INTERSTELLAR MEDIUM DISRUPTION IN THE CENTAURUS A GROUP

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ABSTRACT

We present the results of a 21 cm neutral hydrogen (HI) line detection experiment in the direction of 18 low-luminosity dwarf galaxies of the Centaurus A group, using the Australia Telescope National Facility 64 m Parkes Radio Telescope and the Australia Telescope Compact Array. Five dwarfs have HI masses between \( M_{HI} = 4 \times 10^5 \) and \( 2.1 \times 10^7 M_\odot \), and 0.04 \( M_\odot / L_\odot / B < M_{HI} / L_B < 1.81 M_\odot / L_\odot / B \). The other 13 have upper limits between \( M_{HI} = 5 \times 10^3 \) and \( 4 \times 10^6 M_\odot \) \( (M_{HI} / L_B < 0.24 M_\odot / L_\odot / B) \). Two of the mixed-morphology dwarfs remain undetected in HI, a situation that is in contrast to that of similar Local Group and Sculptor group objects, which all contain significant amounts of neutral gas. There is a discontinuity in the HI properties of Centaurus A group low-luminosity dwarfs that is unobserved among Sculptor group dwarfs. All objects fainter than \( M_B = -13 \) have either \( M_{HI} > 10^5 M_\odot \) or \( M_{HI} < 10^6 M_\odot \). This gap may be explained by the ram pressure stripping mechanism at work in this dense environment in which all galaxies with \( M_{HI} < 10^7 M_\odot \) have been stripped of their gas. The required intergalactic medium density to achieve this is \( \sim 10^{-3} \text{ cm}^{-3} \).

Key words: galaxies: dwarf — galaxies: evolution — galaxies: individual (Centaurus A) — galaxies: ISM

1. INTRODUCTION

Galaxy morphology is a static description of an evolving stellar system. It is the visual manifestation of the physical processes that shaped the global optical light distribution over a Hubble time. It is the present-day star formation, generating discrete pockets that leads to the irregular B-band appearance of late-type dwarfs. Star formation activity, however, can only operate until the resources for producing new stars in the form of neutral hydrogen reservoirs are exhausted. This eventually results in an object with a smooth, featureless light distribution (an early-type dwarf), devoid of any significant amount of interstellar medium (ISM). Whether these evolved late-type galaxies will have the same properties as the present-day early-type dwarf galaxies is a much discussed matter (Mayer et al. 2001; Pedraz et al. 2002; Simien & Prugniel 2002; Grebel et al. 2003; De Rijcke et al. 2003, 2004; van Zee et al. 2004; Read & Gilmore 2005). The evolutionary phase between the two major morphological types provides observable objects (known as “transition-type dwarfs”; dE/dIrrs) with a continuum in both gas and stellar properties between the two extremes: gas-rich dwarf irregular galaxies (dIrrs) and gas-poor dwarf elliptical galaxies (dEs; also incorporating dwarf spheroidal galaxies [dSphs] and dwarf S0 galaxies [dS0s]).

In essence, to be classified as “early type” a dwarf galaxy only needs to have had no recent star formation. This could, in principle, be independent of the presence or absence of HI gas. Indeed, while the Local Group dEs exhibit a wide variety of star formation histories (e.g., Grebel 2001), few show signs of recent star formation (Tolstoy et al. 2004; Babusiaux et al. 2005; Olszewski et al. 2006), yet some are not completely devoid of H I. The two early-type galaxy companions to M31, NGC 185 and NGC 205 (Young & Lo 1997), and the Sculptor dSph (Carignan et al. 1998; Bouchard et al. 2003) are examples (see also Blitz & Robishaw 2000) in which traces of HI are detected (\( M_{HI} \gg 10^5 M_\odot \)). Moreover, all known Local Group transition-type galaxies have been detected in HI: LGS 3 contains \( M_{HI} = 6 \times 10^5 M_\odot \) (Young & Lo 1997; Robishaw et al. 2002), Phoenix has \( 1 \times 10^5 M_\odot \) (St-Germain et al. 1999; Gallart et al. 2001), Antlia has \( 7 \times 10^5 M_\odot \) (Barnes et al. 2001), DDO 210 has \( 2 \times 10^6 M_\odot \), and Pegasus has \( 5 \times 10^6 M_\odot \) (Lo et al. 1993). The same observation is made for the four known transition-type galaxies of the Sculptor group: these have \( 3 \times 10^5 < M_{HI} < 10^6 M_\odot \) (Bouchard et al. 2005). Two dSO galaxies, ESO 384-G016 in the Centaurus A (Cen A) group and NGC 59 in the Sculptor group, have also been detected with \( M_{HI} > 10^6 M_\odot \) (Beauchaine et al. 2006). Similarly, in galaxy clusters, up to 15% of early-type dwarfs still have substantial amounts of HI (\( M_{HI} \gtrsim 10^7 M_\odot \); Conselice et al. 2003). It is therefore incorrect to believe that only currently star-forming or irregular galaxies contain ISM.

The detection of HI in early-type dwarf galaxies is an important step in understanding any morphological evolution scenario. Gas depletion is still viewed as the key factor driving the transition from late to early type (e.g., Conselice et al. 2003). Morphological properties of galaxies are strongly correlated to their environment (Dressler 1980; Binggeli et al. 1987, 1990; van den Bergh 1994), Factors such as ram pressure (Einasto et al. 1974), tidal fields (Moore et al. 1996), galactic winds (Marcolini et al. 2004), and enhanced star formation efficiency (Bulkeley et al. 2005) can, in principle, remove or exhaust the gas from a late-type dwarf and force the transition. However, since ISM is detected in some early-type dwarfs, there are other options one needs to study.

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(1) Gas depletion is not an end state; i.e., gas can be accreted from various sources, such as stellar winds and the intergalactic medium (e.g., Mould et al. 1990). (2) The gas is not depleted but is difficult to detect; e.g., the ISM resides in an ionized state (Mashchenko et al. 2004). In these cases, dEs may still have the means to form new stars and thus to oscillate between morphologies; some could be quiescent mixed-morphology dwarfs.

By identifying and analyzing low-mass dwarf galaxies that contain H i, we can constrain this theory of evolution. For the Local Group, the work has been conducted by Blitz & Robishaw (2000) and Bouchard et al. (2006), who have identified a number of early-type dwarfs possibly associated with H i emission. In the Sculptor group, only one “genuine” early-type dwarf, i.e., one without any detected ISM, could be found (Bouchard et al. 2005), in accordance with morphological predictions (Jerjen et al. 2000b). This makes the Sculptor group one of the rare environments in which late-type dwarfs vastly outnumber early types; for example, down to MB ~ −10, Sculptor has one early-type dwarf against 18 late types (Côté et al. 1997, hereafter CFC97; Karachentseva & Karachentsev 1998, hereafter KK98; Jerjen et al. 2000b), while the Local Group has at least 17 early-type dwarfs against 16 late-type dwarfs (Mateo 1998). The Sculptor group has an elongated shape extending over ~3 Mpc (Jerjen et al. 1998; Karachentsev et al. 2004) and is therefore more of a galaxy “cloud” than a gravitationally bound entity; it does not have high galaxy density regions. This makes environmental influences such as ram pressure and tidal stripping largely ineffective and may explain the lack of early-type objects.

The Cen A group is a much denser environment than Sculptor. CFC97 identified ~20 dIrr galaxies in the Cen A group using photographic plates, as well as H i and Hα spectroscopy. In a complementary study, 13 dwarf galaxy candidates of early and mixed morphology were detected by Jerjen et al. (2000a), five of which had their distances measured and membership confirmed by the surface brightness fluctuation technique (Jerjen et al. 2000b). Several other catalogs and studies describing galaxies of the Cen A group have also been published (KK98; Banks et al. 1999; Karachentseva & Karachentsev 2000; Karachentsev et al. 2002, 2007). In total, the Cen A group contains at least 54 galaxies and has NGC 5128 (Cen A) and NGC 5236 (M83) at the center of its principal density peaks. Of this number, ~50 galaxies are dwarfs (with absolute B magnitude fainter than MB > −18): 32 are late type, 14 are early type, and 4 are of mixed morphology. This rich group environment is, after Sculptor, the next logical target to search for H i–rich dEs.

This paper presents the results of Parkes single-dish and Australia Telescope Compact Array (ATCA) H i observations in the direction of 18 Cen A dwarf galaxies. The aim was to obtain a complete picture of H i properties in all known Cen A group dwarf galaxies to a low H i mass limit. The paper is structured as follows: Section 2 contains information on the target selection and observations. The main results of this investigation are found in § 3, while the analysis and implications are discussed in § 4. Finally, § 5 presents the conclusions of the paper.

2. OBSERVATIONS

2.1. Sample Selection

The Cen A galaxy group (Fig. 1) was chosen because it represents a widely different environment from the low-density Sculptor group, which we studied earlier (Bouchard et al. 2005). The relatively large number of galaxies, the presence of an active radio galaxy (Cen A), and the high overall density of the group make it more akin to a cluster environment. The biggest advantage of the Cen A group, however, is its short distance from the Milky Way (~4.1 Mpc), which makes deep and detailed H i studies of its members possible.

Our aim is to study the H i properties of galaxies that are the most susceptible to mass-loss mechanisms. These mechanisms operate most effectively at the faint end of the galaxy luminosity function. From the lists compiled by CFC97, Jerjen et al. (2000a), KK98, and Karachentsev et al. (2007) we see that the Cen A group contains 35 known dwarfs with MB ~ −14 (14 early-type, 17 late-type, and 4 mixed-type), and we observed 18 of these: 10 early-type, 4 late-type, and all 4 mixed-type. The properties of these dwarfs, i.e., the morphological types, spatial positions, radial distances, apparent magnitudes, Galactic extinctions, and optical heliocentric radial velocities, are summarized in Table 1. While all these galaxies have previously been observed with the H i Parkes All-Sky Survey (HIPASS; Barnes et al. 2001), that survey lacked sufficient resolution or sensitivity to constrain the properties of these low-mass objects. They were reobserved with either the Parkes Radio Telescope or the ATCA.

2.2. Parkes Observations

Using the same approach as Bouchard et al. (2005), the 64 m Parkes Telescope3 was employed to obtain high spectral resolution H i line spectra in the direction of the early-type dwarfs AM 1343–452, ESO 269-G066, Cen A-dE1, and Cen A-dE4. The observations were conducted in 2005 February (project P475). The multibeam instrument in MX (beam-switching) mode and the narrowband correlator with the MB7...2048 settings provided a bandwidth of 8 MHz divided into 2048 channels and two polarizations. The central frequency was set at 1417 MHz, resulting in an H i velocity coverage from −100 to 1500 km s−1, with a channel width of 0.82 km s−1. The beam size is 14.1′, or 18 kpc.

Fig. 1.—Sky distribution of the Cen A group galaxies. The large squares mark the positions of the major galaxies, while circles represent early-type dwarfs, triangles represent late-type dwarfs, and diamonds represent mixed-morphology dwarfs. Filled symbols represent the observed galaxies.

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3 The Parkes Telescope is part of the Australia Telescope, which is funded by the Commonwealth of Australia for operation as a National Facility managed by CSIRO.
TABLE 1

Position and Optical Parameters of the Sample

| Galaxy   | Type | R.A. (J2000.0) | Decl. (J2000.0) | $D^a$ (Mpc) | $m_B$ (mag) | $A_B^b$ (mag) | $v_0^c$ (km s$^{-1}$) | References |
|----------|------|----------------|----------------|-------------|-------------|--------------|----------------|------------|
| ESO 219-G010 | dE   | 12 56 10       | -50 08 38      | 4.79 ± 0.43 (s) | 16.42 ± 0.16 | 0.957        | ...           | 1, 2       |
| ESO 269-G037 | dIrr | 13 03 33       | -46 35 06      | 3.48 ± 0.35 (t) | 16.26       | 0.574        | ...           | 3, 4       |
| [KK98]208c |       | 13 05 02       | -40 04 58      | 5.78 ± 0.46 (t) | 16.33       | 0.436        | 619 ± 43      | 4, 5       |
| Cen A-dE1  | dE   | 13 12 45       | -41 49 57      | 4.21 ± 0.33 (t) | 17.75 ± 0.11 | 0.493        | ...           | 1, 5       |
| ESO 269-G066 | dE  | 13 13 09       | -44 53 24      | 4.05 ± 0.53 (s) | 14.59 ± 0.08 | 0.401        | 784 ± 31      | 1, 2       |
| Cen A-dE2  | dE/dIrr | 13 21 33      | -31 52 43      | ...           | 18.13 ± 0.18 | 0.288        | ...           | 1, 1       |
| SGC 1319.1-4216 | dE | 13 22 02       | -42 32 07      | 3.87 ± 0.31 (t) | 15.68 ± 0.14 | 0.665        | ...           | 1, 5       |
| [CFC97]Cen8 | dIrr/dE | 13 22 56      | -33 34 22      | ...           | 17.65 ± 0.08 | 0.296        | ...           | 1, 4       |
| AM 1320-230 | dE   | 13 23 29       | -23 23 35      | ...           | 17.53 ± 0.08 | 0.348        | ...           | 1, 1       |
| UGCA 365  | dE   | 13 36 31       | -29 14 06      | 5.18 ± 0.41 (t) | 15.53       | 0.229        | 573 ± 1       | 5, 6       |
| [KK98]208a | dIrr | 13 36 35       | -29 34 17      | 4.68 ± 0.42 (t) | 14.3        | 0.192        | ...           | 3, 3       |
| AM 1339-445 | dE   | 13 42 05       | -45 12 18      | 3.53 ± 0.31 (s) | 16.32 ± 0.1  | 0.477        | ...           | 2, 7       |
| Cen A-dE3  | dE   | 13 46 00       | -36 20 15      | ...           | 17.41 ± 0.15 | 0.266        | ...           | 1, 1       |
| AM 1343-452 | dE   | 13 46 16       | -45 41 05      | 3.73 ± 0.32 (s) | 17.57 ± 0.11 | 0.522        | ...           | 1, 2       |
| Cen A-dE4  | dE   | 13 46 40       | -39 58 41      | ...           | 17.60 ± 0.14 | 0.260        | ...           | 1, 1       |
| ESO 384-G016 | dE/dIrr | 13 57 01      | -35 20 01      | 4.23 ± 0.11 (s) | 15.11 ± 0.06 | 0.318        | 561 ± 32      | 1, 2       |
| Cen A-dE5  | dE   | 14 30 05       | -33 28 45      | ...           | 18.43 ± 0.13 | 0.326        | ...           | 1, 1       |
| ESO 272-G025 | dE/dIrr | 14 43 25      | -44 42 18      | ...           | 14.77       | 0.694        | 624 ± 10      | 3, 4       |

Note.—Units of right ascension are hours, minutes, and seconds, and units of declination are degrees, arcminutes, and arcseconds.

$^a$ The distance values marked with “t” denote a measurement using the tip of the red giant branch method, and “s” is used for the surface brightness fluctuation method.

$^b$ The $A_B$ values are from Schlegel et al. (1998).

$^c$ [KK98]208 was not explicitly targeted but was in the field of view of UGCA 365.

References.—For values of $D$ and $m_B$: (1) Jerjen et al. 2000a; (2) Jerjen et al. 2000b; (3) Karachentsev et al. 2002; (4) CFC97; (5) Karachentsev et al. 2007; (6) Huchmeyer et al. 2003; (7) Rejkuba et al. 2006.

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AM 1339-445, and ESO 384-G016 with the 1.5A array configuration; [CFC97]Cen6 and Cen A-dE5 with the 750D configuration; ESO 219-G010, Cen A-dE2, AM 1320-230, and Cen A-dE3 using the EW367 configuration; and SGC 1319.1-4216, UGCA 365, and ESO 272-G025 with the EW352 configuration. In addition, observations in the direction of [CFC97]Cen5 were also conducted but are not presented here. This galaxy is a background spiral galaxy not associated with the Cen A group (Bouchard et al. 2004).

The arrays were chosen so that the final synthesized beam would encompass a maximum of the anticipated flux structure while not being much larger. Precisely, it was the different distances to each object and their respective morphological appearances that were taken into account. This was done to avoid overresolving the sources, which would have led to detection difficulties, while also avoiding the dilution of the HI signal with the surrounding noise.

The observations were carried out in 2003 February and March and in 2004 March and April (project C1133).

The FULL_4_1024-128 correlator configuration was employed with the central frequency of 1417 MHz for HI line velocity coverage from 200 to 1000 km s\(^{-1}\) or of 1416 MHz for coverage from 400 to 1200 km s\(^{-1}\). The spectra were divided into 1024 channels each of 0.82 km s\(^{-1}\). For each observing session the radio continuum source PKS 1934-638 was observed for 10 minutes for use as a flux and bandpass calibrator. A phase calibrator was also observed for typically 5 minutes every 40 minutes of on-source integration. Total integration times ranged between 270 and 650 minutes (see Table 2).

The data were reduced with the MIRIAD software package using standard procedures. The continuum was fitted and subtracted using a low-order polynomial. Each data cube was produced using “natural” weighting of baselines, CLEANed, and RESTOREd to a Gaussian beam of the same size as the main lobe of the synthesized beam.

3. RESULTS AND HI PROPERTIES

Our program has detected HI emission in five galaxies: the dIrr ESO 269-G037, the dIrr [CFC97]Cen6, the dIrr UGCA 365, the dE/dIrr ESO 384-G016, and the dE/dIrr ESO 272-G025. Line emission maps can be found in Figures 2 and 3; the spectra are
in Figure 4. Of the 11 galaxies that were not detected, two are of mixed morphology, Cen A-dE2 and [CFC97]Cen8, while one is a dIrr, [KK98]208. The rest are early-type dwarfs.

In Table 2 we compile the H\textsc{i} detection parameters or upper limits on the H\textsc{i} content. For each galaxy, we list the telescope that was used and the total on-source integration time, $T_{\text{int}}$, in minutes. For the detected galaxies, the heliocentric radio velocities $V_{\odot}$ and velocity dispersions $\sigma_V$ of the gas are listed. The total H\textsc{i} flux in Jy km s$^{-1}$ is given by

$$S_{\text{H}\textsc{i}} = \int S_v \, dv,$$

where $S_v$ is the flux value within each channel of velocity width $dv$. The H\textsc{i} mass $M_{\text{H}\textsc{i}}$ in solar units $M_\odot$ was calculated using the standard formula,

$$M_{\text{H}\textsc{i}} = (2.356 \times 10^5)D^2S_{\text{H}\textsc{i}},$$

where $D$ is the radial distance in megaparsecs. When $D$ was unavailable from the literature, a value of 4.3 $\pm$ 0.7 Mpc was adopted, which corresponds to the mean and standard deviation of the distances to all galaxies in the Cen A group (Karachentsev et al. 2007).

The H\textsc{i} mass-to-blue luminosity ratio $M_{\text{H}\textsc{i}}/L_B$ in solar units $M_\odot/L_B$ is

$$M_{\text{H}\textsc{i}}/L_B = \left(1.5 \times 10^{-7}\right)10^{0.4(m_B-A_B)}S_{\text{H}\textsc{i}},$$

where $m_B$ is the apparent integrated $B$-band magnitude of the object and $A_B$ is the $B$-band Galactic extinction value along the line of sight (see Table 1). The absolute magnitude of the Sun was taken as $M_{\odot,B} = 5.5$ (Bessell et al. 1998). The quoted errors are the results of quadratic error propagation, and when no errors were mentioned for $m_B$, these values were taken as $0.1$ mag.

Where the galaxies were not detected, Table 2 lists upper limits for $S_{\text{H}\textsc{i}}$, $M_{\text{H}\textsc{i}}$, and $M_{\text{H}\textsc{i}}/L_B$. These upper limits were calculated with the same equations as above but using a value of $S_v$ equal to 3 times the rms in the spectra integrated over 10 km s$^{-1}$. The rms was typically $\sim 4$ mJy beam$^{-1}$ in ATCA observations and $\sim 1$ mJy beam$^{-1}$ in Parkes data.

We should note, however, that while ESO 269-G066 is listed as not detected in Table 2, it contains a prominent H\textsc{i} feature in its spectrum at $v_0 = 231 \pm 1$ km s$^{-1}$ with $S_{\text{H}\textsc{i}} \sim 0.33$ Jy km s$^{-1}$ (Fig. 5). This feature was not reported by Beaulieu et al. (2006), who observed the same object with the Green Bank Telescope, covering a heliocentric velocity range from 600 to 1000 km s$^{-1}$; they have placed an upper limit of $M_{\text{H}\textsc{i}} < 1.6 \times 10^6 M_\odot$ (corrected to a distance of 4.05 Mpc). The optical velocity of this object was estimated to be $v_0 = 784 \pm 31$ km s$^{-1}$, measured from Balmer absorption lines (Jerjen et al. 2000b). It therefore seems unlikely that this H\textsc{i} feature is associated with the dwarf. A systemic velocity of 231 km s$^{-1}$ would also be inconsistent with a Cen A group association; most other objects have velocities greater than 500 km s$^{-1}$. Inspection of the high velocity cloud (HVC) catalog (Putman et al. 2002) reveals many HVCs.
in the vicinity of ESO 269-G066 at $v_0 \sim 200$ km s$^{-1}$, and one may have been caught in the 14' beam of the Parkes telescope. We conclude that no H i is associated with this galaxy, which therefore has $M_{H_1} < 10^3 M_\odot$.

4. ANALYSIS

4.1. Early-Type Dwarfs

The first interesting result from our H i study that should be pointed out is that none of the 10 observed dwarfs classified as dE have been detected in H i. The $M_{H_1}$ upper limits range between 1.0 and $6.5 \times 10^5 M_\odot$, and the $M_{H_1}/L_B$ upper limits are between 0.002 and 0.20 $M_\odot/L_i$. To understand the implications of the $M_{H_1}/L_B$ results, one should consider two extreme examples: Cen A-de5 and ESO 269-G066. While both have roughly similar H i mass upper limits, $M_{H_1} = 3.4 \times 10^5$ and $1.0 \times 10^5 M_\odot$, respectively, they have very different $M_{H_1}/L_B$ ratios.

Cen A-de5 is the faintest galaxy of our sample and has an absolute magnitude $M_B = -10.1$ (for an assumed distance of 4.3 Mpc). Although this object is brighter than some Local Group dwarfs (e.g., Ursa Minor, $M_B = -7.6$; Mateo 1998), it is among the faintest known galaxies in the local universe. It has $M_{H_1}/L_B < 0.2 M_\odot/L_i$. At the bright end of our optical luminosity distribution, ESO 269-G066 has $M_B = -13.8$ and $M_{H_1}/L_B < 2 \times 10^{-3} M_\odot/L_i$.

As a first approximation, both these galaxies can be considered dominated by an old and metal-poor stellar population (see Jerjen et al. 2000b). The mass loss expected from the evolution of such a population is of the order of $0.1 M_\odot/L_i$ over a Hubble time (Bouchard et al. 2005). It becomes immediately obvious that while the $M_{H_1}/L_B$ upper limit for Cen A-de5 does not exclude such mass loss material being in the form of H i, it is very stringent on the state of ESO 269-G066. In this latter case, any neutral gas buildup is, at best, insignificant. The upper limit on $M_{H_1}/L_B$ actually requires that the ISM in this galaxy is either completely ionized or, more likely, has been regularly and thoroughly swept out of the dwarf. For comparison purposes, the Local Group dE galaxies NGC 185 and NGC 205, both satellites of M31, have $M_{H_1}/L_B = 4 \times 10^{-3}$ and $3 \times 10^{-3} M_\odot/L_i$, respectively (Young & Lo 1997).

4.2. Mixed-Type Dwarfs

Of the four mixed-type dwarfs that were observed, two were detected in H i: the dE/dIrr ESO 384-G016 with $M_{H_1} = (4.4 \pm 0.8) \times 10^6 M_\odot$, and $M_{H_1}/L_B = 0.13 \pm 0.02 M_\odot/L_i$, and the dE/dlr ESO 272-G025 with $M_{H_1} = (7 \pm 2) \times 10^5 M_\odot$, and $M_{H_1}/L_B = 0.10 \pm 0.01 M_\odot/L_i$. The two others, the dE/dlr Cen A-de2 and the dlr/dE [CFC97]Cen8, have upper limits of $M_{H_1} < 5.1 \times 10^5 M_\odot$, $M_{H_1}/L_B < 0.24 M_\odot/L_i$, and $M_{H_1} < 5.5 \times 10^5 M_\odot$, $M_{H_1}/L_B < 0.17 M_\odot/L_i$, respectively.

We note that Beaulieu et al. (2006) previously observed ESO 384-G016 with ATCA and found $M_{H_1} = (5.6 \pm 0.3) \times 10^5 M_\odot$, in good agreement with our result. They had a longer integration time, which resulted in a higher signal-to-noise ratio and, most probably, a more accurate result.

These authors have also found that single-dish observation yielded $M_{H_1} = (6.5 \pm 0.1) \times 10^5 M_\odot$, which highlights the fact that approximately 25% of the flux resides in scales inaccessible to our array configuration. We also note that ESO 272-G025 had previously been detected in H i but not in H i (CFC97).

At first sight, this situation may seem to contrast that of both the Local Group and the Sculptor group, in which all mixed-morphology galaxies have been detected in H i. On closer inspection, however, Local Group mixed-morphology dwarfs have $M_{H_1}/L_B$ between 0.21 and 1.4 $M_\odot/L_i$, (St-Germain et al. 1999; Blitz & Robishaw 2000; Bouchard et al. 2006), while in the Sculptor group these objects have $M_{H_1}/L_B$ between 0.08 and 0.18 $M_\odot/L_i$ (Bouchard et al. 2005). The $M_{H_1}/L_B < 0.24 M_\odot/L_i$ constraint imposed on the two nondetected Cen A dwarfs does not exclude H i contents similar to those of Sculptor mixed-morphology dwarfs.

4.3. Late-Type Dwarfs

It comes with some surprise that not all observed late-type dwarfs were detected in H i. While ESO 269-G037, [CFC97]Cen6, and UGCA 365 all have considerable amounts of ISM—$M_{H_1} = (4 \pm 1) \times 10^5 M_\odot$, and $M_{H_1}/L_B = 0.04 \pm 0.02 M_\odot/L_i$, respectively—[K98]208 was not detected with limits of $M_{H_1} < 4.1 \times 10^5 M_\odot$, and $M_{H_1}/L_B < 0.05 M_\odot/L_i$. From empirical evidence, we would have expected most dIrr galaxies to have $M_{H_1}/L_B$ between 0.1 and 10 $M_\odot/L_i$ at $M_B = -14$ (Warren et al. 2006).

The galaxy [K98]208 was added to the sample after the observations, as it resides only 30' away from UGCA 365. The upper limit for $M_{H_1}$, and correspondingly that for $M_{H_1}$, is higher than for any other galaxy of our sample (see Table 2) and, with $M_B = -14.2$, this galaxy is optically brighter than most other objects in our sample. This makes the $M_{H_1}/L_B$ ratio limit of 0.05 $M_\odot/L_i$ surprisingly low for a dIrr. No dwarf galaxy in the Koribalski et al. (2004) sample has a value this low (see also Warren et al. 2006).

[K98]208 also happens to share a line of sight similar to that of the spiral galaxy NGC 5236 (M83), which has H i extending up to and beyond the spatial position of [K98]208. Huchtmeier et al. (2000) claim to have detected the dwarf at $v_i = 400$ km s$^{-1}$, but this detection is confused with the 21 cm signal from NGC 5236. The northern spiral arm of NGC 5236 is easily detected in our data at the velocity mentioned by Huchtmeier et al. (2000), but there are no signs of kinematically decoupled H i emission near the dwarf. It is also worth noting that Karachentsev et al. (2002) found, in the color-magnitude diagram of this dwarf, a predominantly old stellar population typical of a dE, in disagreement with its irregular morphology (KK98). However, its extreme low surface brightness makes classification on morphological grounds intrinsically difficult (see Fig. 3 in Karachentsev et al. 2002). Both the stellar population and the H i properties of this object clearly favor an early-type classification.

It is also interesting to note that the dIrr galaxy ESO 269-G037 has $M_{H_1}/L_B = 0.04 M_\odot/L_i$. This value is low for a dwarf of late morphology. Based on stellar photometry, Karachentsev et al. (2002) argued that this galaxy should actually be considered as a dSph. The object may also harbor a small population of blue stars, which would be consistent with the H i result.

4.4. H i Displacement and Ram Pressure

Angular displacement of the H i with respect to the optical center is observed in a number of dwarf galaxies. In the Local Group, this is seen in two of the five mixed-morphology galaxies, Phoenix and LGS 3 (St-Germain et al. 1999; Gallart et al. 2001; Robishaw et al. 2002), while in the Sculptor group this is likely the case for two of the three investigated mixed-morphology dwarfs. In the Cen A group, we only detect a possible H i displacement in ESO 269-G037, but the low signal-to-noise ratio of the map presented in Figure 2 makes it difficult to accurately determine whether the gas is really offset with respect to the optical center.
We do, however, detect a discrepancy between the H\textsc{i} velocity $v_0 = 502.9 \pm 2.4$ km s$^{-1}$ (consistent with the measurement of Beaulieu et al. 2006) and the optical velocity $v_0 = 561 \pm 32$ km s$^{-1}$ (Jerjen et al. 2000b) for ESO 384-G016. While Beaulieu et al. (2006) argued that the H\textsc{i} velocity is probably more accurate than the optical, they also suggested that, based on the H\textsc{i} distribution, this galaxy may be experiencing ram pressure while falling into the group. Jerjen et al. (2000b) noted that this galaxy has an old and metal-poor stellar population and the optical spectra shows no sign of current star formation. Ram pressure stripping may be able to displace the gas while keeping it with a smooth distribution (Gallart et al. 2001), not necessarily triggering star formation. Moreover, the H\textsc{i} is at a lower velocity than the optical, a situation we would expect if ESO 384-G016, at $D = 4.2$ Mpc, were falling onto NGC 5236 at $D = 5.1$ Mpc (Karachentsev et al. 2007). Since the mechanism causing this offset is unlikely to be aligned with the radial direction, the velocity difference should also have produced a measurable angular offset if it were the result of a gentle "push" or have produced star-forming regions if the event were more violent. Alternatively, it may be that the gas is being compressed and star formation is about to start. This object would then evolve back toward a late-type morphology. The spectral information available for this object is of too low signal-to-noise ratio. Further observations will be required to investigate whether the H\textsc{i} line shape may have been influenced by ram pressure.

The eastern H\textsc{i} extension detected by Beaulieu et al. (2006) in ESO 384-G016 is similar to the northwestern H\textsc{i} extension of UGCA 365 (Fig. 2). This latter galaxy is situated $\sim 81$ kpc in three-dimensional distance from NGC 5236 (M83), a separation reminiscent of that of the Large and Small Magellanic Clouds from the Milky Way. It is possible that this object is experiencing ram pressure and tidal stripping as it travels on its orbit around M83.

4.5. Cen A Environment and Dwarf Evolution

The Cen A group is a relatively high-density environment providing external conditions that can influence the evolution of its group members. In fact, one of the most important features of this environment is the presence of the active galaxy NGC 5128 (Cen A). The radio lobes of NGC 5128 may be dramatically affecting nearby objects (see Fig. 6). These regions of hot ionized plasma measure 9° ($\sim 600$ kpc) in the north-south direction and 3° ($\sim 200$ kpc) east-west (e.g., Junkes et al. 1993). This may have affected the evolution of nearby dwarfs.

There are six galaxies projected near NGC 5128. These include the three early-type dwarfs Cen A-dE1, SGC 1319.1-4216, and ESO 269-G066, none of which were detected in H\textsc{i} (Table 2). The three other objects are gas-rich (CF97; Koribalski et al. 2004). The spiral galaxy ESO 270-G017 (also known as Fourcade-Figueroa) and the irregular NGC 5237 are believed to be the remnants of a close interaction between a spiral galaxy and NGC 5128, which may have been at the origin of the latter’s observed dust lane (Dottori & Fourcade 1973; Thomson 1992). Finally, the dIrr ESO 324-G024 is known to have H\alpha and H\beta emission, both signs of active star formation (Lee et al. 2003).

In the case of ESO 269-G066, there is a good agreement in radial distance with NGC 5128: $D = 3.84 \pm 0.35$ Mpc (Rejkuba 2004) compared to 4.05 $\pm 0.53$ Mpc for ESO 269-G066 (Jerjen et al. 2000b). The relative line-of-sight velocity is $\Delta v \sim 240$ km s$^{-1}$. It is possible that the orbit of the dwarf regularly through the lobes of NGC 5128. The very low limit on the H\textsc{i} mass-to-light ratio of ESO 269-G066, $M_{\text{H}i}/L_B < 2 \times 10^{-5}$, and the evidence that it contains mostly old and metal-poor stars (Jerjen et al. 2000b) suggests that these passages through the lobes may be "actively cleansing" the dwarf of any traces of accumulated gas, probably by means of intensified ram pressure and, possibly, heating due to the higher X-radiation field in the plasma. In any case, this would prevent any further star formation. The other early-type dwarfs, Cen A-dE1 and SGC 1319.1-4216, may be in similar positions; however, independent measurement of their distances are required to reveal the likeliness of these objects going through the lobes.

To investigate this intensified ram pressure, we compare in Figure 7 the $M_{\text{H}i}$ and $L_B$ values of all known galaxies from the Cen A and Sculptor group. It becomes apparent that the different global environments, and not just the direct proximity to an active galactic nucleus, acted differently on the evolution of their respective fainter members. When compared to the Cen A group, Sculptor seems to be lacking both low and high H\textsc{i} mass objects in the range $-14 < M_B < -11$. It provides much more of a continuum of H\textsc{i} mass toward fainter objects than the Cen A group does; the latter seems to have more of a dichotomy between the H\textsc{i}-rich and H\textsc{i}-deficient objects. Precisely, Sculptor has a single galaxy with no detected H\textsc{i} and $M_{\text{H}i}/L_B < 0.05 M_\odot /L_\odot$, while, on the other hand, Cen A has at least...
16 galaxies that were not detected in H\textsc{i} and at least eight with $M_{\text{H}}/L_B < 0.05 \, M_\odot \, L_\odot / B$. The Cen A environment seems much more efficient in removing gas from dwarfs than that of Sculptor. In addition, Cen A also has a much more prominent population of galaxies with $1 \, M_\odot \, L_\odot / B < M_{\text{H}}/L_B < 10 \, M_\odot \, L_\odot / B$ than Sculptor.

Gunn & Gott (1972) determined that the ISM of a galaxy will be stripped away by ram pressure if

$$\rho_{\text{IGM}} \geq \rho_{\text{ISM}} \left(\frac{\sigma_{\text{ISM}}}{v_p}\right)^2$$

for a galaxy with an ISM of density $\rho_{\text{ISM}}$ and velocity dispersion of $\sigma_{\text{ISM}}$, traveling at a velocity $v_p$ through an intergalactic medium of density $\rho_{\text{IGM}}$. By adopting $v_p = 10 \, \text{km s}^{-1}$, a value typical for the studied dwarfs (e.g., Mateo 1998; Bouchard et al. 2005), and taking a value of $v_p \sim 300 \, \text{km s}^{-1}$, we find that if $\rho_{\text{IGM}} \geq 10^{-3} \rho_{\text{ISM}}$, ram pressure will eventually remove all the gas in a low-mass dwarf. In the case of the dE ESO 269-G066 the ISM density is $\rho_{\text{ISM}} < 10^{-5} \, \text{cm}^{-3}$ ($M_{\text{H}} < 10^5 \, M_\odot$ inside a presumed radius of 1 kpc). This value is much lower than that of the dIrr ESO 324-G024, where $\rho_{\text{ISM}} = 15 \, \text{cm}^{-3}$ ($M_{\text{H}} = 1.5 \times 10^8 \, M_\odot$ inside a radius of 1 kpc; CFC97). An IGM density of the order of $10^{-3} \, \text{cm}^{-3}$ would therefore strip away any gas accumulation in ESO 269-G066 but otherwise leave ESO 324-G024 intact. These values for $\rho_{\text{IGM}}$ are consistent with the values measured by X-ray observations of NGC 5128 (Cooke et al. 1978; Feigelson et al. 1981) and of loose galaxy groups (Mulchaey et al. 1996; Helson & Poonman 2000).

Figure 7 shows that, for the faint objects of the Cen A group ($M_B > -13$), there seems to be a threshold in H\textsc{i} masses at values of $M_{\text{H}} \sim 10^7 \, M_\odot$. All objects below this value have at least a factor of 10 less H\textsc{i} than the ones above. In fact, there is only one detected galaxy below this limit: the dIrr ESO 269-G037 with $M_{\text{H}} = 4 \times 10^7 \, M_\odot$. It seems that the dwarfs situated above the threshold have kept their H\textsc{i}, while the ones below are efficiently swept clean of ISM.

Assuming that the $10^7 \, M_\odot$ threshold does indeed exist, we can redefine the morphological classification of dwarf galaxies based on H\textsc{i} properties. In the $M_B > -14$ regime of the Cen A group, there are 13 late-type dwarfs ($M_{\text{H}} \simeq 10^7 \, M_\odot$) that may keep their ISM for a long period of time. These are objects like [CFC97]Cen6 ($M_{\text{H}}/L_B = 1.8$). They have an important untapped and stable potential for further star formation. There is also a single detected transition-type galaxy (ESO 269-G037) that might currently be losing its ISM through ram pressure stripping. Finally, there are 12 early-type dwarf candidates, where no ISM has been detected. Much like Ursa Minor in the Local Group or ScI-dE1 in the Sculptor group, their lack of ISM prohibits any further star formation, and they have reached their final evolutionary state. If any of the latter type contained H\textsc{i}, they would be considered transition-type objects because such low H\textsc{i} content would be short-lived and prone to ram pressure stripping. The current sensitivity of H\textsc{i} observations allows us to distinguish the late-type dwarfs but does not allow a differentiation between the early- and transition-type dwarfs at the distance of the Cen A group (4.3 Mpc).

Finally, we note that the present investigation has targeted some of the faintest known members of the Cen A group. The H\textsc{i} survey for these galaxies, i.e., fainter than $M_B > -14$, is now complete to an H\textsc{i} mass of $10^6 \, M_\odot$. However, it is most likely that not all dwarf galaxies of the Cen A or Sculptor groups have been found to date. For example, in the Local Group the ~40 members are fainter than $M_B > -10$. In the Cen A group there are only four galaxies of the ~45 galaxies that are this faint. The advent of next-generation optical surveys will probably uncover new group members. These future discoveries and H\textsc{i} follow-up work will give an even better insight into the properties for galaxies at the faint end of the luminosity function, for different environments.

5. CONCLUSIONS

We have presented Parkes single-dish and ATCA interferometric H\textsc{i} observations of 18 low-luminosity dwarf galaxies belonging to the Cen A group, with an emphasis on early-type dwarfs. This was done in order to identify objects with H\textsc{i} reservoirs and, therefore, potential for further star formation. As a result, we can constrain dwarf galaxy evolution scenarios by providing a thorough analysis of a nearby dense environment.

The main conclusions can be summarized as follows:

1. Of the 18 observed dwarfs, five were detected: three were late-type dwarfs and two were of mixed morphology. None of the early-type objects were found to contain H\textsc{i}. The detection limits on all nondetected early- and mixed-type objects are in the range from $M_{\text{H}} = 10^5$ to $6.5 \times 10^5 \, M_\odot$. $M_{\text{H}}/L_B < 0.24 \, M_\odot \, L_\odot / B$.

2. Unlike the Local Group and the Sculptor group, in which all mixed-morphology dwarfs are detected in H\textsc{i}, only two of the
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