A New Galaxy in the Local Group: the Antlia Dwarf Galaxy

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ABSTRACT

We report the discovery of new member of the Local Group in the constellation of Antlia. Optically the system appears to be a typical dwarf spheroidal galaxy of type dE3.5 with no apparent young blue stars or unusual features. A color-magnitude diagram in $I$, $V - I$ shows the tip of the red giant branch, giving a distance modulus of 25.3 ± 0.2 (1.15 Mpc ± 0.1) and a metallicity of -1.6 ± 0.3. Although Antlia is in a relatively isolated part of the Local Group it is only 1.2 degrees away on the sky from the Local Group dwarf NGC3109, and may be an associated system.

Subject headings: galaxies: distances and redshifts–Local Group– galaxies: stellar content

1. Introduction

Despite their unassuming appearance dwarf galaxies hold the key to many questions of galaxy formation, structure and evolution. Their spatial distribution and the information they provide about the faint end of the galaxy luminosity function provide key constraints on theories of galaxy formation, while the input they provide to theories on the nature of dark matter and of star formation in low density environments are crucial to our understanding of these issues (see, for example, Binggeli, Sandage, & Tamman 1988). The internal dynamics of dwarf galaxies has given evidence of an unusually high ratio of dark to luminous matter (Mateo 1994, Hargreaves et al. 1996) and the complexity of the star formation history of the nearby Local Group dwarf spheroidal (dSph) galaxies continues to challenge theories of star formation (Hodge 1994, Elmegreen et al. 1996). Within the Local Group the motions of the more distant dwarf members can be used to probe both the dark matter halo of the Group as a whole and via the timing argument provide
an independent estimate of the age of the Universe (Lynden-Bell 1981). For all of these studies more examples of nearby dwarf galaxies are needed.

However, by their nature dwarf galaxies are elusive and comparatively few are known, especially extreme dwarves with $M_B \gtrsim -11$. In a sample of nearby galaxies intended to be complete to 10 Mpc (Schmidt & Boller 1992), essentially all galaxies with $M_B > -11$ are in the Local Group. Figure 1 illustrates how the faint end of the luminosity function of nearby galaxies is dominated by the contribution of the Local Group members. This indicates that extreme dwarves must be sought nearby. Searches have been undertaken toward M31 and three local dwarves found (Van den Bergh 1972). An automated search in high galactic latitudes found the Sextans dwarf (Irwin et al. 1990). However, Local Group dwarves, especially those on the outskirts, may be found anywhere on the sky, so an all-sky search is necessary to find them.

To this end a visual inspection of glass copies of all 894 ESO-SRC IIIaJ survey plates covering the southern sky ($\delta < 3^\circ$) has been performed. Objects resembling the Andromeda dSphs and the Tucana dwarf, that is of very low surface brightness (VLSB), diffuse and large ($\gtrsim 1'$), were noted and augmented by similar objects picked up during the UK Schmidt Telescope Unit (UKSTU) visual inspection of the original survey plates (S. Tritton, personal communication). The astronomical reality of the candidates was checked, where possible, by examining the equivalent ESO R survey glass copies; the extra color information also providing a useful discriminant against Galactic reflection nebulosity. After cross-checking our list of VLSB objects with published catalogues of extragalactic objects having known radial velocities and against catalogues of known Galactic planetary nebulae - the main “contaminant” at low Galactic latitudes - the remaining 75 candidates were digitized on the PDS microdensitometer at the Royal Greenwich Observatory. On the digitized scans several of these candidates appeared to be marginally resolved at the limiting magnitude, $B_j \approx 22.5$, of the photographic survey material. Deeper followup imaging of the candidates revealed one of them to be a previously unknown Local Group galaxy in the constellation of Antlia.

2. Followup Observations

Objects from the VLSB list were imaged using the 1.5m telescope at Cerro Tololo Interamerican Observatory during the period 2 – 6 March 1997 using a thinned Tek 2048 $\times$ 2048 CCD as detector. At the f/13.5 Cassegrain focus of the 1.5m this results in a scale of 0.24 arcsec per pixel and a field coverage of just over $8 \times 8$ arcmin. Candidates were initially examined by taking 20 minute exposures in the R-band. With the seeing typically between 0.9 – 1.4 arcsec this enabled stellar objects to $R \approx 23$ to be detected. At this depth objects close to or within the Local Group should begin to resolve into stars, with the tip of the Giant Branch becoming readily visible. If a candidate appeared to resolve into stellar components further broadband observations in the V and I-bands together with narrowband Hα were obtained. The raw CCD frames were processed in the standard way (bias-subtracted, trimmed and flat-fielded using twilight flats
taken during the observing run) in almost real time at the telescope to aid in visual inspection of candidates. A series of standard star fields taken from the list of Landolt (1992) were observed at intervals throughout each night. Conditions were generally photometric with the seeing very stable and averaging 1.2 arcsec.

An initial exposure of 20 minutes in R showed the Antlia dwarf, located at $\alpha = 10^h01^m17.5$, $\delta = -27^\circ05'15''$ (B1950), to clearly resolve into stars. Further observations totalling 4800s in V, 3600s in R and 3600s in I were subsequently made to explore the nature of the galaxy. An 1800s H$\alpha$ image revealed no obvious concentrations of young stars or regions of ionised gas. The individual broadband frames in each passband were coaligned and combined to eliminate the effect of cosmic rays. A “true” color picture derived from the combined V,R,I images of the Antlia dwarf is shown in figure 2 and clearly reveals the brightest stellar component of the galaxy.

3. Analysis

3.1. Morphology and magnitude

The distribution of stars revealed by the color image in Figure 2 shows no obvious concentrations, clusters or other groupings and the smooth elliptical morphology is typical of the stellar appearance of Local Group dSph systems, particularly the Tucana dwarf (Lavery & Mighell 1992). It is possible to trace the resolved component to a diameter of some 3 arcmin along the major axis but as the majority of the flux resides in the unresolved component a better approach for estimating the morphological structure is to analyze an appropriately smoothed version of the image.

Prior to smoothing the individual broadband images two different methods were investigated to reduce the influence of bright foreground stars, and the occasional background galaxy, superposed on the central parts of the CCD images. The first method used a straightforward clipping algorithm. All pixels in the CCD frame were clipped to have an intensity no brighter than the peak intensity in any unambiguous Antlia stars. This is straightforward to accomplish since the tip of the Antlia population is at a well defined magnitude (see Figures 3.2 and 3.3). In the second method individual unsaturated stellar images were removed by point-spread-function (PSF) subtraction of an average stellar profile, and saturated stellar images or background galaxies were removed by excising a region around them. Convolution with a flux-conserving Gaussian kernel was then used to obtain a smooth image of the dwarf galaxy. After this processing the ellipticity, radial profile, position angle of the major axis and total integrated flux relative to sky, were straightforward to obtain using standard image analysis techniques (Irwin 1985). These properties together with other derived quantities discussed later are listed in Table 1. Combining the apparent magnitudes with the distance estimate derived below, yields an $M_V = -10.7 \pm 0.3$ and an underlying V–R color of $\approx 0.5$. These values are similar to the brighter dSph galaxies of the Milky Way and very close to those for the M31 dSphs And I, II, III. For comparison, Lavery &
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<th>Cross-Identification</th>
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<td>PGC 029194</td>
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<td></td>
<td>AM 1001-270</td>
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<tr>
<td>Distance</td>
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<td></td>
<td>25.3 ± 0.2</td>
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<td>Radial Profile</td>
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<td>24.3 ± 0.2</td>
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<td>0.80 ± 0.05</td>
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<td>from King model fit)</td>
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Table 1: Properties of the Antlia dwarf galaxy
Mighell (1992) estimated Tucana to have an absolute magnitude of \( M_V = -9.5 \) and a B – R color \( \approx 1.1 \).

### 3.2. Color-magnitude diagram

The stacked V and I frames were analysed using a PSF fitting routine and the derived intensities mapped on to a total intensity system using aperture magnitudes of isolated unsaturated bright stars (Irwin 1985). A V,I color-magnitude diagram (figure 3.2) constructed from a 4 arcmin diameter region centered on Antlia, compared to one constructed from a similarly-sized region from the outer parts of the CCD frame, unambiguously shows the tip of what appears to be a normal red giant branch; no bright blue stars from a young stellar population are evident in the galaxy, nor is there any compelling evidence for an extensive intermediate-age AGB component - although much deeper color-magnitude diagrams are needed to quantify this latter assertion. We tentatively conclude from figure 3.2 that the stellar content of Antlia is most likely dominated by an old stellar population similar to that found in most Local Group dSphs.

### 3.3. Distance and metallicity

We can use the well defined locus of the giant branch to provide a provisional estimate of both the distance and metallicity of the dominant stellar population (cf. Lee , 1993; Lee et al. 1993). The location of the tip of the giant branch is revealed more clearly in the I-band luminosity functions presented in figure 3.3. We estimate \( I_{\text{rgb}} = 21.4 \pm 0.1 \) and from the V,I color distribution the average color at the tip of the giant branch is \( V-I = 1.55 \pm 0.05 \). Located at Galactic coordinates \( l = 263.1, b = 22.3 \), Antlia lies in a region of relatively low Galactic foreground extinction. From the maps of Burstein & Heiles (1982) we estimate the foreground extinction to be given by \( E(B-V) \approx 0.04-0.05 \) which translates to an approximate extinction in the I-band of \( A_I = 0.1 \) and an a reddening of \( E(V-I) = 0.06 \) (cf. Irwin et al. 1995). The expected absolute magnitude of the giant branch tip is only weakly dependent on metallicity for the typical metal poor populations of the Galactic dwarfs (Lee 1993), therefore taking this absolute magnitude to be \(-3.98 \pm 0.05 \) gives a de-reddened distance estimate for Antlia of \( (m - M)_o = 25.3 \pm 0.2 \), where the error includes all the uncertainties above and an additional zero-point error from the photometry of \( \pm 0.04 \).

Following Lee et al. (1993) we can make a provisional estimate of the metallicity of the red giant branch population by comparing the locus of points near the tip of the giant branch with other galaxies having similar published V,I color magnitude diagrams and with Galactic globular clusters. With the caveat that we are not sampling much of the giant branch of Antlia, both Leo I, with \( [\text{Fe/H}] = -2.0 \pm 0.1 \) (Lee et al. 1993), and Tucana, with \( [\text{Fe/H}] = -1.8 \pm 0.2 \) (Saviane et al. 1996), have giant branch loci slightly blueward of Antlia after due allowance for reddening;
while that of NGC 3109 with $[\text{Fe/H}] = -1.6 \pm 0.2$ Lee et al. (1993) agrees to within the errors. An independent estimate can be derived from the mean metallicity–luminosity relation for dwarf galaxies (Da Costa et al. 1991). For an $M_V = -10.7$ dwarf the expected metallicity is $[\text{Fe/H}] \approx -1.7$, in reasonable agreement with the previous value.

### 3.4. Radial profile

The previously derived smooth images of the Antlia dwarf were also used to investigate the surface brightness profile. The intensity-weighted centroid, mean ellipticity and position angle were used to define concentric elliptical annulii and the average flux from the dwarf with respect to sky in these annulii recorded and used to produce the profile shown in figure 3.4. A single component King Model (King 1962) fitted to the geometric mean of the semi-major and semi-minor axis profiles gives a convenient parameterisation of the profile and the results from the fit are listed in Table 1 – although we note that an exponential profile fits almost equally well. The central surface brightness of $24.3 \pm 0.2$ magnitude arcsec$^{-2}$ in the V-band, the core, half-light, and “tidal” radii of 268 pc, 244 pc and 1739 pc respectively, all lie comfortably within the range exhibited by the known Local Group dwarf spheroidal galaxies (see, for example Irwin & Hatzidimitriou 1995). The low concentration index, $c = 0.81$, and profile are most reminiscent of Sextans and Sculptor both of which are also well fit by an exponential profile.

### 4. Other Observations and Discussion

The faint smudge that Antlia makes on the UKST sky survey plates had been previously catalogued by Corwin et al. (1985); Feitzinger & Galinski (1985); and Arp & Madore (1987). Corwin et al. (1985) in particular noted it as a possible nearby dwarf, but to our knowledge it has not previously been followed up optically. Curiously, in an HI survey of southern late-type galaxies, Fouqué et al. (1990) detected Antlia at a heliocentric radial velocity of $361 \pm 2$ km/s with a full velocity width at half maximum of $21 \pm 4$ km/s and also suggested that Antlia was a candidate Local Group member. Additional 21cm observations were made by Gallagher et al. (1995) but they failed to detect Antlia and give an upper flux limit of $<150$ mJy, which although not confirming the earlier result is still consistent with the peak flux of 122 mJy measured by Fouqué et al. (1990). Recently Thuan has been reported as independently confirming the detection and velocity of Fouqué et al. (Karachentsev 1997, private communication). If the detection and integral HI parameters deduced by Fouqué et al. are correct the total HI mass of Antlia is of order $8 \pm 2 \times 10^5$ $M_\odot$, assuming small optical depth and a beamsize larger than the extent of the dwarf (Roberts 1962). Although Antlia would be unique among dSph galaxies in having a significant HI mass, this value would lie on an extension of the well defined correlation between HI mass and B-band luminosity for LSB galaxies (Sprayberry et al. 1995).
The velocity profile width derived by Fouqué et al. (1990) can be combined with the surface brightness properties to derive preliminary total mass and mass-to-light ratio estimates for Antlia. This is of considerable interest since the apparent high mass-to-light ratios of the Galactic dSphs could have been influenced by the presence of the Galactic tidal field (Kuhn 1993). Obtaining a similar result for a more isolated dSph would help to shed light on this subject. Assuming a single component King model, the total mass of the system can be calculated by applying the method of Illingworth (1976). Using the parameters in Table 1 and deriving the line-of-sight $\sigma_{\text{rms}}$ velocity, $\sigma_{\text{rms}} = 9 \pm 2$ km/s, from the HI profile of Fouqué et al. (1990), yields a total mass estimate of $3.3 \pm 1.3 \times 10^7 \text{M}_\odot$, where the error is dominated by the uncertainties in the velocity dispersion. The total mass-to-light ratio is then $20 \pm 8$ in solar units. Alternatively we can use the method of Richstone & Tremaine (1986), which is relatively insensitive to the exact shape of the profile, to compute the central mass-to-light ratio. We find that Antlia has a central mass-to-light ratio $= 15 \pm 6$, where once again the error budget is dominated by the velocity profile uncertainty. Further HI observations are urgently needed to improve the accuracy of these estimates, since the derived mass-to-light ratios are tantalisingly close to those expected by comparison with similarly luminous Galactic dSphs.

Optically, Antlia appears to be a normal dwarf spheroidal in that it has no young stars or HII regions, a smooth morphology and a color magnitude diagram similar to the rest of the Galactic dSphs. As such we would have expected it to have little or no gas, so the HI measurement by Fouqué et al. (1990) is very interesting. Galactic satellite dSphs may have had their gas tidally stripped by repeated interactions with the host system and it has been suggested (for instance, by Faber & Lin 1982) that their precursors could be the numerous dwarf irregular systems found in isolated regions in the Local Group. If Antlia is an otherwise typical dSph, but is confirmed to have gas, then it would be a unique galaxy in the Local Group. Of the other comparable outlying dwarves, LGS3 and Phoenix have populations of young stars and detected gas, while Tucana appears to be a gasless dSph.

At a Galactocentric distance of $1.15 \pm 0.10$ Mpc, Antlia lies close to the boundary of the Local Group and interestingly is only 1.2 degrees away on the sky from the Local Group dwarf NGC 3109 and at a comparable distance (see figure 4). Assuming that the HI velocity is correct, Antlia has a velocity of $\approx 78$ km/s with respect to the center-of-mass of the Local Group, compared to $\approx 120$ km/s for NGC3109, and as such both systems are almost certainly bound to the Local Group. Their proximity suggests that they may themselves form a bound pair.

At the limit of their observed rotation curve, Jobin & Carignan (1990) show a total mass for NGC 3109 of between $8.6$ and $8.9 \times 10^9 \text{M}_\odot$. From the apparent separation on the sky we know that the minimum possible distance between Antlia and NGC 3109 is $\approx 26$ kpc. With these best case parameters the total velocity difference would have to be less than about 54 km/s for Antlia to be bound. On purely gravitational criteria, assuming the total mass of the Local Group is $\approx 3 \times 10^{12} \text{M}_\odot$, the tidal field of the Local Group exceeds that of NGC3109 if Antlia is more than $\approx 130$ kpc from NGC3109 – a weaker constraint than the previous one. Therefore we can not yet
rule out the possibility of Antlia being a satellite of NGC3109, confirmation, or otherwise, awaits supportive HI measurements for Antlia and a good differential estimate of the distance between NGC3109 and Antlia.

Further optical and radio observations are urgently required to unlock the secrets of this fascinating system.

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REFERENCES


Binggeli B., Sandage A. & Tanman G., 1988 ARA&A26, 509

Bottinelli L., Gouguenheim L., Fouqué P., & Paturel G. A&ASuppl. 82, 391

Burstein D., & Heiles, C. 1982, AJ87, 1165

Corwin, H. G. jr., de Vaucouleurs A., & de Vaucouleurs G. 1985, Southern Galaxy Catalog, University of Texas Monographs #4


Feitzinger, J. V. & Galinski, Th. 1985 A&ASuppl. 61, 503.


Irwin, M. J., Bunclark P. S., Bridgeland M. T. & McMahon R. G. 1990 MNRAS244, 16p
Irwin M. J. & Hatzidimitriou D. 1995 MNRAS277, 1354
Jobin M. & Carignan C. 1990 AJ100, 648
King I. R., 1962 AJ67, 471
Lynden-Bell, D., 1981 Observatory 101, 111
Schmidt, K.-H. & Boller, T. 1992, Astronomische Nachrichten 313, 189
Fig. 1.— Number counts of galaxies with $v < 500$ km/s. The Local Group contributes almost all of the galaxies below $M_B = -11$. Data from Schmidt & Boller 1992.

Fig. 2.— The new Local Group dwarf galaxy Antlia. CTIO 1.5m telescope images in V, R and I with total exposure times of 4800s, 3600s and 3600s respectively were combined to produce this “true” color picture. The field shown covers $4 \times 4$ arcmin of sky with North to the top and West to the left.

Fig. 3.— Left: V,I color-magnitude diagram for Antlia, showing the tip of the red giant branch; right, the same diagram for the outer parts of the same CCD frames showing the lack of the red giant population.

Fig. 4.— The I-band luminosity function of a region centered on Antlia (full line) compared with the local field luminosity function (dashed line). The tip of the red giant branch at $I = 21.4$ is very clearly defined.

Fig. 5.— The geometric mean of the semi-major and semi-minor V-band surface brightness profiles of Antlia. A single component, three-parameter King model fit is shown overlain, although a two-component exponential profile fits almost equally well.

Fig. 6.— Projection of the galaxies in the Local Group onto a convenient plane. The large circle at left is the Milky Way, surrounded by its satellite galaxies; at right is M31 with its satellites. Antlia is located near NGC 3109, but distant from almost all other dwarves on the outskirts of the Group. Data taken from Hodge (1994).
Antila radial profile

Surface Brightness (V mag/sq arcsec) vs. Radius (arcmin)

The plot shows the radial profile of Antila with data points and a fitted line, indicating the variation of surface brightness with radius.
LOCAL GROUP

- Sextans B
- Sextans A
- NGC 3109
- Antlia
- EGB0427+63
- Phoenix
- IC 10
- IC 1613
- NGC 6822
- WLM
- Tucana
- SagDIG
- Pegasus

Projected distance (kpc)

Projected distance (kpc)