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THE H I CONTENT OF THE LOCAL GROUP DWARF (SPHEROIDAL OR IRREGULAR?) GALAXY PHOENIX

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ABSTRACT

Neutral hydrogen was detected in the Local Group dwarf galaxy Phoenix. The 21 cm H I line emission, observed at a heliocentric radial velocity of 56 km s^{-1}, is clearly separated from a much larger scale component at $\sim$140 km s^{-1} which was previously associated with the Magellanic Stream. The profile width $\Delta V_{50} \simeq 21$ km s^{-1}, combined with the high inclination of the system, suggests that not much rotation is present in this system which would then be mainly supported by turbulent motions. Using a newly determined distance estimate, the integrated profile gives a total H I mass of $\simeq 1.0 \times 10^5 M_\odot$ for an $M_{\rm H\,I}/L_V \simeq 0.07 M_\odot/L_\odot$. Most of the known properties of Phoenix imply that it is intermediate between typical dwarf irregular and dwarf spheroidal galaxies. It is suggested that, in fact, the two types of galaxies may belong to the same class of objects having a different history of star formation.

Subject headings: galaxies: internal motions — galaxies: interstellar matter — radio sources: 21 cm radiation

1. INTRODUCTION

" Dwarf spheroidals" (dSph) usually refer to dwarf galaxies, with absolute magnitude around $M_V \simeq -10$, devoid of H I gas, and with no trace of recent star formation, while "dwarf irregulars" (dI), which are a few magnitudes brighter, are usually gas-rich systems showing some signs of star formation activity. However, the distinction between those two classes is not always that straightforward. For example, 70% of the stellar population of the dwarf galaxy Carina is between 1 and 10 Gyr old (Mould & Aaronson 1983; Aaronson 1986), and despite this large intermediate age population, a sensitive search (Mould et al. 1990) did not succeed in detecting any H I gas ($M_{\rm H\,I} \leq 10^3 M_\odot$).

The questions of the origin of dwarf galaxies and of a possible (or impossible) evolutionary link between those two types of dwarfs have been recently the subject of many studies (Binggeli 1985; Kormendy 1985; Aaronson 1986; Bothun et al. 1986; Dekel & Silk 1986; Silk, Wise, & Shields 1987). Of special interest also are the large mass-to-light ratios claimed for some nearby dwarf spheroidals (Aaronson 1983; Faber & Lin 1983; Seitzer & Frogel 1985; Kormendy 1986; Aaronson & Olszewski 1986). The implied large quantity of unseen matter, around such small mass concentration, has important implications on the nature of dark matter. However, those large values of (M/L_V) are still quite uncertain (Cuddeford & Miller 1990).

The Phoenix dwarf galaxy is a relatively recent addition to the Local Group membership. It was identified on an ESO (B) Survey by Schuster & West (1976). It is located at $\alpha = 1^{\rm h}49^{\rm m}$ $\delta = -44°42'$ (1950). Well resolved into stars it was thought, by its discoverers, to be a distant globular cluster. Soon afterward, Canterna & Flower (1977), using the CTIO 4 m prime-focus camera, concluded that Phoenix was a dwarf irregular galaxy. This conclusion was based on the fact that Phoenix contains bright blue and red stars similar to what is seen in IC 1613 and other irregular galaxies. This comparison led Canterna & Flower to overestimate the distance of this system (see below). They quoted 1.85 Mpc, a distance large enough to place Phoenix outside of the Local Group.

Mooras & Bajaja (1986), who surveyed the region at 21cm, failed to detect any feature that could be associated with the galaxy and argued that the detected H I which spreads over a much larger region can be related to the Magellanic Stream ($100 < V < 180$ km s^{-1}). They concluded that Phoenix was most probably a dwarf spheroidal rather than a dwarf irregular galaxy despite some evidence for a small amount of star formation up to the present epoch. The photometric CCD study by Ortolani & Gratton (1988) revealed that the stellar population of Phoenix is dominated by an old metal-poor population similar to the one found in galactic globular clusters. These authors also concluded, from the aspect of the wide giant branch, that Phoenix is a dwarf spheroidal galaxy at a distance of $\sim$500 kpc.

In a recent CCD photometric study, van de Rydt, Demers, & Kunkel (1991) redetermined the distance of Phoenix from the apparent I magnitude of its giant branch tip and also by matching the giant branch of Phoenix to those of Fornax and ωCen. A slightly smaller distance of $(m = M_V)_0 = 23.1 \pm 0.1$ is obtained. The luminosity functions of the giant branch of Fornax (Eskridge 1987) and M3 (Sandage 1954) were compared to the counts on the giant branch of Phoenix. Phoenix was also found to contain a number of extremely red stars, presumably carbon stars. Van de Rydt et al. (1991) also estimated that the mass of Phoenix should be about 3 times the mass of M3. Because the young blue population of Phoenix is small and counts for barely 8% of the total number of stars (brighter than $V = 23$), we derive that the stellar mass of Phoenix is of the order of $\sim 10^6 M_\odot$.

2. OBSERVATIONS

The 21 cm H I line observations were obtained using the Parkes 64 m radiotelescope[1] on 1990 August 4. The telescope combined with the horn feed has a half-power beamwidth of 15′ and a flux-to-antenna temperature ratio $S/T_A = 1.62$ Jy K^{-1}. The front end was a cooled FET receiver (developed for the Australia Telescope) yielding an overall system temperature $T_{sys} \sim 40$ K. The back end was the Parkes 1024 channel one-bit autocorrelation spectrometer (Ables et al. 1975) which was configured to give two 512 channels spectra (1 spectrum per polarization) of 10 MHz bandwidth each. This resulted in a channel separation of 4.1 km s^{-1} for a velocity resolution after Hanning smoothing of 8.2 km s^{-1}.

The flux density calibration was done by observing Hydra A (PKS 0915−18) in the 21 cm continuum with an adopted flux density of 41.5 Jy. The velocity scale was checked by observing the source UKS 1908−621 which has a heliocentric radial velocity $V_{sys} = 946$ km s^{-1} and a profile width of $\Delta V_{20} = 92$ km s^{-1}.

A total of 30 minutes integration (3 × 10 minutes on source, alternately with 3 × 10 minutes on a sky reference position 10 minutes of time east, which corresponds to 1°8, well outside the Magellanic Stream) was obtained at the position of Phoenix. The resulting spectrum after baseline subtraction has a r.m.s. antenna temperature noise of 0.018 K and is shown in Figure 1*a*. The component of the Magellanic Stream, seen by Morras & Bajaja (1986) and expected at an H I column density of $N_H \sim 0.5 \times 10^{19}$ cm^{-1}, is clearly seen at a heliocentric radial velocity of 139.2 km s^{-1}. Local Galactic hydrogen is also seen in the difference spectrum between −10 and 20 km s^{-1}.

What is more interesting is the profile seen between 30 and 80 km s^{-1} which is most likely associated with Phoenix. For comparison, Figure 1*b* is a 10 minute integration at the position (1^h24^m, −48°), of the highest column density in the large-scale map of Morras & Bajaja (1986). This spectrum just shows the higher velocity component. At that position, the Magellanic Stream has an H I column density $N_H \simeq 3.0 \times 10^{19}$ cm^{-2} and a central heliocentric radial velocity of 121 km s^{-1}, similar to what is seen by Morras & Bajaja.

For the profile associated with Phoenix, a systemic velocity of 56.4 ± 2.0 km s^{-1} (heliocentric) is derived. This corresponds to a radial velocity of +47 km s^{-1} relative to the LSR which fits rather well the adopted solution of Yahil, Tammann, & Sandage (1977) for the solar motion relative to the centroid of the Local Group. The velocity widths are $\Delta V_{50} = 21.0 \pm 3.5$ km s^{-1} and $\Delta V_{20} = 29.2 \pm 4.0$ km s^{-1}. Considering that the optical isophotes suggest an inclination $i \simeq 55°$, the velocity width implies that very little rotation is present in this system. Only higher resolution synthesis observations will allow us to detect unambiguously any systematic rotation which could only be of a few km s^{-1} since the expected velocity dispersion from random motions must be of the order of 7–10 km s^{-1} (Carignan, Beaulieu, & Freeman 1990).

The H I flux integral between 37.4 and 74.5 km s^{-1} is $FI = 2.44 \pm 0.14$ Jy km s^{-1}. With a distance modulus of 23.1 ($\Delta \simeq 400$ kpc) and an absolute magnitude $M_V \simeq -9.9$ (van de Rydt et al. 1991), a total H I mass $M_{\rm H\,I} = 1.00 \pm 0.05 \times 10^5 M_\odot$ is derived for a $M_{\rm H\,I}/L_V \simeq 0.07 M_\odot/L_\odot$.

A second set of observations was obtained on 1991 May 23 (Fig. 2). Four positions with offsets of 1 beamwidth N, S, E, and W of the central position ($\alpha = 1^h49^m$, $\delta = -44°42'$) were observed. While no H I was detected at the N and E positions, H I is clearly seen in the S and W spectra with $V_\odot \simeq 65$ km s^{-1}. This suggests that the H I distribution is extended along the major axis in the SW direction. Optically, the galaxy is also more extended on the SW side.

[1] The Australia Telescope National Facility is operated in association with the Division of Radiophysics by CSIRO.

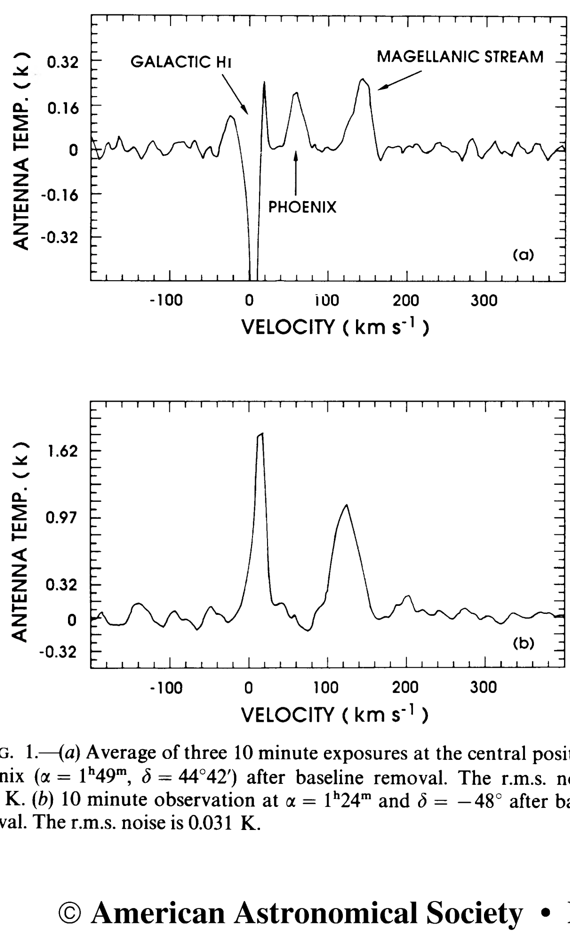

FIG. 1.—(*a*) Average of three 10 minute exposures at the central position of Phoenix ($\alpha = 1^h49^m$, $\delta = 44°42'$) after baseline removal. The r.m.s. noise is 0.018 K. (*b*) 10 minute observation at $\alpha = 1^h24^m$ and $\delta = -48°$ after baseline removal. The r.m.s. noise is 0.031 K.

3. PHOENIX: SPHEROIDAL OR IRREGULAR

Recently, Ortolani & Gratton (1988) suggested that galaxies like Phoenix may belong to an intermediate class between typical irregular galaxies, which are presently undergoing star formation, and dwarf spheroidals where star formation halted a long time ago. In the light of the newly detected H I in Phoenix, it is worth investigating once more this possibility. In Table 1 some global properties of Phoenix are compared with those of well-studied dwarf irregulars and dwarf spheroidals.

First, Fornax which is at the bright end of the luminosity function of dwarf spheroidals has been known for a long time (Demers & Kunkel 1980; Aaronson & Mould 1980) to show evidence of a relatively young stellar population. Despite this, it has so far no detected H I (Knapp, Kerr, & Bowers 1978). However, more sensitive observations with actual low system temperature receivers could possibly detect H I gas at a level of $\sim 200 M_\odot$ in this very nearby (140 kpc) galaxy.

On the other hand, GR8, at 2 mag fainter, is a typical dwarf irregular with a few bright H II regions and $2.0 \times 10^6 M_\odot$ of H I gas. With its H I mass-to-light ratio ∼2, GR8 has more luminous mass in H I gas than in stars. It is also one of the first systems (with M81 dwA: Sargent, Sancisi, & Lo 1983; Sargent & Lo 1985) where it was clearly showed that rotation was

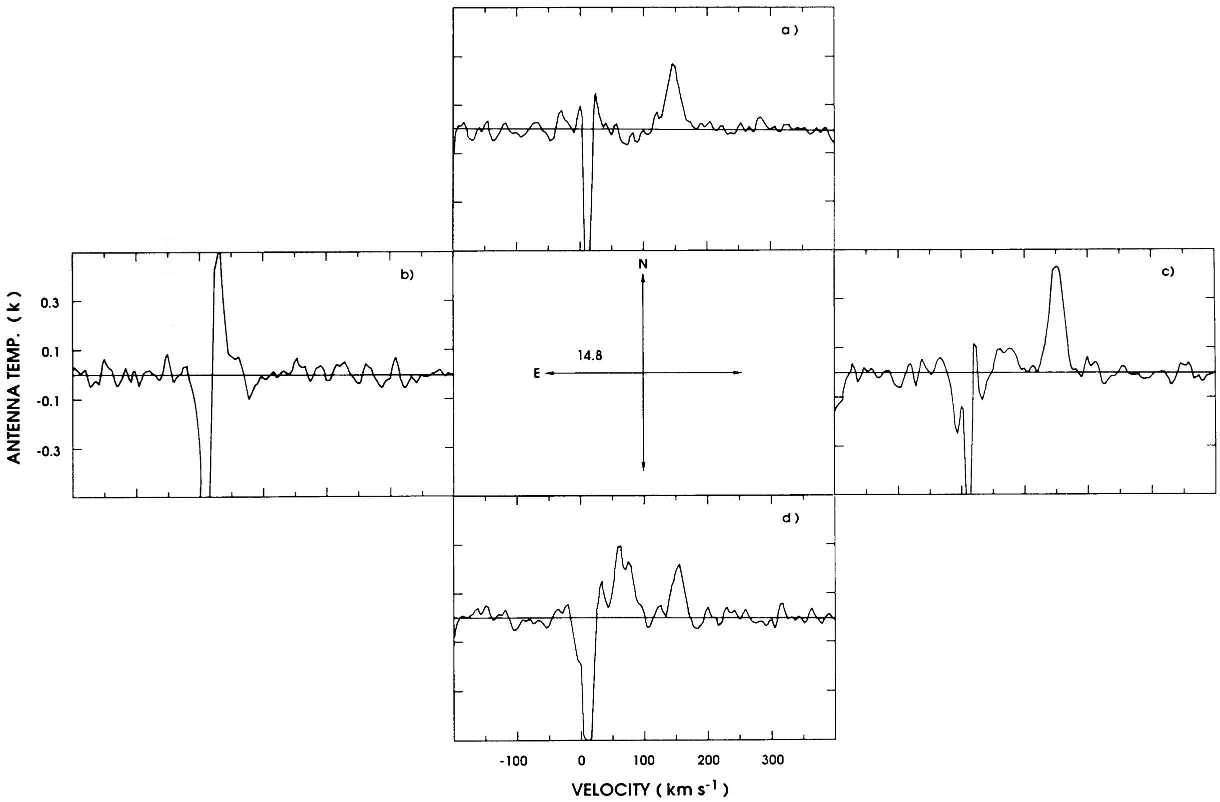

FIG. 2.—Spectra taken with an offset of 1 beamwidth (14'.8) (*a*) north, (*b*) east, (*c*) west, and (*d*) south of the central position illustrated in Fig. 1*a*.

having a minor contribution to its gravitational support (Carignan et al. 1990).

At the low end of the luminosity function, we find Carina and Draco, which are considered bona fide dwarf spheroidals with no detected H I gas: $M_{\rm H\,I} < 10^3\ M_\odot$ for Carina (Mould et al. 1990), and $M_{\rm H\,I} < 68\ M_\odot$ for Draco (Knapp, Kerr, & Bowers 1978). While for Draco, there is no clear sign of an important intermediate age population, this is quite the contrary for Carina (Aaronson 1986).

Finally, comes the "intermediate" case of LGS3 which has $M_{\rm H\,I} \simeq 6.0 \times 10^5\ M_\odot$ for a $M_{\rm H\,I}/L_V \simeq 0.7$. Christian & Tully (1983), who did broad-band photometry and constructed *C-M* diagrams for it, remarked that "LGS3 is unique in one respect. In all other cases, gas-rich dwarfs resolve first into stars on blue plates: in this case red." Similarly, Sargent & Lo (1985), who observed LGS3 at 21 cm, concluded that "LGS3 seems to be unique on several grounds.... it seems possible that LGS3 is one example of an intermediate dwarf galaxy in which the most recent star formation occurred several billion years ago."

In view of the above comparison, we could certainly say that objects like Phoenix and LGS3 form an intermediate class between typical dwarf irregulars and dwarf spheroidals. However, as we have just seen after discussing typical examples of both types of dwarfs, nearly all of them have mainly the characteristics of one class but also some features of the other.

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TABLE 1

PROPERTIES OF FAINT DWARF GALAXIES

Name	M_V	$M_{\rm H\,I}\ (M_\odot)$	$M_{\rm H\,I}/L_V$	$M_{\rm H\,I}/M_{\rm tot}$	$M_{\rm tot}/L_V$	Reference
Fornax (S)	-12.6	$<10^4$	$<10^{-3}$	$<10^{-4}$	2	1
G.R.8 (I)	-10.2	2×10^6	2.0	>0.05	>40	2
Phoenix (?)	-9.9	1×10^5	0.1	0.003	30	3
LGS3 (I)	-9.4	6×10^5	0.7	0.01	27	4
Carina (S)	-9.4	$< 10^3$	$<10^{-2}$	$<10^{-2}$	8	5
Draco (S)	-8.5	$< 10^2$	$<10^{-3}$	$<10^{-5}$	40	1

NOTE.—"I" for dwarf irregular and "S" for dwarf spheroidal.

REFERENCES.—1: Aaronson 1986; 2: Carignan et al. 1990; 3: this paper; 4. Sargent & Lo 1985; 5: Mould et al. 1990.

REFERENCES

Aaronson, M. 1983, ApJ, 266, L11
———. 1986, in Stellar Populations, ed. C. Norman, A. Renzini, & M. Tosi (STScI Symp. Series 1) (Cambridge: Cambridge Univ. Press), 45
Aaronson, M., & Mould, J. R. 1980, ApJ, 240, 804
Aaronson, M., & Olszewski, E. W. 1986, AJ, 92, 580
Ables, J., Cooper, B., Hunt, A., Moorey, G., & Brooks, J. 1975, Rev. Sci. Instr., 46, 284
Binggeli, B. 1985, in Star-Forming Dwarf Galaxies, ed. D. Kunth, T. X. Thuan, & J. T. T. Van (Gif-sur-Yvette: Éditions Frontières), 53
Bothun, G., Mould, J., Caldwell, N., & MacGillivary, H. T. 1986, AJ, 92, 1007
Canterna, R., & Flower, P. J. 1977, ApJ, 212, L58
Carignan, C., Beaulieu, S., & Freeman, K. C. 1990, AJ, 99, 178
Christian, C. A., & Tully, R. B. 1983, AJ, 88, 934
Cuddeford, P., & Miller, J. C. 1990, MNRAS, 244, 64
Dekel, A., & Silk, J. 1986, ApJ, 303, 39
Demers, S., & Kunkel, W. E. 1980, PASP, 91, 761
Eskridge, P. B. 1987, AJ, 94, 1564
Faber, S. M., & Lin, D. N. C. 1983, ApJ, 266, L17
Knapp, G., Kerr, F., & Bowers, P. 1978, AJ, 83, 360
Kormendy, J. 1985, ApJ, 295, 73
———. 1986, in IAU Symp. 117, Dark Matter in the Universe, ed. J. Kormendy & G. R. Knapp (Dordrecht: Reidel), 139
Morras, R., & Bajaja, E. 1986, Rev. Mexicana Astron. Af., 13, 69
Mould, J. R., & Aaronson, M. 1983, ApJ, 273, 530
Mould, J. R., Bothun, G. D., Hall, P. J., Staveley-Smith, L., & Wright, A. E. 1990, ApJ, 362, L55
Ortolani, S., & Gratton, R. G. 1988, PASP, 100, 1405
Sandage, A. 1954, AJ, 59, 162
Sargent, W. L. W., & Lo, K.-Y. 1985, in Star-Forming Dwarf Galaxies, ed. D. Kunth, T. X. Thuan, & J. T. T. Van (Gif-sur-Yvette: Éditions Frontières), 253
Sargent, W. L. W., Sancisi, R., & Lo, K.-Y. 1983, ApJ, 265, 711
Schuster, H. E., & West, R. M. 1976, A&A, 49, 129
Seitzer, P., & Frogel, J. A. 1985, AJ, 90, 1796
Silk, J., Wise, R. F. G., & Shields, G. A. 1987, ApJ, 323, L59
van de Rydt, F., Demers, S., & Kunkel, W. E. 1991, AJ, 102, 130
Yahil, A., Tammann, G. A., & Sandage, A. 1977, ApJ, 217, 903