4559        |
| d1243+4127 | 124355.7+412725 | Ir | 1.40x0.60 | N4736 missed  |
| d1248+3158 | 124852.8+315815 | Ir | 0.70x0.50 | N4559         |
| d1251+4704 | 125114.5+470406 | Ir | 0.70x0.50 | BTS157, 17.5m|
| d1310+3648 | 131058.7+364813 | Ir | 0.35x0.25 | N5033 VLSB   |
going to publish the complete results of our observations after the completion of the program.

## 4 CONCLUSIONS

Using the POSS-II prints, we examined the regions of 27 northern groups of galaxies with expected distances of about 12 Mpc (mean radial velocities in the range $550–1100 \text{ km s}^{-1}$) and with more than three members. The total number of members in these groups with measured radial velocities is 252. As a result of our searches, we added 90 more galaxies without radial velocities, which we consider to be probable members of these groups as low-surface brightness dwarf systems with typical angular sizes of 0.4 arcmin, to this list. Most of them are classified as dIrr galaxies (80%); the remaining galaxies are classified as dE and dSph.

We observed some of the new objects in the 21-cm HI line with the 100-m Effelsberg radio telescope. These observations confirmed that the detected objects could be attributed to the dwarf population of the groups under consideration with a typical diameter of 1.5 kpc, an absolute magnitude of $-13^m$, inner motions of 30 km s$^{-1}$, a hydrogen mass of $\sim 2 \times 10^7 M_\odot$, and an HI mass-to-light ratio of $\sim 1 M_\odot/L_\odot$. The radial velocity measurements from the 21-cm line or optical spectra that we are planning will allow us to improve the luminosity function of the galaxies in nearby groups and to make the estimates of their virial masses more reliable.

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Figure 1: Reproductions of the images of six new low surface brightness dwarf galaxies from the blue POSS-II prints. Each field is 5 arcmin × 5 arcmin in size; north is at the top and east is on the left.