

A NEW MEMBER OF THE LOCAL GROUP: THE TUCANA DWARF GALAXY

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ABSTRACT

We present observations of the recently discovered dwarf galaxy in Tucana, which is a likely member of the Local Group. The system is highly flattened and we classify it as dE5. An upper limit on the distance modulus of 24.75 is determined from a V , $V - I$ color-magnitude diagram. This galaxy has a $B - R$ color of 1.1, and with the upper limit to the distance modulus, an absolute R magnitude of -10 . This apparently isolated dwarf system, being on the opposite side of the Milky Way from most of the Local Group, may provide important constraints on Local Group dynamics.

1. INTRODUCTION

The role of dwarf galaxies in the evolution of the Universe and in cosmological models of the Universe is becoming increasingly evident. Dwarf galaxies may be one explanation for the increase in the faint blue galaxy counts (Broadhurst *et al.* 1988). Dwarf galaxies may contain large amounts of dark matter, as evidenced by the large mass-to-light ($\sim 50 M_{\odot}/L_{\odot}$) ratios determined for the Draco and Ursa Minor systems (Aaronson & Olszewski 1987). These extreme dwarf systems may also provide important tests for models of galaxy formation (Lake 1990).

Though they may be important, finding dwarf galaxies, even just in the Local Group, is difficult. Most of the Milky Way satellite dwarf galaxies have been discovered through visual inspection of the Northern and Southern Sky Survey plates. Though successful for satellite galaxies, extreme dwarf galaxies in the Local Group may be easily missed. The discovery of the new Milky Way satellite dwarf galaxy in Sextans through the APM survey (Irwin *et al.* 1990) was possible, since the galaxy was well resolved into stars. But, for galaxies that are not Milky Way satellites, such techniques may not work, even for Local Group galaxies.

A new dwarf galaxy in Tucana has recently been reported by Lavery (1990). This galaxy was first noticed as an extremely faint smudge on the SERC J plates, with subsequent CCD images resolving the object into stars. This galaxy had been noted in the Southern Galaxy Catalog (Corwin *et al.* 1985) with a revised position determined by Spellman *et al.* (1989) of $\alpha(1950) = 22^{\text{h}}38^{\text{m}}27.9^{\text{s}}$ and $\delta(1950) = -64^{\circ}40'53''$, but was not noted in the ESO Southern Galaxy Catalog or the Nearby Galaxy Catalog (Tully 1988). Here, we present observations of this serendipitously "rediscovered" extreme dwarf galaxy.

2. OBSERVATIONS

Initial observations were made on the Mount Stromlo 1.0 m telescope of the Siding Spring Observatory on 1990 August 18. A coated GEC CCD in 2×2 binning mode was used at the f/8 Cassegrain focus, giving a scale of $1.1''$ per pixel. Total exposure times were 15 and 30 min in R and B , respectively.

Subsequent observations were made on the Anglo-Australian 3.9 m telescope of the Siding Spring Observatory on 1990 September 7. A Thomson 1024×1024 CCD used with a f/1 focal reduction system at the prime focus was employed, giving a scale of $\sim 1''$ per pixel. Exposures of 5 min were obtained in both the V and I bands.

For both nights of observations, conditions were photometric. The standard stars were taken from the E regions of Graham (1982). Basic CCD reduction of bias subtraction and flatfield correction were made. Photometric calibration of the AAT images was made using PAWSPHOT (Mighell 1989, and references therein).

3. DATA

Figure 1 [Plate 6] is the V image of the galaxy obtained on the AAT. The brighter stars are easily resolved. The galaxy is quite flattened and appears to be elliptical in shape. Smoothed and unsmoothed contour plots of the R -band images were used to determine an ellipticity of ~ 0.5 for the galaxy. We give a preliminary classification for this dwarf galaxy as dE5, which must be confirmed with much deeper imaging observations. The bright object close to the apparent center of the galaxy is most likely a foreground galactic star, but if it were the nucleus of this dwarf galaxy, it would be extremely interesting for future observations. A low resolution spectrum of this object shows only the usual stellar absorption features of Ca II K and H , the G band, and $H\beta$. Accurate velocity information will be needed to determine whether this object is actually the galaxy nucleus.

Apparent B and R magnitudes were determined for this galaxy by summing the pixels in an area of $200''$ by $300''$ centered on the galaxy, after removal of obvious foreground contaminating objects, and subtracting an average sky value determined just away from the galaxy. We find an apparent R magnitude of 14.6, and a $B - R$ color of 1.1. The error in the apparent magnitude is dominated by the uncertainty about which objects in the field are part of the galaxy and is estimated to be ± 0.2 mag. Combining this apparent R magnitude with the upper limit on the distance modulus of 24.7 (see below), implies an $M_R \sim -10$. This is similar to that for the Carina system and about 1 mag brighter than the two dwarf Milky Way satellite systems in Draco and Ursa Minor.

Figure 2 is a V , $V - I$ color-magnitude diagram for an area of $5'$ by $5'$ centered on the galaxy. For comparison, in Fig. 3, we show the color-magnitude diagrams of two sky regions of equivalent area as that used for Fig. 2. The lack of stars below $V = 22$ with colors in the range of 0.8–1.6 in the sky regions is quite obvious when compared to the CM diagram for the dwarf galaxy.

In order to estimate the number of excess stars in the galaxy CM diagram, each CM diagram was divided into four regions, as shown by the dashed lines. The total number of

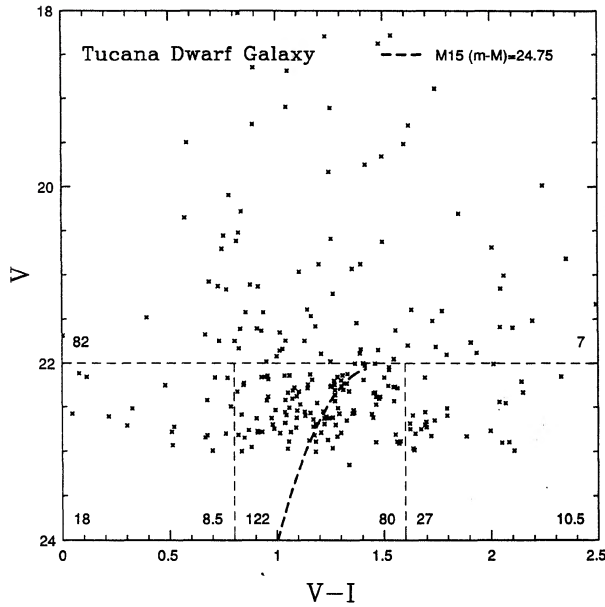


FIG. 2. The $V, V-I$ color magnitude diagram of the Tucana Dwarf Galaxy. The dashed curve represents the giant branch of M15 shifted for a distance modulus of 24.75. In the lower left-hand corner of the four dashed regions is the total number of stars in that region. The number in the lower right-hand corner of each region is the excess number of stars above the nearby fields.

stars in each region of each CM diagram is shown in the bottom left-hand corner of each region. The excess number of stars in each region of the galaxy CM diagram is shown in the lower right-hand corner of each region. For stars of $V < 22$, there is no real excess of stars in the galaxy CM diagram compared to the sky regions. Few, if any, of these stars are associated with the dwarf galaxy. In the three regions with $V > 22$, the excess number of stars is 8.5 (1.8σ), 80 (6.7σ), and 10.5 (1.8σ), respectively, for a total of 99 stars ($> 7\sigma$). This distribution of stars is consistent with all the stars having a color of $V-I = 1.2$ with an error of ± 0.3 . There is an obvious lack of young, blue stars in this galaxy.

Looking specifically at Fig. 2, there are two concentrations of stars between V of the 22nd and 23rd magnitude at $V-I$ of 1 and 1.3. Because of the large photometric color errors, which we estimate to be ± 0.2 mag, it is impossible to know whether these two groups are the top of the giant branch just affected by scatter, or if the group at $V-I = 1.3$ is the giant branch and the group at $V-I = 1.0$ is part of the asymptotic giant branch. For determining an upper limit for the distance modulus, we will consider only the stars at $V-I = 1.3$ to be giant branch stars. To estimate the distance modulus, the red giant branch of M15 was fitted by eye to the galaxy stars. The giant branch was taken from Da Costa & Armandroff (1990).

Our best fit for the M15 giant branch, which is plotted in Fig. 2, gives $(m-M)$ equal to 24.75, which would place the base of the giant branch at $m_V = 25.4$. We take this value of $(m-M)$ of 24.75 to be the upper limit for the distance modulus and so this galaxy is at most 900 kpc distant. The preliminary distance modulus of 22.3 given by Lavery (1990) seems highly unlikely.

The use of a metal-poor giant branch, such as that of M15, is justified by the correlation of mean metallicity with lumi-

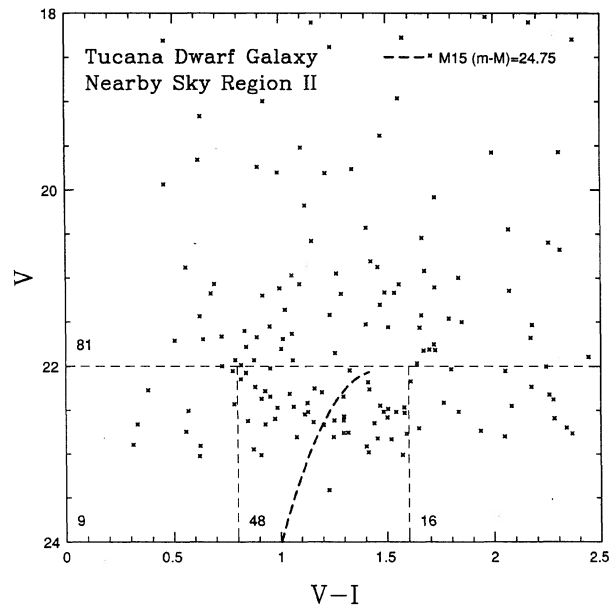
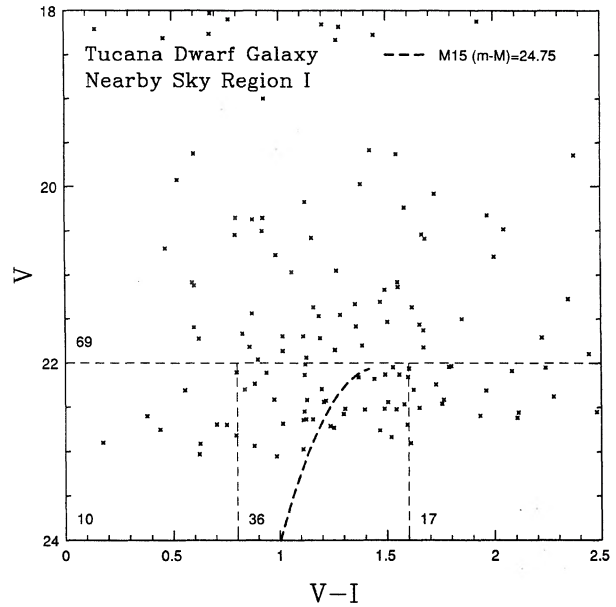


FIG. 3. The $V, V-I$ color-magnitude diagram of two nearby field areas. The dashed curve represents the giant branch of M15 shifted for a distance modulus of 24.75. In the lower left-hand corner of the four dashed regions is the total number of stars in that region.

nosity for dwarf spheroidals in the Local Group (Buonanno *et al.* 1985). We have taken the mean metallicities and absolute V magnitudes from Da Costa *et al.* (1991) for 11 Local Group dwarf spheroidal galaxies to derive the relation $[\text{Fe}/\text{H}] = -3.21 - 0.14 M_V$ using a simple linear least-squares fit. This relation is similar to that derived by Buonanno *et al.* (1985), though the actual values are different, mostly due to the inclusion of the Sextans and the Andromeda I dwarf galaxies, both of which seem to be more metal-rich than expected for their luminosities (Da Costa *et al.* 1991). Though values for either the mean metallicity or

the luminosity of several systems in the relation have changed slightly (Da Costa 1991), the effect on the relationship is minimal. We have not used the recent value for the mean metallicity of the Leo I system of $[\text{Fe}/\text{H}] = -1.0$ (Reid & Mould 1991), in contrast to the previous value of -1.8 . Including this new value would change the constant in the relation by only 0.1 dex (-3.21 to -3.13) and not alter our conclusions. But, if this value is confirmed, the significance of the mean metallicity–luminosity relation might be questioned.

Applying the above relation to the Tucana dwarf galaxy, with $M_V \cong -9.5$, gives a mean metallicity of $[\text{Fe}/\text{H}] = -1.9$ for the Tucana dwarf, similar to that for the Carina dwarf galaxy. This low metallicity suggests that the giant branch of M15, with $[\text{Fe}/\text{H}] = -2.0$, is the most appropriate giant branch for comparison, and that the distance modulus is truly in the range of 24–25. The use of a more metal-rich, i.e., redder, giant branch would suggest a lower value for the distance modulus and, therefore, a lower absolute luminosity for the Tucana dwarf. This is contrary to the mean metallicity–luminosity relation, in which higher metallicity systems have a higher absolute luminosity.

A mass determination for the Tucana dwarf galaxy should provide an important test on the recent results of large mass-to-light ratios for extreme dwarf systems. Observations of Draco and Ursa Minor (Aaronson & Olszewski 1987) and Carina (Seitzer & Frogel 1985) suggest the presence of large dark matter components in these systems. These three systems are all satellite systems of the Milky Way, whereas the Tucana dwarf is a relatively isolated system. If this large M/L ratio, of order 10–100, for the dwarf galaxies is real, the mass for the Tucana dwarf will be of order 1×10^7 solar masses, similar to the Carina system (Seitzer & Frogel 1985).

Given the faintness of the stars in this dwarf system, the easiest method for determining a radial velocity would be

through H I, if detectable. With this in mind, H I observations were attempted using the Parkes Radio Telescope for us by Cote. A 10 MHz bandwidth centered on $V_0 = 500$ km s^{-1} was used for a total integration time of 2 by 10 min. Unfortunately, no detection was made at the 0.15 Jy level (3σ).

4. CONCLUSION

The Tucana dwarf galaxy is a new member of the Local Group with an upper limit on its distance of 900 kpc. It has galactic coordinates of $l = 323^\circ$ and $b = -47.4^\circ$. It appears quite flattened, with a preliminary classification of dE5, and quite small in size, having an absolute magnitude of $M_R \cong -10$ and $(B - R) \cong 1.1$.

This dwarf galaxy should prove to be a very intriguing object. It appears to be similar to the extreme dwarf systems in Andromeda, yet is relatively isolated in the Local Group. Being almost on the opposite side of the Milky Way from M31, M33 and most of the Local Group dwarfs, this dwarf system may provide some interesting information on the history of the Local Group. Once an accurate distance modulus and velocity are measured, the Tucana dwarf elliptical may play an important role in models of Local Group formation (see Peebles 1989). Such models may be able to determine whether this galaxy was once a satellite galaxy or has always been an isolated system in the Local Group.

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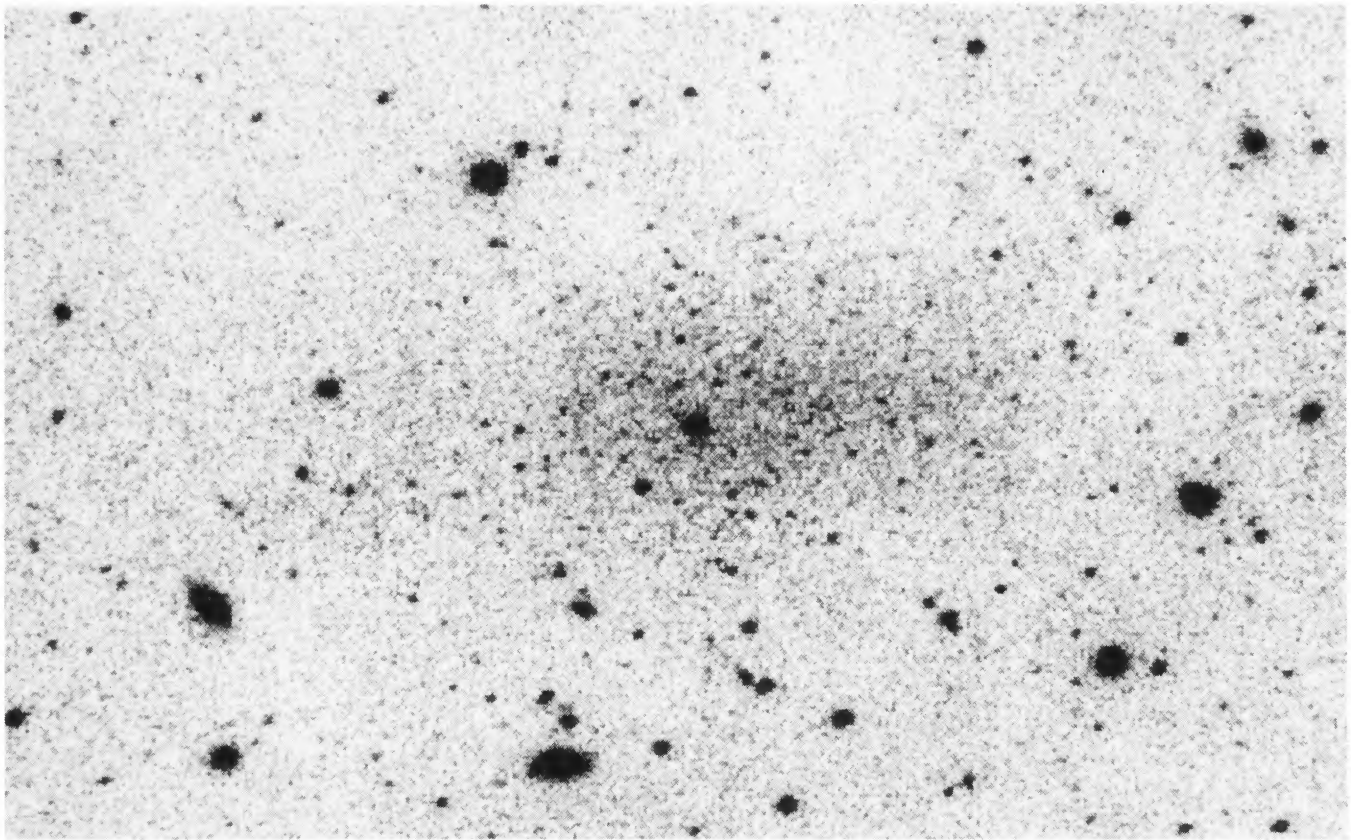


FIG. 1. The *V*-band image of the Tucana Dwarf Galaxy obtained on the AAT. The image is 250" by 400" in size. North is at the top and east is at the left.

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