

# Associations of Dwarf Galaxies

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## ABSTRACT

Hubble Space Telescope Advanced Cameras for Surveys has been used to determine accurate distances for 20 galaxies from measurements of the luminosity of the brightest red giant branch stars. Five associations of dwarf galaxies that had originally been identified based on strong correlations on the plane of the sky and in velocity are shown to be equally well correlated in distance. Two more associations with similar properties have been discovered. Another association is identified that is suggested to be unbound through tidal disruption. The associations have the spatial and kinematic properties expected of bound structures with  $1 - 10 \times 10^{11} M_{\odot}$ . However, these entities have little light with the consequence that mass-to-light ratios are in the range  $100 - 1000 M_{\odot}/L_{\odot}$ . Within a well surveyed volume extending to 3 Mpc, all but one known galaxy lies within one of the groups or associations that have been identified.

*Subject headings:* galaxies: distances, galaxies: clusters, dark matter

## 1. Introduction

The possibility was raised by Tully et al. (2002) [TSTV] that bound associations of dwarf galaxies may be common. In that paper, five interesting examples were identified that were thought to be within  $\sim 5$  Mpc. In terms of dimensions and velocity dispersions the entities resemble scaled down versions of familiar nearby loose groups like the Local Group. They have dimensions of a few hundred kpc and velocity dispersions of a few tens of  $\text{km s}^{-1}$ , implying group masses of  $1 - 6 \times 10^{11} M_{\odot}$ . However there is little light. The implied mass-to-light ratios ( $M/L$ ) for four of the five entities identified by TSTV were very large.

The identification of dwarf galaxy associations goes back two decades to a project that defined groups through a merging tree algorithm (Tully 1987, 1988). Each linkage between galaxies was characterized by a luminosity density given by the separations and summed luminosities of the contributing systems. Two levels of structure – ‘groups’ and ‘associations’ – were defined by luminosity density thresholds. The ‘group’ threshold satisfactorily captured familiar loose groups like the Local Group. The ‘association’ threshold, set an order of magnitude lower in luminosity density, captured two kinds of entities. Associations of type 1 involve the extended regions around groups defined by the higher luminosity density threshold and can include several groups and/or several individual galaxies (call these ‘associations of group peripheries’). Associations of type 2 are derived from linkages between galaxies that have such insignificant luminosities that the luminosity density fails to reach the threshold to be called a group (call these ‘associations of dwarfs’). It is this latter kind of association that interests us in the present discussion. Only limited attention was brought to these entities when they were identified in 1987 because to suggest that they were bound was to suggest that  $M/L$  values are extreme. TSTV asked belatedly that we consider this possibility.

Except for one nearby case, the TSTV associations were identified in the absence of

distance information. The candidate members simply lie near each other in projection and have similar redshifts. Thanks to the amazing capability of Advanced Cameras for Surveys (ACS) on Hubble Space Telescope (HST) to detect faint stars, it has been possible to determine accurate distances to all the suspected members of the TSTV dwarf associations. We use the standard candle property of the tip of the red giant branch (TRGB) (Lee et al. 1993; Sakai et al. 1996; Makarov et al. 2006; Rizzi et al. 2006). In this paper, we revisit the discussion of the putative dwarf groups, now with excellent distances in hand.

## 2. HST Observations

The observations that will be reported here are part of a major program to define the nearby structure in the distribution of galaxies. The genesis of the program arose out of all-sky searches for dwarf galaxies and follow up HI observations that established redshifts (Fisher & Tully 1981; Karachentseva and Karachentsev 1998; Karachentseva et al. 1999; Karachentsev et al. 2000; Karachentseva and Karachentsev 2000; Huchtmeier et al. 2001). In recent years, members of our team have reported on observations of the resolved stellar populations in nearby galaxies made with HST (Karachentsev et al. 2002a,b,c, 2003a,b, 2006a,b), summarized in the Catalog of Neighboring Galaxies (Karachentsev et al. 2004).

Accurate distances can be derived from the observed luminosity of the brightest red giant branch stars in a galaxy. Red giant stars increase in brightness while their Helium cores grow until they attain sufficient mass that they cannot be supported by electron degeneracy pressure and begin burning to Carbon. The well specified mass of the core at this point results in a well defined TRGB luminosity (Iben & Renzini 1983). It has been empirically found that the tip luminosity is particularly stable for metal poor systems ( $[\text{Fe}/\text{H}] < -0.7$  dex) at  $I$  band, with  $M_I \sim -4.05$  (Lee et al. 1993). The location of the TRGB can be identified with sobel filter edge detection methods (Sakai et al. 1996) or

maximum likelihood methods Méndez et al. (2002). Our preferred procedure is an extension of the maximum likelihood method (Makarov et al. 2006). The absolute value of the TRGB and influences that might cause it to vary have been discussed over the years (Da Costa & Armandroff 1990; Salaris & Cassisi 1998; Barker et al. 2004). The calibration that we use and current uncertainties are discussed by Rizzi et al. (2006). For this paper we accept  $M_I = -4.05$  and no zero point offset for the HST flight filter F814W magnitudes with either WFPC2 or ACS.

The bulk of the observations reported here were obtained with ACS during HST cycle 13, program 10210. Some raw material was drawn from the HST archives as needed to complete the sample. ACS data was reduced with the DOLPHOT program (Dolphin 2006) while WFPC2 data was reduced with HSTPHOT (Dolphin 2000). The TRGB fitting uses the modified maximum likelihood method of Makarov et al. (2006). A montage of images of the 20 galaxies observed in HST program 10210 is presented in Figure 1.

Our current observations present the opportunity to show the spectacular advance over WFPC2 data made possible by ACS. Figure 2 compares single HST orbit observations made by the two instruments on identical galaxies. The gain with ACS over WFPC2 is better than  $1^m$  with the same exposure time. Another  $0.4^m$  gain comes from a factor two longer exposure times. In the case of UGC 8651, the color-magnitude diagram (CMD) obtained from the ACS observations contains a well resolved red giant branch with the TRGB clearly located. One also sees the main sequence, asymptotic giant branch (AGB), and red supergiants. These populations are also seen in the WFPC2 CMD although not so cleanly. A good distance measurement of  $3.0 \pm 0.2$  Mpc can be made for UGC 8651 with both datasets (Makarov et al. 2006). The same cannot confidently be said in the case of KK 16. The ACS observation is clean with a very dominant RGB, and weak representation of the main sequence, red supergiants, and AGB. We measure a good distance of  $5.5 \pm 0.3$  Mpc

with the ACS data. If only the WFPC2 data were available the distance uncertainty would be large. KK 16 is a relatively easy case because the young population is a minor contributor to the CMD. A much more difficult case is shown in the bottom panels. The ACS data tells us that UGC 3974 is at a distance of  $8.0 \pm 0.8$  Mpc. In the ACS CMD we see very strong contamination from young stars. Note the subtle difference between the WFPC2 CMDs of KK 16 and UGC 3974, the latter with large main sequence and supergiant populations which signal us to expect a substantial presence of AGB stars. We realize that the clump of faint red stars in the UGC 3974 WFPC2 CMD are all AGB stars and that the TRGB is lost at the faint cutoff. From the analysis of Makarov et al. (2006) it is concluded that single orbit observations with WFPC2 provide distances that can be trusted out to  $\sim 5$  Mpc while ACS provides comparable reliability out to  $\sim 10$  Mpc.

Table 1 contains TRGB and distance determinations for all galaxies relevant to the current discussion. Entries are either (1) suspected members of one of the associations that are discussed, and/or (2) lie in the well surveyed volume with  $|b| > 30$  and distance between 1.1 and 3.2 Mpc. Column information includes association name, galaxy names (common and PGC), equatorial, galactic, and supergalactic coordinates, blue apparent magnitude, morphological type, velocity in the Local Group frame, HST program that provides the CMD, the TRGB magnitude at I band, foreground obscuration at I band, distance modulus, distance (Mpc), velocity of galaxy minus mean velocity of association, 3-D distance of galaxy from centroid of association (kpc), and absolute blue magnitude.

### 3. Previously Identified Associations

Prospective bound associations were identified by TSTV and Tully (2005a); hereafter T05. In the following discussion, the numeric names originate with the Nearby Galaxies (NBG) catalog (Tully 1988) or are derivatives of that source. The first number identifies

the cloud or filament that contains the association – usually 14, the one we live in. The second number identifies the specific entity and is preceded by a negative sign for groups and a positive sign for associations. As mentioned above, the difference between ‘groups’ and ‘associations’ in the NBG catalog was a factor ten in luminosity density threshold. In the present discussion we continue to use the designation ‘association’ to describe entities with very low luminosity densities even though we will argue that these structures are bound, hence, dynamically, not very different from entities like the Local Group.

### 3.1. 14+12 (NGC 3109) Association

The NBG catalog used the 14+12 identification for all galaxies on the periphery of 14-12, our Local Group. We now use the name for the dominant subset of these immediate neighbors; galaxies including NGC 3109 that lie in the constellations of Sextans and Antlia. These same objects were constituted as a separate group by van den Bergh (1999). TSTV considered 6 candidates for membership but DDO 155 = GR8 is too far away in both projection and distance to be retained and LSBC D634-03 turned out to be a distant dwarf projected onto a high velocity cloud concentration. On the other hand, a new candidate for membership has recently turned up, KKH 60. This new candidate is near Sex B in position and velocity (Makarov et al. 2003) but remains without a distance measure.

It was already known to TSTV that NGC 3109, Sex A, and Sex B are at similar distances based on HST CMDs and that Antlia is at a similar distance based on groundbased CMD (Aparicio et al. 1997; Whiting et al. 1997). Now we have observed Antlia with HST. Figure 3 shows the one new and three old HST CMDs. The TRGB are clearly defined and distances are confined to the remarkably small interval of 1.25 – 1.44 Mpc. The rms scatter about the mean of 1.37 Mpc is only 90 kpc. The standard deviation in position on the sky is much larger: 320 kpc. The scatter in velocity (Local Group standard of rest)



is only  $18 \text{ km s}^{-1}$ . The rms line-of-sight velocity dispersion for this group is adjusted for observational uncertainties following Materne (1974), as it will be for all the groups to be discussed. Individual observational uncertainties are taken to be  $\pm 5 \text{ km s}^{-1}$  for these dwarf galaxies with narrow HI profiles so corrections to group dispersions are only  $\sim 1 \text{ km s}^{-1}$ .

The discussion of mass estimations will be put off to a later section. Properties of the association are summarized in Table 2. The brightest galaxy in this association is NGC 3109 with  $M_B = -15.5$ . The 14+12 = NGC 3109 Association is the nearest distinct structure of multiple galaxies to the Local Group.

### 3.2. 14+8 Association

For Tully (1987), the close trio UGC 8651, UGC 8760, and UGC 8833 was the archetype of associations of dwarfs. UGC 9240 is near enough to these three that it must be considered as a fourth member. In TSTV, before distances were known, it was guessed based on velocities that these galaxies would be at  $\sim 5 \text{ Mpc}$ . They turn out to be significantly closer, at  $3.06 \text{ Mpc}$  with a scatter of only  $210 \text{ kpc}$ . This compares with the scatter in projection of  $220 \text{ kpc}$ . The scatter in velocity is  $11 \text{ km s}^{-1}$ . The galaxies are all dwarfs with  $-12.4 > M_B > -14.2$ . CMDs are shown in Figure 4.

### 3.3. 17+6 (NGC 784) Association

At the time of the construction of the NBG catalog, the 14 and 17 clouds were seen as discrete but they are probably a continuation of the same filament. The NBG catalog identifies only the pair NGC 784 and UGC 1281 with association 17+6. KK 16 and KK 17 have subsequently been found. NGC 784 and UGC 1281 are galaxies comparable to the SMC with  $M_B = -16.6$  and  $-15.9$  respectively and with prominent Pop I features in the

CMDs. KK 16 and KK 17 are dwarfs with only weak Pop I signatures. The distance of 5.2 Mpc is somewhat larger than anticipated by TSTV. The scatter in distance is 230 kpc. This compares with the projected scatter of 170 kpc. The velocity dispersion is  $17 \text{ km s}^{-1}$ .

UGC 685 is located 1.3 Mpc from the centroid of the association and is not expected to be a bound member. CMDs for members of the association and this outlier are shown in Figure 5.

### 3.4. 14+19 Association

In this case, the NBG catalog identification with the 14 cloud is probably not warranted. The connection with the local 14 cloud was based on the small mean velocity of  $182 \text{ km s}^{-1}$ . The large mean distance of 7.9 Mpc suggests these galaxies are probably part of the 15 cloud (the Leo Spur). The low velocity and large distance implies a peculiar velocity in the line-of-sight of  $-350$  to  $-400 \text{ km s}^{-1}$ . The Leo Spur generally manifests large motions toward us (the ‘local velocity anomaly’ (Tully et al. 1992)). Only two of the four candidate galaxies in the 14+19 Association had been identified when the NBG catalog was published.

These galaxies lie beyond the range of WFPC2 SNAP observations and published distance estimates based on WFPC2 observations were picking up the onset of the AGB rather than the RGB. With ACS we adequately distinguish these separate features (see lower panels of Fig. 2). Even with the increased uncertainty in the TRGB measurement so near the photometric limit, the observed scatter in the distances of the four galaxies is only 290 kpc, 4% of the mean distance. The scatter in projected separations is 560 kpc. Velocity dispersion is  $22 \text{ km s}^{-1}$ . The brightest galaxy is UGC 3974 with  $M_B = -16.0$ . The association lies at low Galactic latitudes but there is fortuitously low obscuration in the

region.

The large distance found for the 14+19 association puts the membership of UGC 3755 in doubt. This galaxy is 1 Mpc from the centroid of the group. The issue of its membership will be reconsidered in Section 5.

It is to be noted that an interim discussion of the dynamics of this association by T05 was based on distances obtained from WFPC2. As mentioned, those distance measures are badly underestimated. CMDs are shown in Figure 6.

### 3.5. 14+13 (NGC 55) Association

When the NBG catalog came out the principal members of this entity, NGC 55 and NGC 300, were taken to be part of the Sculptor Group, 14-13 in the NBG catalog, with NGC 253 as the dominant galaxy. It subsequently became evident that NGC 55 and NGC 300 are to the foreground. Three other galaxies are associated: ESO 294-10, ESO 407-18, and ESO 410-05. The latter, at a distance of 1.94 Mpc, is a dE system with a velocity that was measured only recently (Bouchard et al. 2005). The mean distance for the five galaxies is 2.07 Mpc, with a dispersion of 125 kpc. The dispersion in projection is 230 kpc. Another galaxy, IC 5152, has essentially the same distance (1.97 Mpc) and velocity ( $V_{LG} = 75 \text{ km s}^{-1}$ ) but is 830 kpc away in projection. The status of this outlier will be considered during the discussion of the association dynamics.

The newly determined velocity of  $V_{LG} = 176 \text{ km s}^{-1}$  for ESO 410-05 causes a dramatic revision of our understanding of the dynamics of the 14+13 Association. The line-of-sight rms velocity dispersion jumps from  $\pm 15 \text{ km s}^{-1}$  with 4 systems to  $\pm 36 \text{ km s}^{-1}$  with 5 systems, with obvious implications for the mass.

The velocity dispersion in this case, as with all the other associations discussed in this

paper, is in the Local Group standard of rest (Karachentsev & Makarov 1996). Members of this nearby association subtend  $\sim 20^\circ$  on the sky and it can be asked if the velocity dispersion can be reduced by a correction for a proper motion of the association centroid. The possibility was pursued in this case because it could be seen that there was a gradient in  $V_{LG}$  of  $\sim 37 \text{ km s}^{-1} \text{ degree}^{-1}$  along an axis with an orientation that could be defined to  $\sim \pm 25^\circ$ . However the amplitude of motion required to reduce the velocity dispersion of the association candidates is ludicrous. A large transverse velocity of  $2,000 \text{ km s}^{-1}$  would only reduce the internal velocity dispersion of the association from  $38 \text{ km s}^{-1}$  to  $29 \text{ km s}^{-1}$ . The lesson learned was that any reasonable proper motion has only a modest impact on the observed velocity dispersion. The issue is less important for more distant associations because they subtend smaller angles on the sky.

The 14+13 Association has the dimension and velocity dispersion characteristics of the entities discussed previously but it differs because two of the galaxies are not dwarfs: NGC 55 with  $M_B = -17.9$  and NGC 300 with  $M_B = -17.7$ . As a consequence, it will be seen that this association has a lower mass to light ratio than the others and can be viewed as a transition structure between associations of dwarfs and classical loose groups like the Local Group. CMDs are shown for the candidate association members in Figure 7.

#### 4. Are There Any Other Nearby Dwarf Associations?

The associations that have been discussed were considered by TSTV to be the most interesting cases within a group averaged velocity of  $400 \text{ km s}^{-1}$  (ie, suspected to lie within  $\sim 5 \text{ Mpc}$ ; although we now find that the 14+19 association is substantially more distant at  $8 \text{ Mpc}$  and moving with a large peculiar motion toward us!). We took the opportunity with the HST observations to check out other possibilities.

#### 4.1. 14+14 Association

Our closest attention was given to the region around NGC 1313. In the NBG catalog, NGC 1313 and ESO 115-21 constitute the 14-14 pair while a 14+14 association lies nearby to one side including NGC 1311, IC 1959, and ESO 154-23. The only new galaxy to come to light that might belong with 14-14 is KK 27. The CMDs for a possible 14-14 trio are shown in the upper part of Figure 8 and for the 14+14 trio in the lower part of the same figure.

The distance information from the CMDd show that the 14+14 trio are distinctly behind the 14-14 trio. We infer that the two trios are dynamically distinct. In the case of 14-14, KK 27 is found to be a dE companion to NGC 1313. We do not have a velocity for this galaxy so the kinematic information for the 14-14 structure remains too sparse to be given attention.

The 14+14 trio have the joint properties that resemble the high mass end of our associations. The velocity dispersion is relatively high at  $35 \text{ km s}^{-1}$ . At a distance of 5.8 Mpc, the three galaxies are all in the SMC luminosity range with  $-15.5 > M_B > -16.2$ . The projected inertial radius of 250 kpc compares with the rms difference in distance of 310 kpc. Properties of the proposed association are summarized in Table 2.

#### 4.2. 14+7 (NGC 4214) Association

In the first systematic search for dwarf galaxies across the entire northern sky, van den Bergh (1966) found the largest concentration of prominent dwarfs was in the constellation of Canes Venatici. The nearer of these lie in a structure called Canes Venatici I by de Vaucouleurs (1975) and the 14-7 Group in the NBG catalog. Now that excellent TRGB distances are becoming available, it is becoming evident that this structure breaks up into distinct foreground and background components that are completely confused in velocity

and position on the sky (Karachentsev et al. 2003b). The more luminous galaxies, including NGC 4736, lie in the background component at 4.4 Mpc and constitute the main 14-7 Group. The foreground objects congregate around NGC 4214 at 2.8 Mpc and will henceforth be referred to as the 14+7 Association.

At least six low luminosity systems lie in the foreground association, making it the best populated association of dwarfs known (these include NGC 3741, 4163, 4214 and DDO 99, 113, 125). CMDs based on HST archival material are presented for these galaxies in Figure 9. The CMD for the outlier UGC 8508 is shown in Figure 10. Presently, only about half the galaxies in the Canes Venatici region with appropriate velocities have good distance measures so there is the prospect that the list of members of the 14+7 association will grow. Accordingly, this association merits special attention because it can provide better statistical information than the other associations have afforded. If additional members are identified then they will improve our kinematic knowledge, hence mass estimate, but they will not add much light. The remaining candidates are all much less luminous than NGC 4214 at  $M_B = -17.1$ .

### 4.3. The dregs within 3 Mpc

Most known galaxies within 3 Mpc and at high Galactic latitude now have excellent distance estimates through the TRGB method. Are there any interesting structures in the objects that are *not* assigned to previously identified condensations? We consider all galaxies that are beyond the traditional Local Group (taken to include Tucana and SagDIG at the periphery) but within 3 Mpc in the compilation by Karachentsev et al. (2004) or as updated by a few new objects and improved TRGB detection algorithms (Makarov et al. 2006; Karachentsev et al. 2006a). There are 43 such galaxies. Because of incompleteness problems we will not give attention to the zone within 30 degrees of the Galactic plane

except to say that there are 13 known objects in or peripheral to the Maffei Group where the supercluster plane crosses the plane of our Galaxy in the north and 5 known objects in the region of Circinus and the Centaurus Group at the southern crossing. Probably other galaxies await discovery in this zone.

Ignoring this obscured half of the sky leaves 25 galaxies. One galaxy (KK 127) injected into our sample strictly on the basis of its low velocity is probably a high negative velocity member of the Coma I Cluster at 16 Mpc. (Note: high negative velocity members of a similar nature in the Virgo Cluster had already been discounted from consideration in the Karachentsev et al. (2004) catalog.) Then 19 galaxies belong to the 14+13, 14+12, 14+7, and front of the 14+8 dwarf associations that were discussed earlier, including the recently discovered KKH 60 that does not have a distance measure. Passing over these 20 high latitude objects connected with already established structures takes the count to be considered to only five, all with good distances.

One of these five, KKR 25, is well separated from the others. It is nearby, with a TRGB measurement that puts it at a distance of 2.14 Mpc. The CMD is seen in Fig. 10. A claimed velocity of  $V_{helio} = -139 \text{ km s}^{-1}$  has not been confirmed (Begum & Chengalur 2005) and is probably attributable to confusion with local HI. Nonetheless, the distance to KKR 25 is reliable and citizens of that dwarf spheroidal galaxy must see the Milky Way as the nearest giant system. It is a factor two more distant than the zero velocity surface separating Local Group infall from cosmic expansion (Karachentsev et al. 2002a) but still within the zero energy surface (Peirani & Pacheco 2005) so conceivably is bound to the Local Group. Beyond it is the Local Void (Tully & Fisher 1987). It is the most isolated galaxy known in this small volume (it’s nearest known neighbor is the dwarf KK 230 at a distance of 1.1 Mpc) and, remarkably, it is gas deficient!

What is to be made of the last four? By name they are: UGC 8091 = DDO 155 =

GR8, UGC 9128 = DDO 187, KKH 86, and KK 230 at a mean distance of 2.3 Mpc. Their CMDs are seen in Figure 10. They are close to each other but not so close that we would expect them to be bound, with an ensemble inertial radius in 3-dimensions of 570 kpc (inertial radius  $R_I = [\Sigma_i^N r_i^2 / N]^{1/2}$  where  $r_i$  is the distance of galaxy  $i$  from the centroid of the  $N=4$  objects). The velocity dispersion of the four is  $37 \text{ km s}^{-1}$ , at the upper limit of the associations of dwarfs previously discussed. Turning these dimensions and velocities into masses assuming a bound system implies values like  $1 - 2 \times 10^{12} M_\odot$ , comparable to the Local Group. However the observed galaxies are all extreme dwarfs in the range  $-8 > M_B > -13$ . If bound, it would require that  $M/L_B \sim 50,000 M_\odot$ .

We do not expect that these four galaxies are bound together. There is a monotonic increase in the velocity of each galaxy with distance from us, the property expected if the objects are in relative expansion. These 4 galaxies might be considered as an ‘unbound association’. That 4 of 5 ‘leftovers’ in a volume of  $\sim 50 \text{ Mpc}^3$  at high latitudes within 3 Mpc should be contained within a volume of  $1 \text{ Mpc}^3$  suggests some sort of linkage. We will revisit the matter in the next section with the suggestion that this region is being tidally disrupted.

## 5. Masses of the Associations Revisited

Let it be understood clearly that we do not expect that the associations of dwarfs are in dynamical equilibrium. Crossing times can be 80% of the Hubble time,  $H_0^{-1}$ . Guidance regarding the dynamical state of the structures can come from consideration of the nearest generally accepted groups like the Local Group including M31 and the Milky Way, the M81 Group including M81 and the NGC 2403 sub-region (Karachentsev et al. 2002a), and the Centaurus Group including Cen A and M83 as distinct dynamical centers (Karachentsev et al. 2006b). In each of these well known cases, there are dynamically evolved regions around major galaxies, marked by a predominance of early type companions and motions that are



both positive and negative with respect to the dominant host. In each case, too, there are more extended, lower density, relatively unevolved regions, marked by predominantly late morphological types and infall velocity patterns. The associations of dwarfs resemble the latter, low density regions, lacking a semblance of a core.

The zero-velocity surface or radius of first turnaround for our Local Group occurs at about 900 kpc from the centroid of the Milky Way and Andromeda galaxies (Karachentsev et al. 2002c; Tully 2005b). One can scale to the equivalent surface for a dwarf association mass by using the property that turnaround today occurs at the same density everywhere. Hence in the spherical approximation,  $r_{dw} = r_{LG}(M_{dw}/M_{LG})^{1/3}$ . With  $M_{LG} = 2 \times 10^{12} M_{\odot}$  and  $r_{LG}^{1t} = 900$  kpc, then

$$r_{dw}^{1t} \sim 330 M_{11}^{1/3} \text{ kpc} \quad (1)$$

where  $M_{11}$  is the mass of the association halo in units of  $10^{11} M_{\odot}$ . This scaling relation provides a rough requirement to be met as we evaluate whether an association might be bound or whether an individual galaxy is a serious candidate for membership.

Results for the ensemble of associations are summarized in Table 2. As a general comment, it will be noted that most of the  $M/L$  values are lower than reported by TSTV and T05. Mostly, these reductions result from better distances. In addition, the earlier work had considered velocities in the Galactic standard of rest (de Vaucouleurs et al. 1991) while here velocities are considered in the Local Group standard of rest (Karachentsev & Makarov 1996), removing gradients caused by the motion of our Galaxy toward M31. Most velocity dispersions are reduced a bit as a consequence, hence inferred masses are reduced.

Following T05, masses are calculated in two ways, the first making use of the “projected mass estimator” of Heisler et al. (1985) and the second based on the virial theorem without luminosity weighting. There was a lengthy discussion in T05 regarding mass estimate uncertainties which are considerable. The factor of 2 difference between the virial mass

estimate and the estimate that arises from the simple assumption that the structure is bound gives a rough measure of systematic uncertainties. Probably a better measure of uncertainties is given by tracking how mass and  $M/L$  values for a given entity have bounced around between TSTV, T05, and the present results presented in Table 2. The median variation for a given entity is a factor 3, simply arising from incremental improvements in distances, velocities, luminosities, and membership assignments.

Figure 11 shows relative velocities as a function of relative distances for the galaxies identified with the seven associations. If gravity played no role then one would expect a Hubble law dependence between velocity and distance. If motions were predominantly radial infall then one could expect nearer galaxies in a group to be systematically redshifted compared with farther galaxies in the group. There is a slight hint of a positive correlation between velocity and distance in Fig. 11 but it comes exclusively from the 14+14 and 17+6 associations. The uncertainty in the distribution of points in this figure is too great to warrant a dynamical interpretation. It is to be appreciated that overall expansion or contraction are subtle effects given the very small dispersions in velocities and significant errors in distances. Here are comments on each of the proposed associations in turn.

*14+12 (NGC 3109) Association.* In TSTV and T05, the velocity dispersion was measured in the Galactic rest frame. With the transform from Galactic to Local Group rest frame the velocity dispersion increases slightly, resulting in larger mass estimates than previously. The new candidate KKH 60 does not yet have a distance measure. The mass calculations include this fifth candidate placed at the mean group distance and at  $\pm 3\sigma_d$  excursions from the mean distance where  $\sigma_d$  is the dispersion in the distances of the four established members. The addition of the fifth candidate causes mass estimates to drop 20%, an insignificant amount compared with other sources of error. Modifying the distance over the  $\pm 3\sigma_d$  range increase mass estimates by only  $\sim 15\%$ , a negligible amount.

The 14+12 Association is nearby the Local Group (1.37 Mpc from the Milky Way and 1.7 Mpc from the Local Group mass centroid). It can be asked if the association is stable against tidal disruption. An association mass of  $\sim 1.6 \times 10^{11} M_{\odot}$  would be stable against disruption from the Local Group with  $\sim 1.8 \times 10^{12} M_{\odot}$  out to a sphere radius of  $\sim 500$  kpc. This dimension is larger than the dimension of the association, so tidal disruption is not inferred to be a problem today, although it is a close call. It turns out that the 14+12 Association presents the most vulnerable case from the standpoint of tidal disruption among the associations that have been currently identified. The possibility of tidal disruption does have relevance in a few situations regarding outliers.

*14+8 Association.* Mass and  $M/L$  estimates dropped from T05 because of a lower velocity dispersion in the Local Group frame and a 30% increase in the attributed luminosity. These changes provide a warning that the results have large uncertainties. Still,  $M/L$  values are an order of magnitude larger than values attributed to nearby spiral rich groups (Karachentsev 2005).

*17+6 (NGC 784) Association.* The mass estimates dropped substantially from T05 for two reasons. In this case the velocity dispersion dropped dramatically passing to the Local Group rest frame. Moreover, with improved distances, the 3-dimensional inertial radius is shown to be only 2/3 its previously assumed value.

The dwarf galaxy UGC 685 lies 1.3 Mpc from the centroid of the 17+6 Association. The zero-velocity surface for this association is inferred from Eq.(1) to lie at  $\sim 380$  kpc so UGC 685 must be not be bound with the others.

*14+19 Association.*  $M/L$  estimates are reduced, partially because of a reduced velocity dispersion and partially because of a significant increase in distance. The virial mass estimator for this group is subject to significant error because of the proximity of UGC 3974 and KK 65. The virial mass estimator is unstable if numbers are small and there are

instances of close pairs.

At a distance of almost 8 Mpc, we are forced to reevaluate if UGC 3755 should be considered a member. At this large distance, we find it is 1 Mpc from the centroid of the 4 candidates. It is seen in Table 2 that the mass found for the 14+19 association is  $\sim 4 \times 10^{11} M_{\odot}$  whether 3 or 4 members are considered. The zero velocity turnaround surface of a bound system would be at a radius of  $\sim 520$  kpc according to Eq. (1). We conclude that UGC 3755 would not be within the association infall region. Nonetheless, if we consider the model of spherical infall with  $\Omega_{\Lambda} = 0.7$  and  $\Omega_m = 0.3$  discussed by Peirani & Pacheco (2005), we infer that the bound surface of a mass of  $4 \times 10^{11} M_{\odot}$  would lie at a radius of  $\sim 1.2$  Mpc. UGC 3755 could yet be trapped by the 14+19 Association.

*14+13 Association.* This interesting case was discussed by TSTV and T05: an association with the same properties as the others in terms of dimensions and velocity dispersion but *not* deficient in light. The addition of ESO 410-05 changes the picture. This small galaxy is clearly a member based on its coordinates and distance but its inclusion causes the velocity dispersion to jump by a factor 2.4 and mass estimates to jump by a factor 6. Whereas previously this association stood apart with a low value of  $M/L$ , now with an increased mass estimate it lies in an interesting transition regime between associations of dwarfs and entities like the Local Group.

The 14+13 Association has an outlier: IC 5152 is 820 kpc from the centroid of the association, beyond the zero-velocity turnaround radius of  $\sim 570$  kpc anticipated by Eq. (1). The tidal radius for the 14+13 Association ( $1.6 \times 10^{11} M_{\odot}$  at 2 Mpc from the Local Group with  $1.8 \times 10^{12} M_{\odot}$ ) is at a radius of  $\sim 1$  Mpc so IC 5152 is near the tidal surface.

*14+14 Association.* This entity is a new addition. With only 3 candidate members the derived parameters are uncertain. However they are within the range of the other cases.

*14+7 Association* Discussion of this entity is preliminary because other potential members are identified but, lacking good distance measures, are entangled with the background 14-7 Group. The six confirmed members already constitute the largest association of dwarfs known. The luminosity of the association is reasonably established because of the dominance of NGC 4214 so the high value of  $M/L$  reported in Table 2 already has a firm basis. A seventh galaxy with a good distance, UGC 8508, lies  $\sim 900$  kpc from the centroid of the association, undoubtedly beyond the infall region but possibly bound (ie, within the zero-energy surface).

*The dregs.* If we ignore intuition and consider the four galaxies UGC 8091 = DDO 155, UGC 9128 = DDO 187, KKH 86, and KK 230 to be bound then one gets the results reported in Table 2. The entity would bear closer resemblance to the Local Group in terms of dimensions, velocity dispersion and inferred mass than to the associations that have been discussed. The combined luminosity is much lower than any of the other cases, so the inferred  $M/L$  is much larger.

As was noted, the distances of the four galaxies among the dregs increase monotonically with velocity, the condition expected if the objects are unbound. Given the proximity of the Local Group, these galaxies would need at least  $1.4 \times 10^{11} M_{\odot}$  (whence  $M/L > 5000 M_{\odot}/L_{\odot}$ ) to stabilize against tidal disruption. The most reasonable assumption is that the four galaxies are *not* bound and the dynamical analysis provides no information regarding the distribution of mass in their vicinity. We may be seeing a tidally disrupted, evaporating association. Little can be said with a case of one. Presently our three-dimensional census of dwarfs and their distances is very incomplete beyond 3 Mpc even at high Galactic latitudes.

## 6. Discussion

It is sobering to see the changes that have occurred in the inferred masses and  $M/L$  values for the putative associations of dwarfs since they were identified by TSTV and rediscussed by T05. The changes result from updates in distances, velocities, luminosities, and membership assignments. Yet the fundamental conclusion remains the same. *If the associations are bound then  $M/L$  values are very high.*

There was an extensive discussion in T05 in favor of the proposition that the associations of dwarfs are bound and, if so, of the uncertainties that arise in mass estimates. Here, we will briefly recall the two arguments regarding the more important of these issues; that the associations are bound.

The first argument notes the continuity of inferred dark matter halo properties of the associations of dwarfs with more familiar groups of spirals. Figure 12, a modification of a plot in T05, compares group velocity dispersions and projected inertial radii for both dwarf associations and spiral groups. A continuum of these properties are seen from spiral group velocity dispersions of  $\sim 100 \text{ km s}^{-1}$  and radii of  $\sim 600 \text{ kpc}$  down to dwarf associations at  $\sim 25 \text{ km s}^{-1}$  and radii of  $\sim 250 \text{ kpc}$ . However, while there is a continuity in dynamical properties, whence inferred mass properties, there is a break in the relationship with light between the spiral and dwarf regimes.

The second argument develops out of the observation that dwarf galaxies are highly correlated in position. Figure 6 in T05 shows the 3-dimensional 2-point correlation for galaxies at distances between one and five Mpc at high Galactic latitude, demonstrating a strong peak on scales less than 500 kpc. We will make the same point by looking at the latest data available for the restricted shell between 1.1 and 3.2 Mpc and  $|b| > 30$  where there is a high level of completion. The lower distance limit excludes galaxies considered to be part of the Local Group. The upper limit excludes galaxies considered to be members of

the nearest well known groups around M81 and in Sculptor, Centaurus, and Canes Venatici. There are 24 galaxies with well established distances within this volume of  $66 \text{ Mpc}^3$ . A small number of additional galaxies identified but without measured distances are plausibly within this volume.

The clumping of these 24 galaxies is extreme. Two of these, along with NGC 3109 and Antlia which are slightly below  $b = 30$ , are at 1.4 Mpc in an enclosing spherical volume of  $0.4 \text{ Mpc}^3$  (plus suspected companion KKH60). Five, with NGC 55 the brightest, are at 2.1 Mpc in  $0.3 \text{ Mpc}^3$  (plus sixth outlier IC 5152). Six, with NGC 4214 the brightest, are at 2.8 Mpc in  $0.6 \text{ Mpc}^3$  (plus seventh outlier UGC 8508). Four, with UGC 9240 the brightest, are at 3.1 Mpc in  $0.4 \text{ Mpc}^3$ . Five more, with UGC 9128 the brightest, at 2.3 Mpc are more loosely linked within  $1.4 \text{ Mpc}^3$ . Hence 23 of 24 galaxies with good distances lie in five regions enclosing  $\sim 3 \text{ Mpc}^3$  of the available  $66 \text{ Mpc}^3$ . The distribution of these galaxies is shown first in Figure 13 in projection on the sky and then in Figure 14 in two projections in supergalactic cartesian coordinates. These galaxies inhabit only a small part of the available volume.

We have presented two arguments that build a strong circumstantial case that dwarf galaxies in associations, like galaxies in spiral-dominated groups, are born in overdense regions that are bound. In cases like the ‘dregs’ including UGC 9128, and the association outliers like IC 5152 and UGC 8508, it is suspected that tidal forces have had a disrupting influence. However, in the remaining cases we infer that the associations remain bound and, consequently our effort to estimate masses has validity.

The results are illustrated in Figures 15 and 16. The data in these figures is extracted from T05 except for updated values drawn from the current paper for the associations of dwarfs and revised values for the Local, M81, and Centaurus groups (Karachentsev 2005; Karachentsev et al. 2006b). The situation is not significantly changed. If associations of

dwarfs are representative of bound structures on mass scales below  $10^{12} M_{\odot}$  then there is a sharp break below this scale in the relationship between light and mass. The expression fit to the data in Fig. 15 (minimizing the square of deviations in mass) is:

$$L_B = \phi M^{\gamma} e^{M^{\dagger}/M} \quad (2)$$

where the power law slope is  $\gamma = 0.59$ , the exponential cutoff is characterized by  $M^{\dagger} = 6 \times 10^{11} M_{\odot}$ , and the normalization is  $\phi = 2700$ .

A similar minimum in  $M/L$  with a sharp increase at lower masses has been suggested by others. The shallow faint end slope of observed luminosity functions of galaxies compared with the halo mass function has indicated a paucity of light at low masses (Marinoni & Hudson 2002; van den Bosch et al. 2003, 2005). Semi-analytic models have found a similar effect, arising out of feedback heating that damps the accumulation of gas and star formation in low mass halos (Benson et al. 2000). Those hints of a rapid increase of  $M/L$  toward lower masses are based on theoretical considerations. The claims made in T05 and this paper are directly based on observations.

How has the present study clarified the situation? It has convincingly been shown that the strong correlations in projection and in velocity of a large fraction of nearby dwarf galaxies are, in fact, strong correlations in three-dimensions. The associations of dwarfs have the spatial distribution and kinematic properties expected of structures like the Local Group but less massive by factors 3 to 10. We infer that these associations are bound but dynamically unevolved. To make up the implied masses, they presumably contain dark matter sub-halos on scales of  $10^9 - 10^{10} M_{\odot}$  that contain too little gas and too few stars to be currently detected.

There is a strong incentive to increase the size of the census of nearby galaxies. We probably have identified all galaxies brighter than  $M_B \sim -10$  at  $|b| > 30^{\circ}$  and within 3 Mpc. Aside from lonely KKR 25, every object in this volume is associated either with



a luminous group or an association of dwarfs or the ‘dregs’ evaporating association. Our current knowledge is predominantly the consequence of a series of observations with HST WFPC2. The added sensitivity of ACS doubles the range available for accurate distance measurements. It is within our capability to get distances good to 5% for all galaxies at high latitudes with  $M_B < -10$  and within 6–8 Mpc. With completion in a volume an order of magnitude greater than currently available, the statistics will improve and the case should become clear regarding whether or not associations with little light are bound.

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Table 1. Candidate Association Members or Galaxies with  $1.1 < d < 3.2$  Mpc at  $|b| > 30$ .

Group	Names	RA (J2000) Dec	SGL	SGB	$B_T$	Ty	$V_{LG}$	HST	$I_{tip}$	$\pm$	$A_I$	$m - M$	$d$ (Mpc)	$\Delta V$	$R$ (kpc)	$M_B$
14+12	NGC 3109, DDO 236	100306.6 -260932	262.0981	-45.1065	10.10	9	110	8601	21.71	0.03	0.13	25.63	1.34	15	307	-15.53
	U5373, SexB, D 70	095959.8 +051957	233.1991	-39.6203	11.75	10	111	8601	21.80	0.02	0.06	25.79	1.44	16	450	-14.03
	Sex A, DDO 75	101101.3 -044248	246.1704	-40.6659	11.94	10	94	7496	21.82	0.06	0.09	25.78	1.43	-1	212	-13.84
	Antlia	100403.9 -272001	263.0984	-44.8031	16.19	10	66	10210	21.60	0.13	0.15	25.49	1.25	-29	346	-9.30
14+13	NGC 55	001508.4 -391313	332.6740	-2.4102	8.78	9	111	8697	22.66	0.03	0.03	26.68	2.17	-5	186	-17.90
	NGC 300	005452.6 -374057	299.2306	-9.4984	8.89	7	114	9492	22.52	0.03	0.03	26.54	2.04	-2	322	-17.65
	UGCA 438, E407-18	232622.2 -322329	11.8694	9.2990	13.80	10	99	8192	22.72	0.06	0.03	26.74	2.22	-17	404	-12.94
	ESO 410-005	001531.5 -321047	357.8469	-0.2573	14.85	-5	176	8192	22.42	0.05	0.03	26.44	1.94	60	196	-11.59
	ESO 294-010	002633.3 -415119	320.4159	-5.2699	15.51	10	81	8601	22.42	0.08	0.01	26.46	1.96	-35	195	-10.95
	IC 5152	220241.2 -511747	343.9191	11.5285	10.95	10	75	8192	22.47	0.08	0.05	26.47	1.97	-41	817	-15.52
14+07	NGC 4214	121538.6 361941	160.2577	1.5936	10.15	10	295	6569	23.32	0.03	0.04	27.33	2.92	46	179	-17.18
	UGC 7577, DDO 125	122740.9 432944	137.7581	5.9272	12.86	10	240	8601	23.18	0.03	0.04	27.19	2.74	-9	381	-14.33
	NGC 4163	121209.1 361009	163.2040	0.8761	13.54	10	164	9771	23.33	0.02	0.04	27.34	2.94	-85	227	-13.81
	UGC 6817, DDO 99	115053.0 385249	166.1978	-2.1220	13.59	10	248	8601	23.11	0.04	0.05	27.11	2.64	-1	294	-13.52
	NGC 3741	113606.2 451701	157.5712	-2.0769	14.28	10	264	8601	23.52	0.06	0.05	27.52	3.19	15	510	-13.24
	UGCA 276, DDO 113	121457.9 361308	161.1018	1.4295	15.61	10	283	8601	23.51	0.06	0.04	27.51	3.18	34	182	-11.91
	UGC 8508	133044.4 545436	111.1410	17.9057	14.06	10	186	8601	23.13	0.04	0.03	27.15	2.69	-63	896	-13.09
14+08	UGC 9240, DDO 190	142443.4 +443133	82.0084	26.8518	13.05	10	263	8601	23.21	0.04	0.02	27.24	2.80	-6	463	-14.19
	UGC 8760, DDO 183	135050.6 +380109	77.7919	20.4675	14.35	10	257	10210	23.54	0.06	0.03	27.55	3.24	-12	213	-13.20

Table 1—Continued

Group	Names	RA (J2000) Dec	SGL	SGB	$B_T$	Ty	$V_{LG}$	HST	$I_{tip}$	$\pm$	$A_I$	$m - M$	$d$ (Mpc)	$\Delta V$	$R$ (kpc)	$M_B$
	UGC 8651, DDO 181	133953.8 +404421	89.7337	18.5795	14.46	10	272	10210	23.36	0.05	0.01	27.40	3.02	3	184	-12.94
	UGC 8833	135448.7 +355015	69.7137	21.0897	15.09	10	285	10210	23.50	0.07	0.02	27.53	3.20	16	258	-12.43
17+06	NGC 784	020117.0 285015	140.9029	-6.3056	11.98	8	386	10210	24.64	0.05	0.11	28.58	5.19	8	114	-16.59
	UGC 1281	014931.5 323517	136.8680	-2.5928	12.67	8	367	10210	24.59	0.03	0.09	28.55	5.13	-11	310	-15.88
	KK 16	015520.3 275714	139.7495	-5.4137	16.	10	400	10210	24.78	0.05	0.14	28.69	5.47	22	330	-12.7
	KK 17	020010.2 284953	140.6333	-6.0816	17.	10	360	10210	24.51	0.07	0.11	28.45	4.91	-18	282	-11.4
	UGC 685	010722.4 164102	128.4313	1.6065	14.51	10	349	10210	24.42	0.03	0.11	28.36	4.70	-29	1257	-13.84
14-14	NGC 1313	031815.4 -662951	283.3598	-28.2223	9.19	6	270	10210	24.25	0.03	0.21	28.09	4.15			-18.90
	ESO 115-021	023748.1 -612018	282.7904	-25.9622	13.23	6	337	10210	24.49	0.03	0.05	28.49	4.99			-15.26
	KK 27	032102.4 -661909	282.9130	-28.5528	16.17	-3		10210	24.19	0.07	0.15	28.09	4.15			-11.92
14+14	ESO 154-023	025651.2 -543423	271.8077	-30.2306	12.62	7	412	10210	24.79	0.03	0.03	28.80	5.76	-13	373	-16.18
	IC 1959	033309.0 -502442	261.2838	-36.8068	13.21	8	464	10210	24.88	0.05	0.02	28.91	6.06	39	443	-15.70
	NGC 1311	032006.7 -521113	265.2951	-34.2690	13.09	9	398	10210	24.67	0.03	0.04	28.68	5.45	-27	311	-15.46
14+19	UGC 3974, DDO 47	074152.0 +164754	203.0986	-55.5005	13.51	10	160	10210	25.54	0.04	0.06	29.53	8.04	-19	245	-16.02
	UGC 4115	075702.4 +142312	207.0078	-56.2273	14.21	10	210	10210	25.44	0.05	0.05	29.44	7.72	31	443	-15.23
	KK 65, CG 87-33	074232.0 +163339	203.3957	-55.6679	15.42	10	168	10210	25.53	0.07	0.06	29.52	8.01	-11	199	-14.10
	UGC 3755	071351.6 +103119	206.0134	-63.3576	14.71	10	190	10210	25.47	0.06	0.17	29.35	7.41	11	1067	-14.64

Table 1—Continued

Group	Names	RA (J2000) Dec	SGL	SGB	$B_T$	Ty	$V_{LG}$	HST	$I_{tip}$	$\pm$	$A_I$	$m - M$	$d$ (Mpc)	$\Delta V$	$R$ (kpc)	$M_B$
Dregs	UGC 9128, DDO 187	141556.5 +230319	25.5731	24.3518	14.27	10	172	10210	22.75	0.05	0.05	26.75	2.24	11	301	-12.48
	U8091, D155, GR8	125840.4 +141303	310.7381	4.6684	14.57	10	136	5915	22.64	0.05	0.05	26.64	2.13	-25	490	-12.07
	KKH 86	135433.6 +041435	339.0439	15.4650	16.68	10	209	8601	23.07	0.13	0.05	27.07	2.60	48	673	-10.39
	KK 230	140710.5 +350337	63.7099	23.5498	17.84	10	126	9771	22.63	0.08	0.03	26.65	2.14	-35	697	-8.81
Isol	KKR 25	161347.9 +542216	83.8790	40.3703	17.	-5		8601	22.62	0.15	0.02	26.65	2.14			-9.7

Fig. 1.— The 20 newly observed galaxies. Top: Antlia and UGC 9128; 2nd row: UGC 8651 and UGC 8833; 3rd row: UGC 8760 and KK 27; bottom: NGC 1313 and UGC 685.

Fig. 1.— continued. Top pair: ESO 115-021 and UGC 1281; middle pair: NGC 784 and NGC 1311; bottom pair: KK 17 and KK 16.

Fig. 1.— continued Top pair: ESO 154-023 and IC 1959; middle pair: UGC 3755 and UGC 3974; bottom pair: UGC 4115 and KK 65.



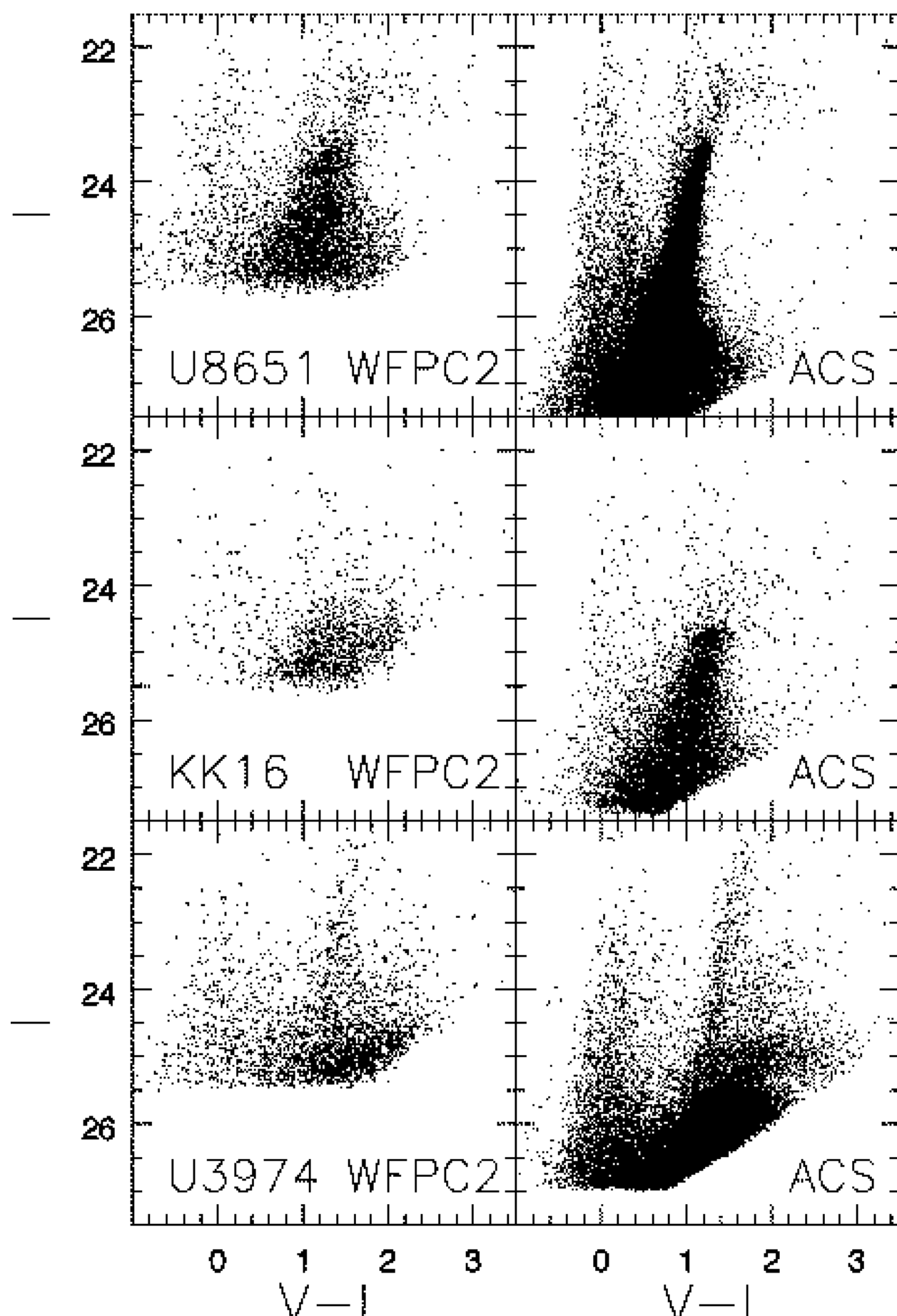
Table 2. Properties of Groups of Dwarf Galaxies.

Group	Principal Galaxy	No.	Dist. (Mpc)	$R_I^{3D}$ (Mpc)	$V_r$ (km s <sup>-1</sup> )	$L_B$ (10 <sup>8</sup> $L_\odot$ )	$M_{pm}$ (10 <sup>11</sup> $M_\odot$ )	$M_{vir}$ (10 <sup>11</sup> $M_\odot$ )	$M_{pm}/L$ ( $M_\odot/L_\odot$ )	$M_{vir}/L$ ( $M_\odot/L_\odot$ )	$M/L_B^{old}$ ( $M_\odot/L_\odot$ )	$t_x H_0$
14+12	NGC 3109	5	1.37	0.35	18	3.7	1.9	1.4	510	360	1220/ 300	0.86
14+13	NGC 55	5	2.07	0.28	36	40.7	3.8	6.5	90	160	13/ 17	0.33
		6 <sup>c</sup>		0.45	36	43.2	6.7	8.4	160	190		0.54
14 +7	NGC 4214	6	2.94	0.32	42	13.7	5.5	8.: <sup>a</sup>	400	590 <sup>a</sup>		0.30
14 +8	UGC 8760	4	3.06	0.30	11	1.4	0.4	0.5	300	380	250/ 945	1.2
17 +6	NGC 784	4	5.2	0.26	17	10.5	1.3	1.7	120	160	330/1110	0.68
14+14	ESO154-23	3	5.8	0.38	35	10.0	7.3	10.4	730	1040		0.48
14+19	UGC 3974	3	7.9	0.31	26	6.6	4.0	2.: <sup>a</sup>	600	300 <sup>a</sup>		0.52
		4 <sup>b</sup>		0.67	22	7.7	3.5	2.: <sup>a</sup>	450	300 <sup>a</sup>	1060/2040	1.3
Dregs	DDO 155	4	2.28	0.57	37	0.3	13.	16.	44000	56000		0.66

<sup>a</sup>Virial mass estimate biased low: close pair

<sup>b</sup>Including UGC 3755 in group

<sup>c</sup>Including IC 5152 in group



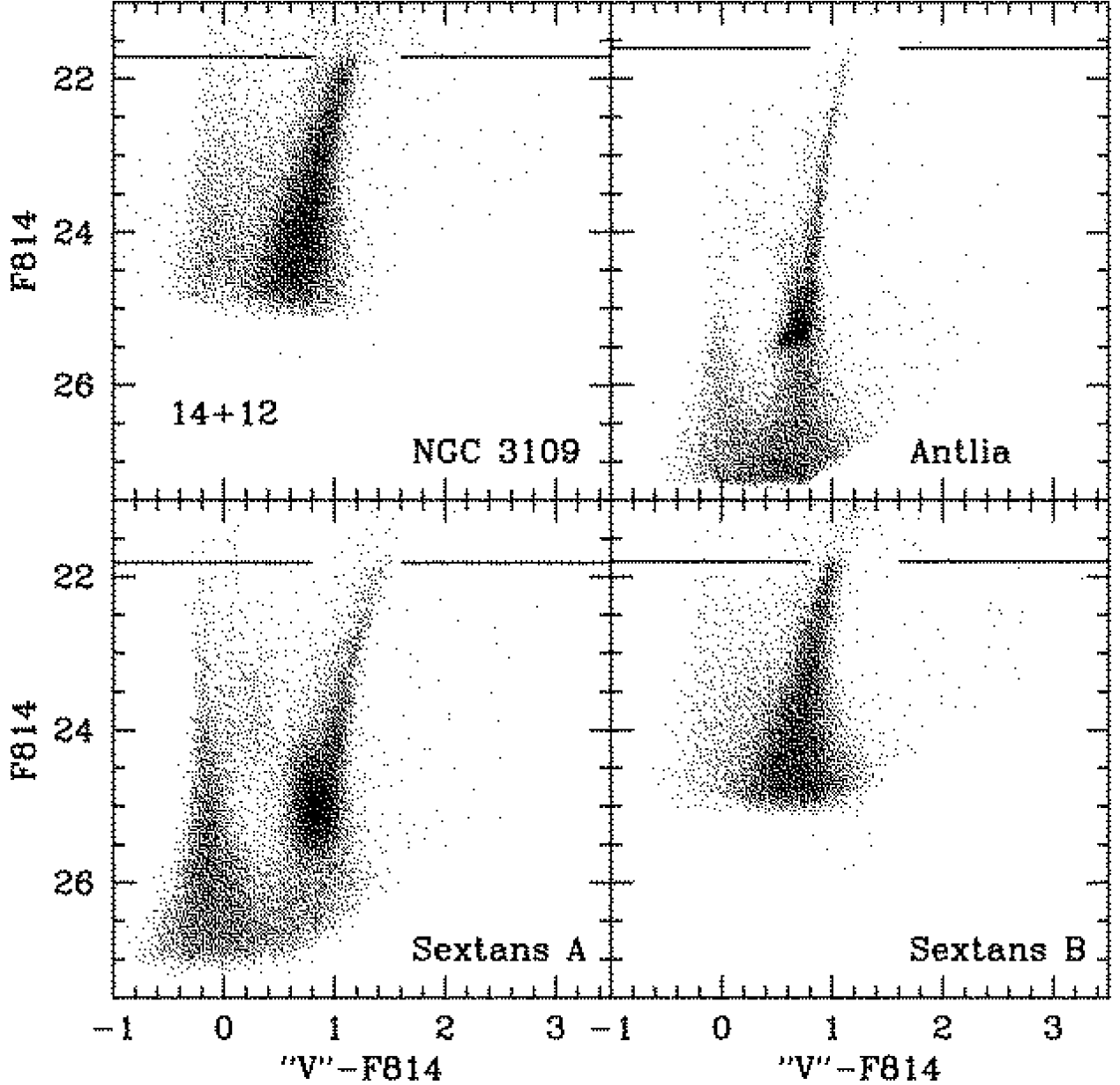


Fig. 3.— 14+12 Association. The NGC 3109 and Sex B data come from HST program 8601 with 600s exposures in the F814W filter. The Sex A data comes from a 9,600s exposure in the F814W filter in program 7496. The Antlia data was acquired in 1174s at F814W with ACS in our program 10210. In the case of Sextans A, the “V” image is obtained with the F555W filter. In the other cases, “V” is obtained with the F606W filter. The data for Sex A and Antlia is superior but the TRGB is well defined in all cases (marked by horizontal lines in each panel).

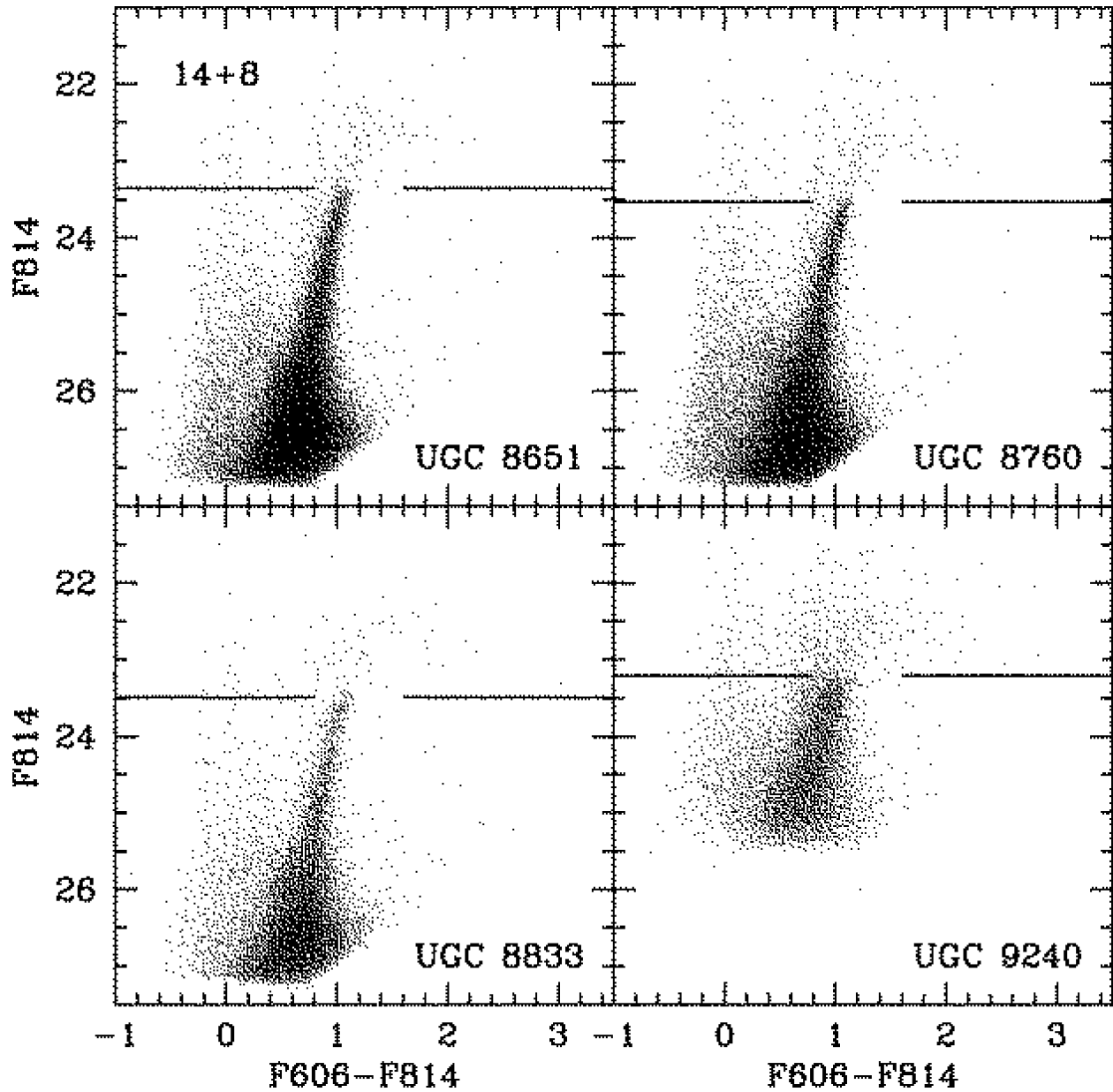


Fig. 4.— 14+8 Association. The data for UGC 8651, UGC 8760, and UGC 8833 come from our program 10210 with F814W exposures of 1209s, 1209s, and 1189s, respectively. The data for UGC 9240 is provided by program 8601 with a 600s exposure in the F814W band. Horizontal lines mark the TRGB.

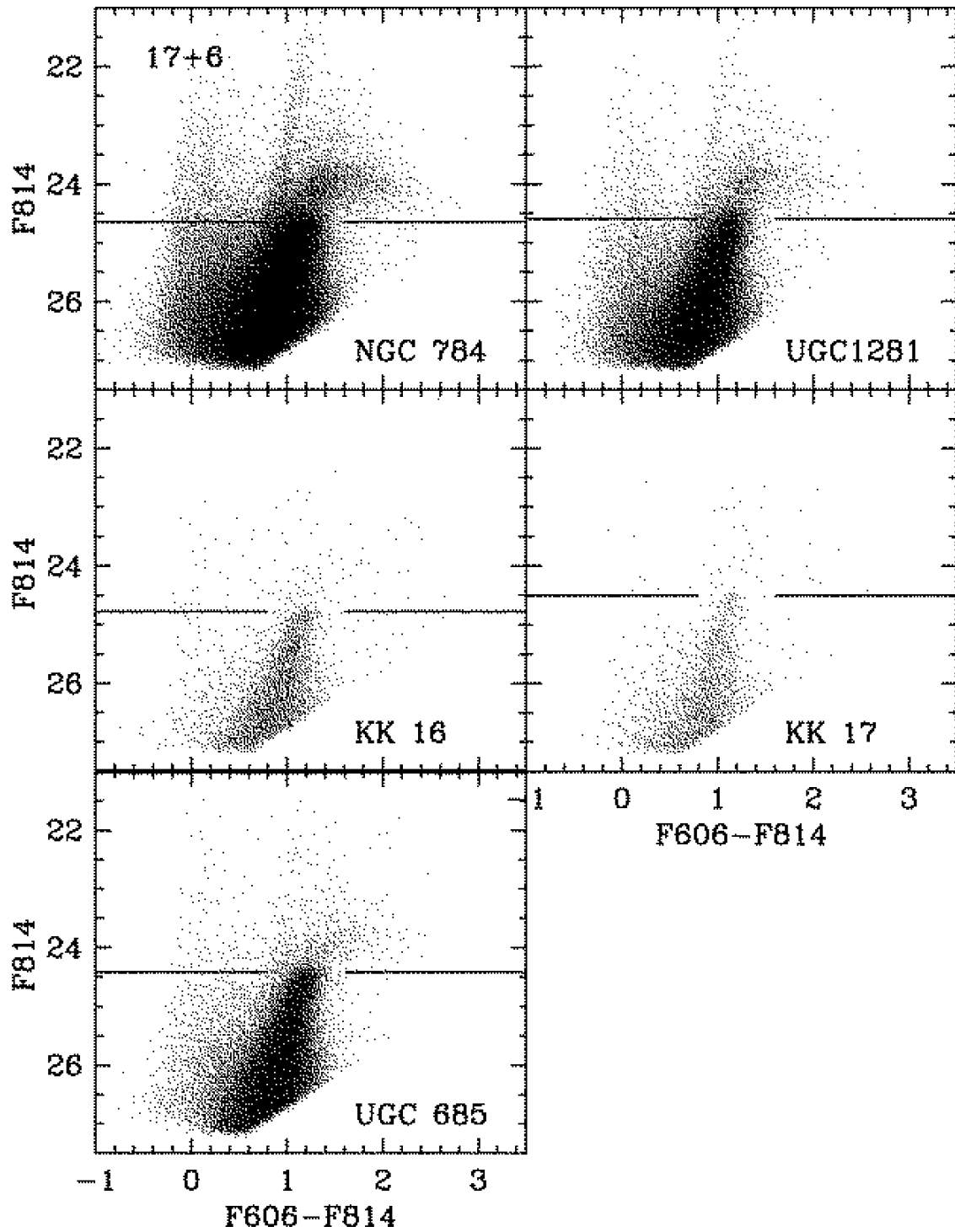


Fig. 5.— 17+6 Association. All data from our program 10210 with F814W exposures of 1226s. TRGB marked by horizontal lines.

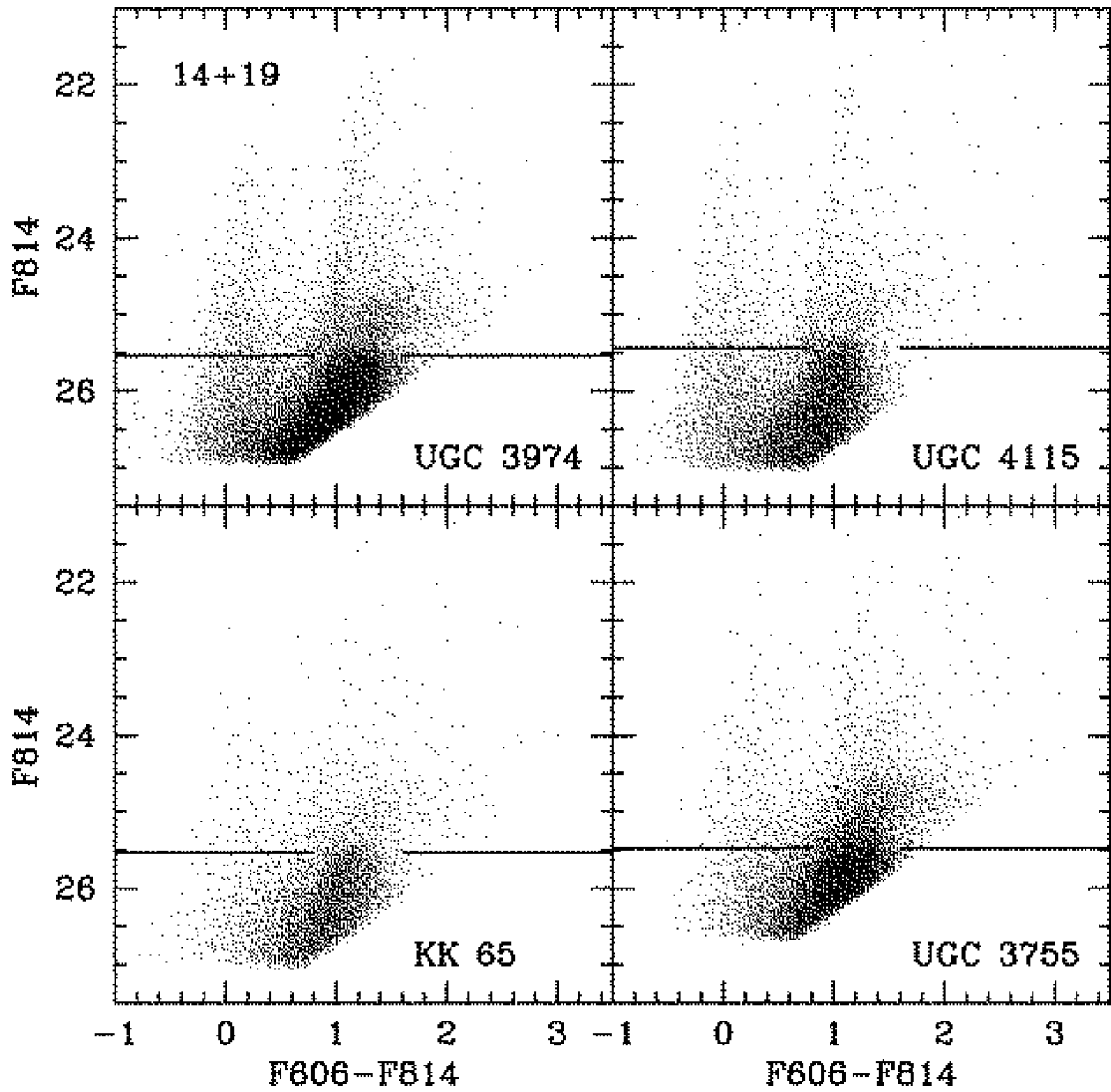


Fig. 6.— 14+19 Association. All data from our program 10210 with F814W exposures of 1226s. TRGB marked by horizontal lines.

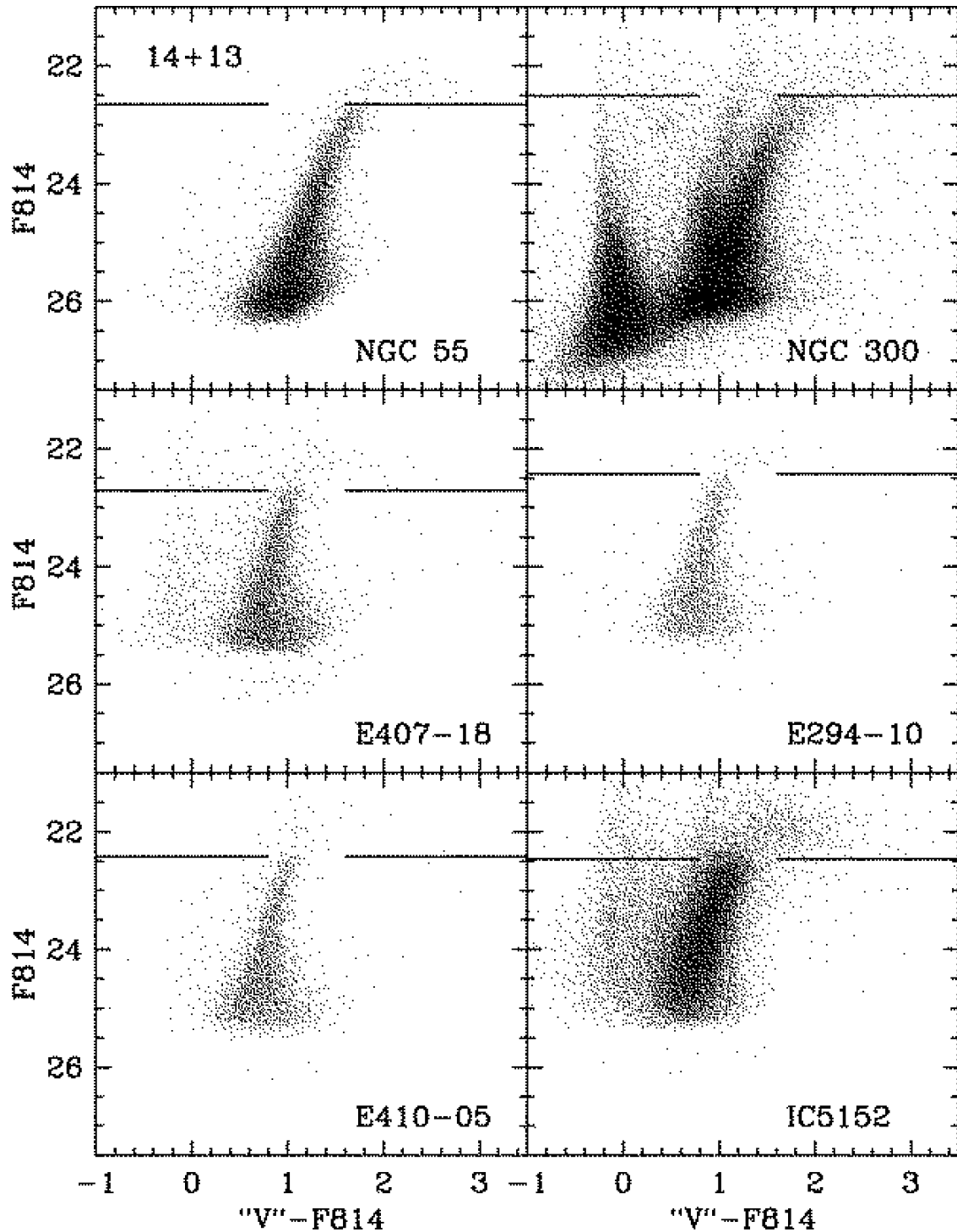


Fig. 7.— 14+13 Association. All data acquired with WFPC2. NGC 55: 2,500s in F814W; NGC 300: 1,000s in F814W; ESO 407-18, ESO 294-10, ESO 410-05, and IC 5152: 600s in F814W. For NGC 55, the “V” filter is F555W. For the others, the “V” filter is F606W. TRGB marked by horizontal lines.

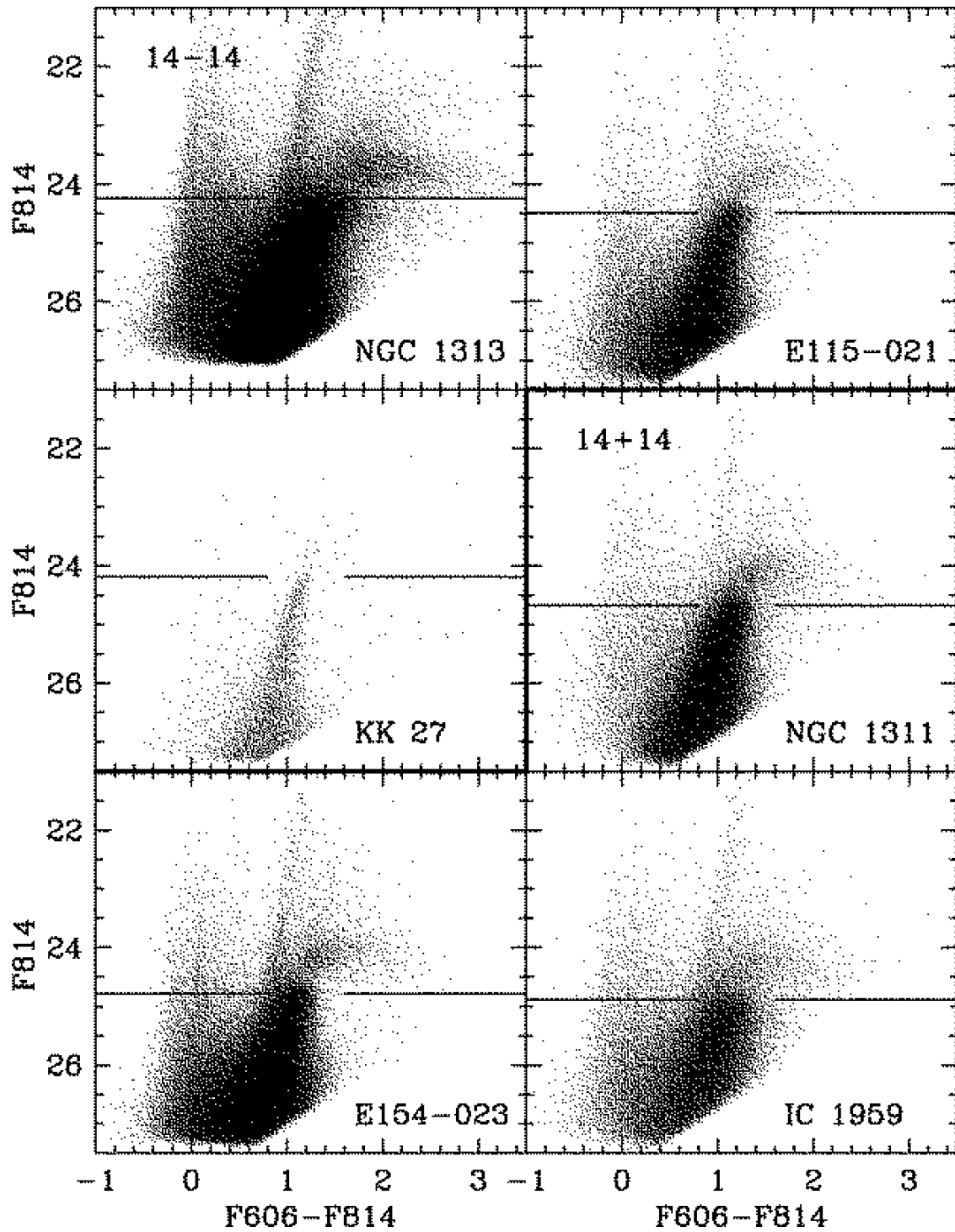


Fig. 8.— 14-14 Group (above heavy outline) and 14+14 Association (below heavy boundary).

All data from our program 10210. TRGB marked by horizontal lines.



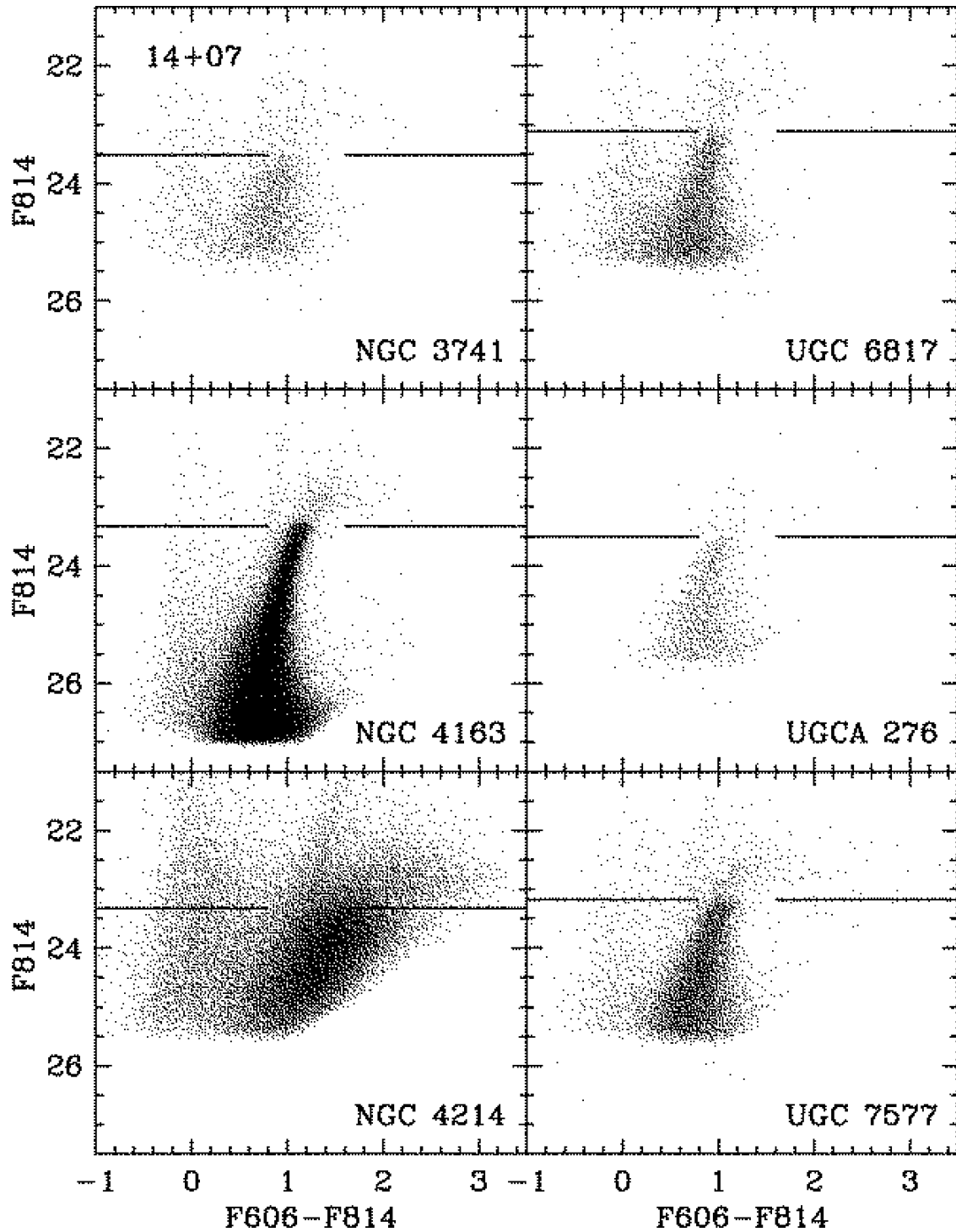


Fig. 9.— 14+7 Association members. All these CMDs are derived from HST archival material. UGC 8508 is an outlying candidate member. KKR 25 is the galaxy most notable for its isolation.

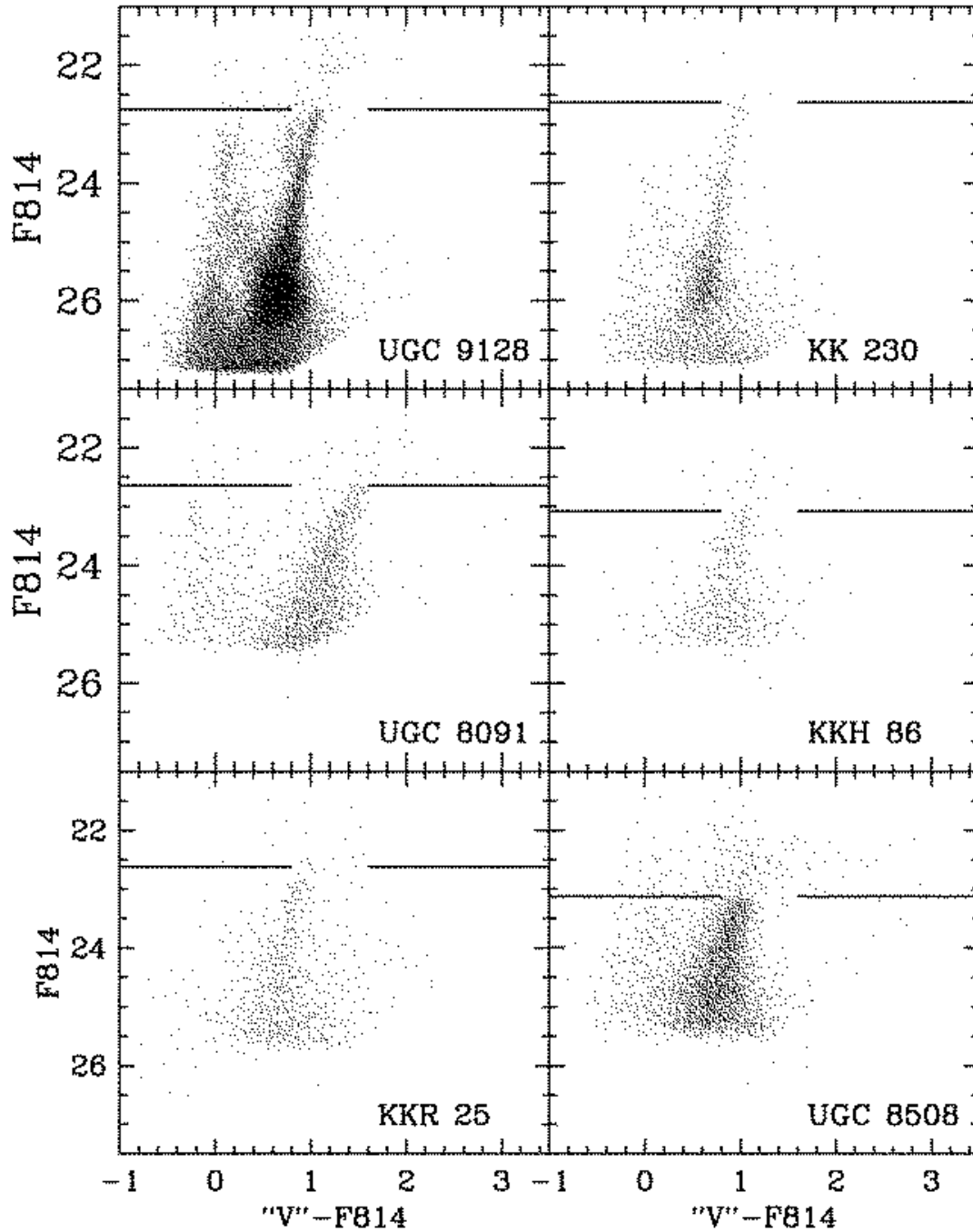


Fig. 10.— Dregs in vicinity of DDO 155. CMD for UGC 9128 is from our ACS program 10210. The other data are from the HST archive. In the case of UGC 8091 = DDO 155 the  $V$  data is obtained in the F555W filter; otherwise F606W.

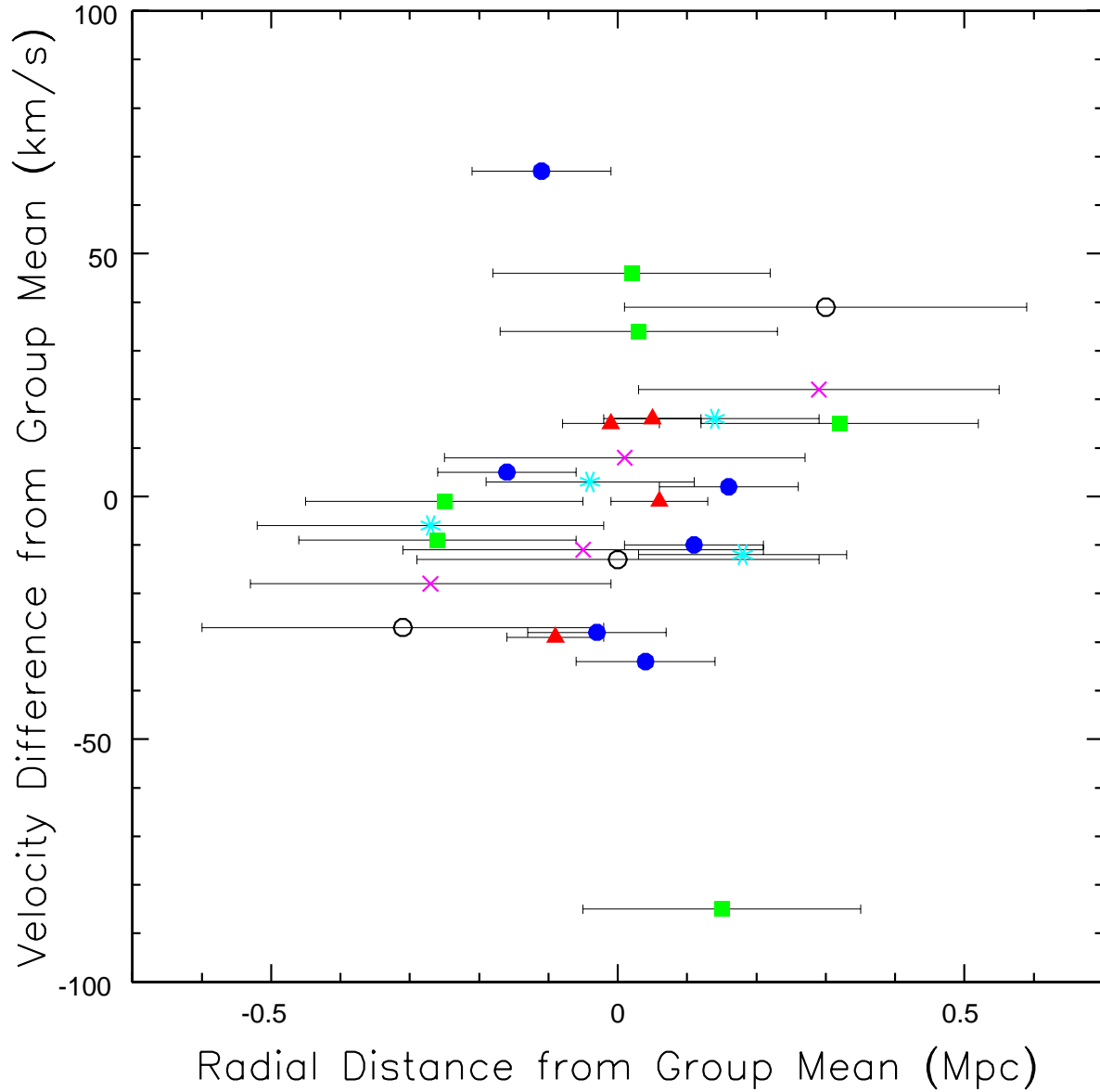


Fig. 11.— Velocity difference compared with association mean as a function of distance compared with the association mean. Triangles: 14+12 Group; eight-point stars: 14+8 Group; filled circles: 14+13 Group; crosses: 17+6 Group; squares: 14+7 Group; open circles: 14+14 Group.

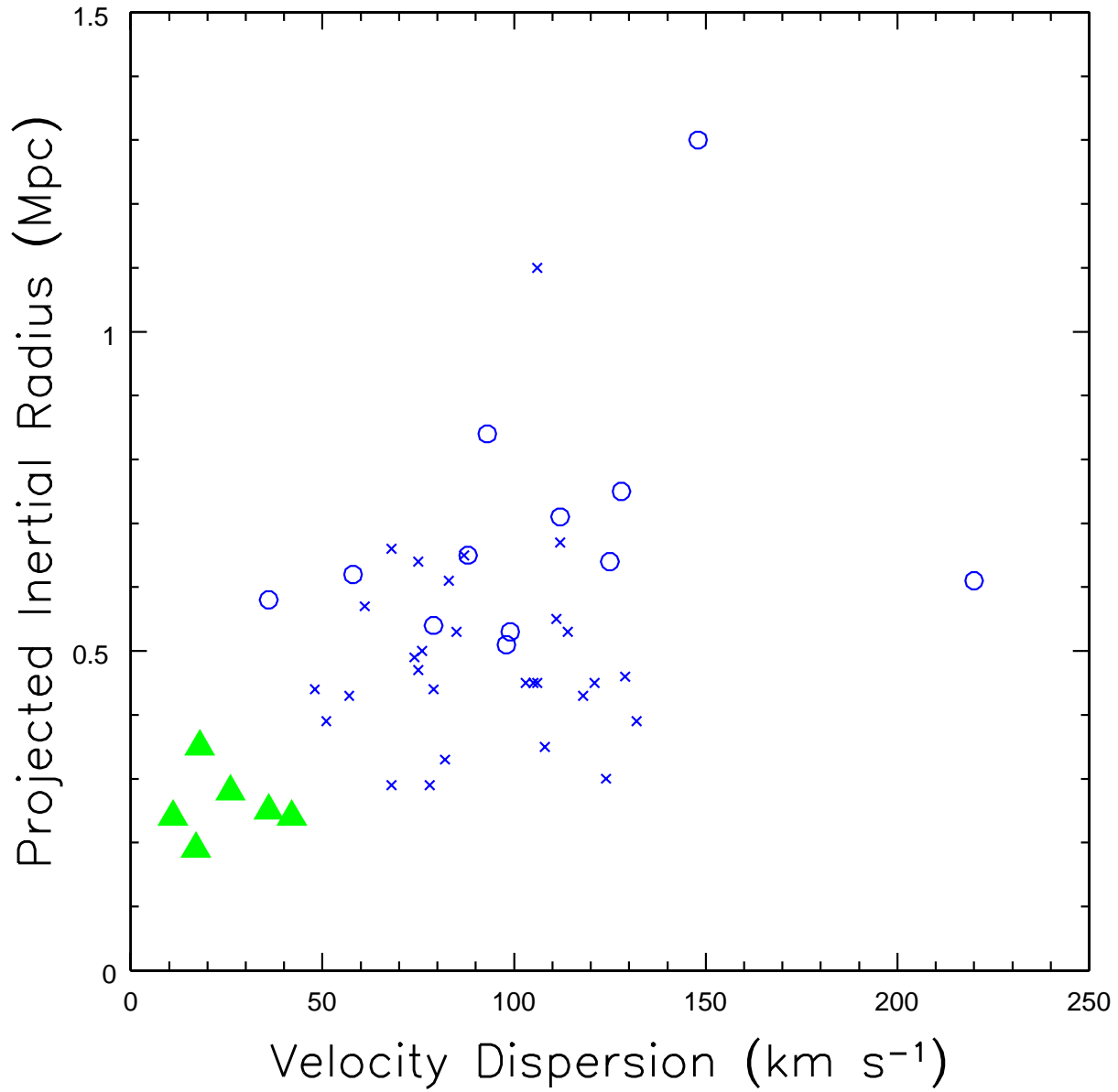


Fig. 12.— Projected inertial radius vs velocity dispersion for associations of dwarfs and spiral dominated groups. Triangles: associations of dwarfs. Circles: spiral dominated groups with at least 6 galaxies with  $M_B < -17$ . Crosses: less populated groups.

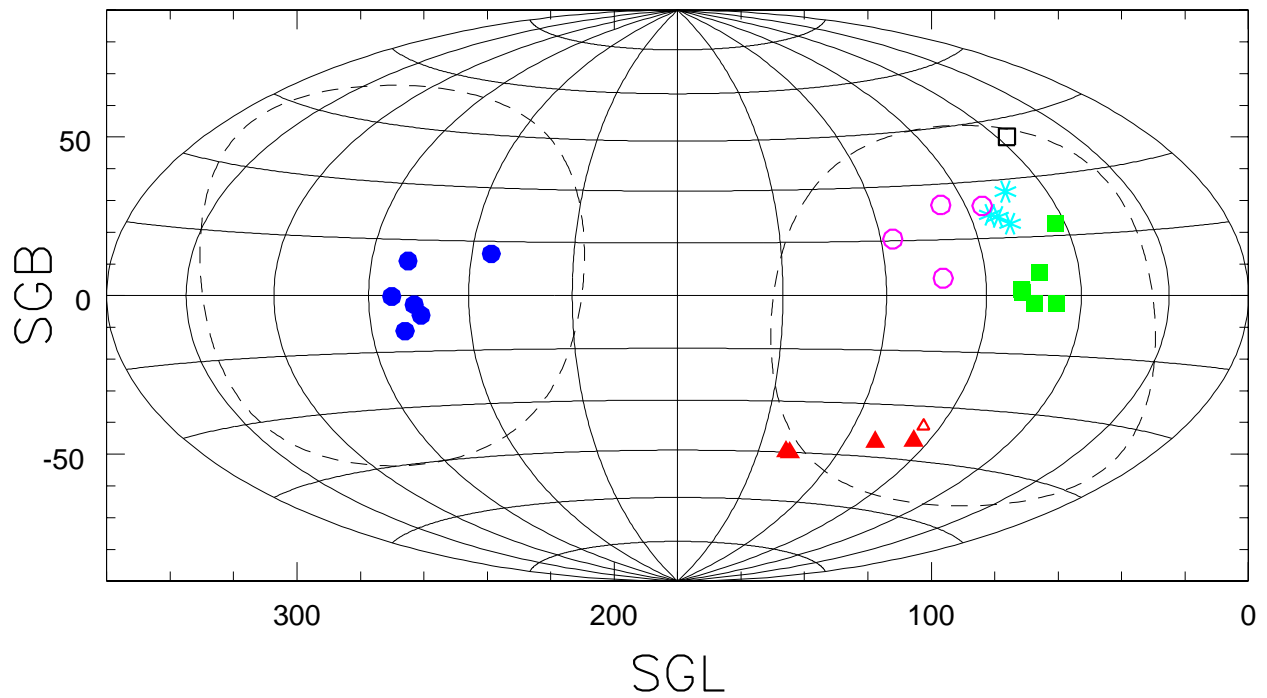


Fig. 13.— Distribution in supergalactic coordinates of galaxies with accurately known distances between 1.1 Mpc and 3.2 Mpc and at high Galactic latitude. Triangles: 14+12 Group; filled circles: 14+13 Group; filled squares: 14+7 Group; eight-point stars: 14+8 Group; open circles: dregs; open square: KKR 25. Dashed contours:  $b = \pm 30$ . The small open triangle locates KKH 60 which is suspected to lie within this volume. Other candidates lie in the region around the 14+7 Association.

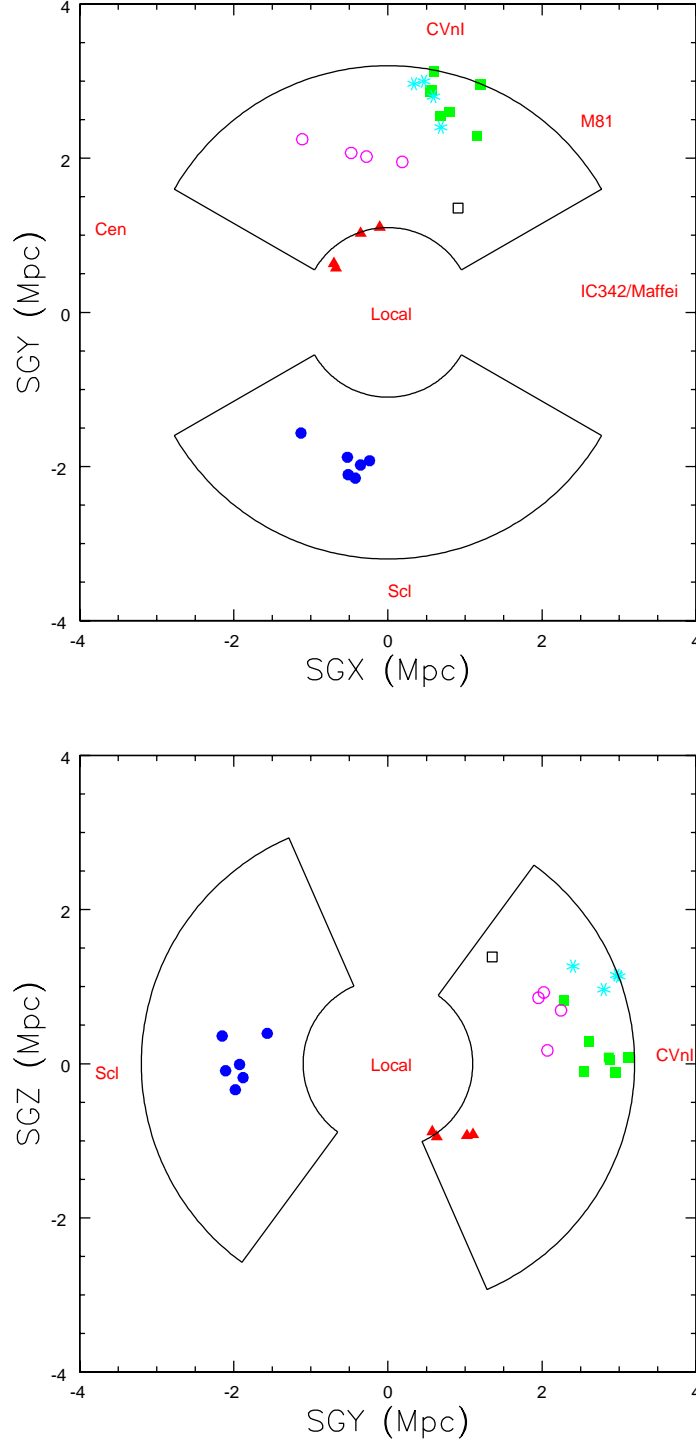


Fig. 14.— Locations of 26 galaxies with accurate distances in the shell between 1.1 and 3.2 Mpc and  $|b| > 30$ . The borders are shown for the central planes of each plot; ie, at  $SGZ=0$  and  $SGX=0$  respectively. Symbols as in Fig. 13. Locations of nearest groups beyond 3.2 Mpc are indicated by labels.

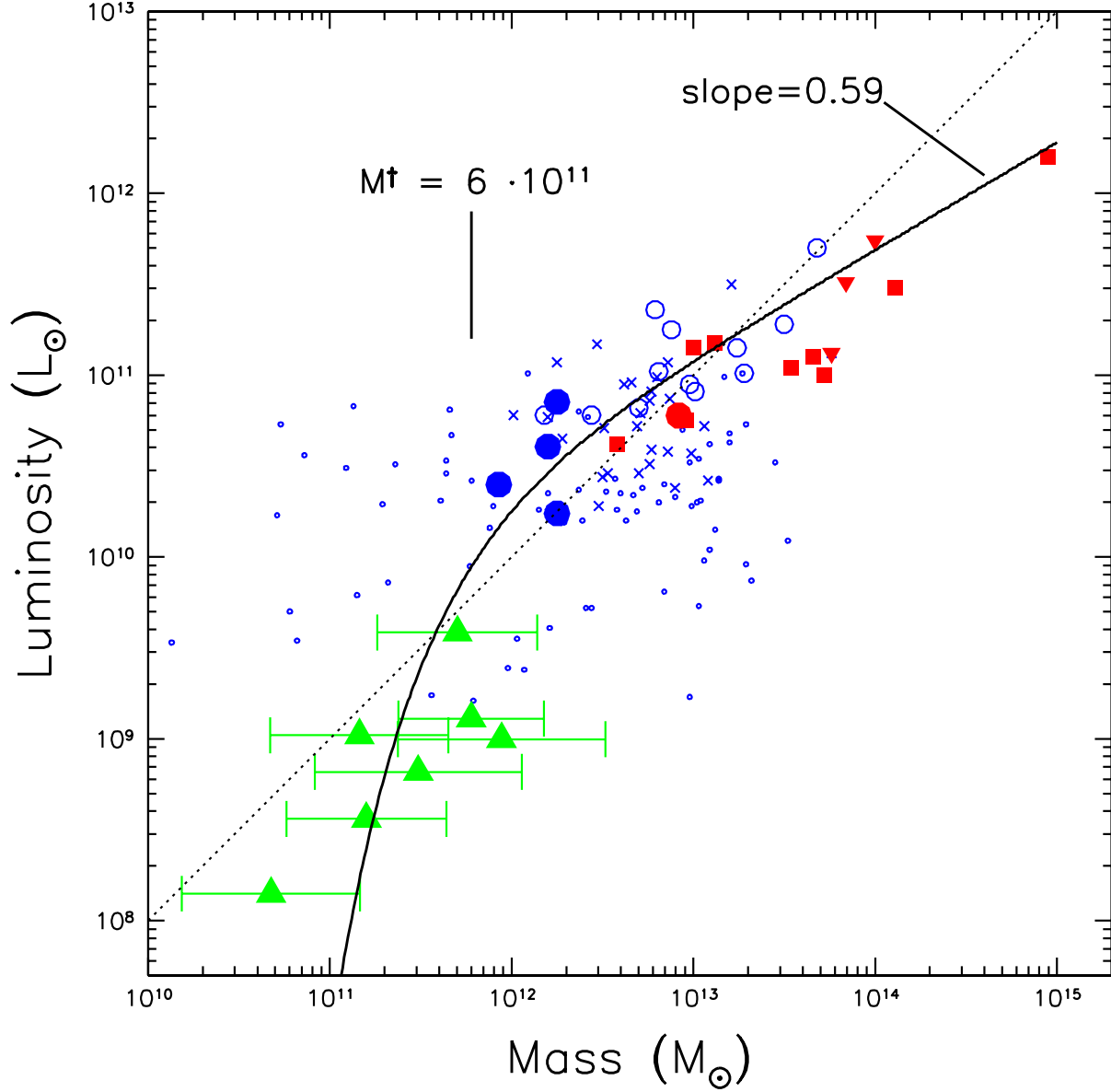


Fig. 15.— Luminosity as a function of mass for groups and associations in the Local Supercluster. Squares and inverted triangles: groups dominated by E/S0 galaxies. Open circles: groups dominated by spirals (large filled circles: Local, M81, CVnI, and Cen A groups). Crosses and tiny circles: small groups (down to pairs). Large triangles with error bars: associations of dwarf galaxies discussed in this paper. Dotted line:  $M/L_B = 100$ . Solid curve: fit to data. This figure is carried over from T05 with updated information on the associations of dwarfs. See that paper for details.

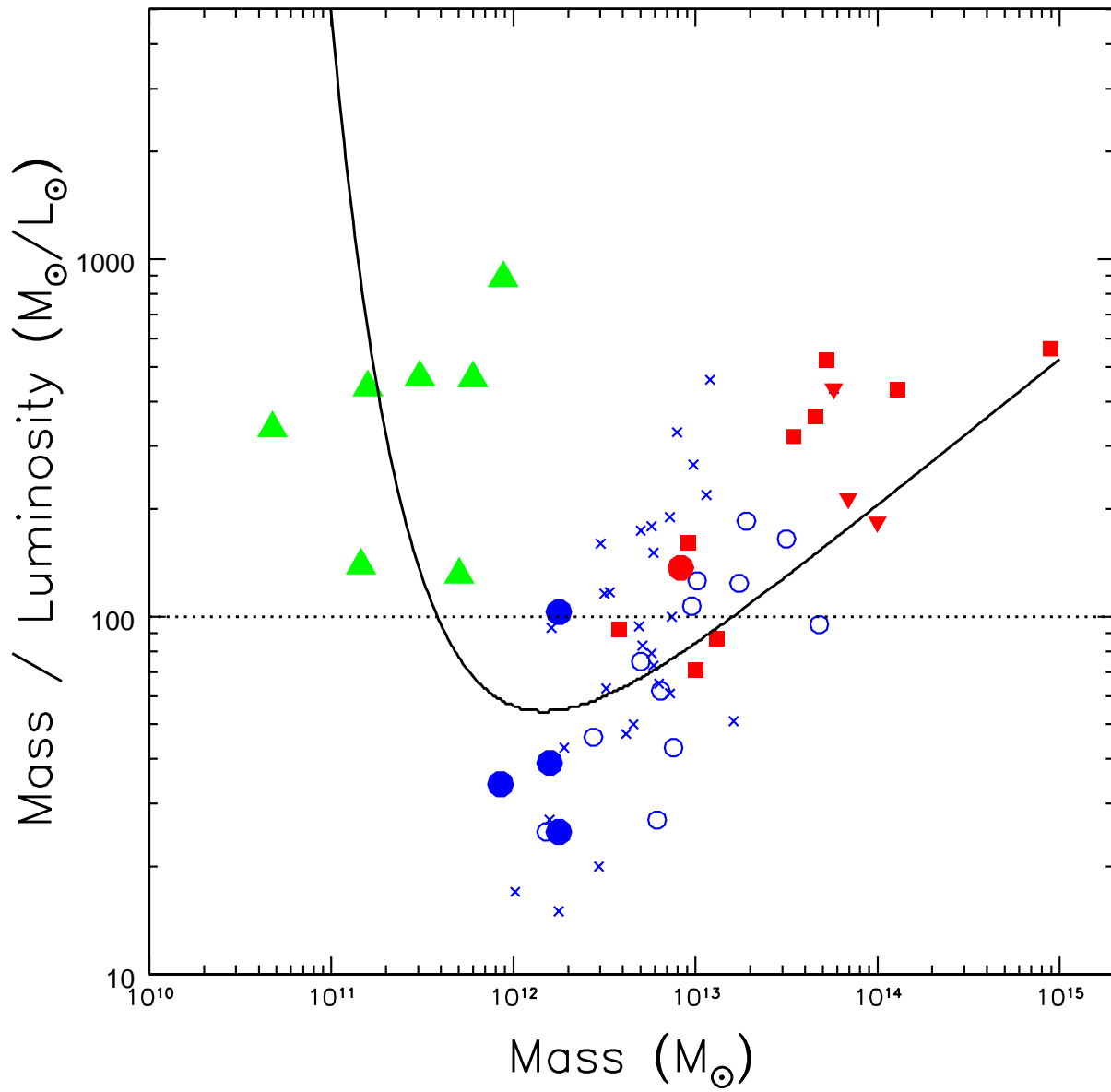


Fig. 16.—  $M/L_B$  as a function of mass for groups and associations. Symbols and lines have the same meanings as in the previous plot. The previous tiny circles representing groups of 2–4 members have been excluded.



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This figure "Figure1c.jpg" is available in "jpg" format from:

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