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AN UPPER LIMIT ON THE H I CONTENT OF THE CARINA DWARF SPHEROIDAL GALAXY

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ABSTRACT

Neutral hydrogen 21 cm measurements of the Carina dwarf spheroidal galaxy yield an upper limint on its H I content of $\sim 10^3\ M_\odot$. For $(M/L) \sim 30$, this translates into an upper limit of 10^{-4} on its fractional H I content. It is possible that Carina has efficiently cleansed itself of gas because red giant wind velocities are of the order of the escape velocity. It is then interesting to ask how Carina retained its gas for the first few billion years of its existence.
Subject headings: galaxies: interstellar matter — stars: winds

I. INTRODUCTION

Physically small and intrinsically faint elliptical galaxies are known as dwarfs. The smallest and faintest of these are referred to as dwarf spheroidal galaxies. Eleven galaxies define the class. Eight of these are satellites of the Milky Way. They are known by the names of their host constellations: Draco, Ursa Minor, Carina, Leo I and II, Sextans, Sculptor, and Fornax. Three more are satellites of M31.

The dwarf spheroidal companions of the Milky Way have an interesting dual character. On the one hand, a galaxy such as Ursa Minor has a color-magnitude diagram almost indistinguishable from that of a Galactic globular cluster. On the other, there are systems like Carina in which there is a considerable stellar population of intermediate age. The other five dwarf spheroidals are a blend of these characteristics—some more like Ursa Minor, others more like Carina. The fraction of the light in each galaxy that comes from a population of age between 1 and 10 billion years ranges from 5% for Sculptor up to 70% for Carina (Aaronson 1985*a*, *b*). Indicators of an intermediate-age population include the presence of asymptotic giant branch carbon stars, anomalous Cepheid variable stars, and an overluminous main-sequence turnoff. These aspects are reviewed by Da Costa (1988).

Stringent upper limits have been set on the mass of neutral hydrogen in six of the seven local dwarf spheroidal galaxies (Knapp, Kerr, and Bowers 1978). These upper limits are $\sim 10^4\ M_\odot$ for Fornax and Leo I and II. For Sculptor, the data show a small positive perturbation[2] in the baseline at the now accurately known heliocentric velocity (107 km s^{-1}). The upper limits on H I in Draco and Ursa Minor are much lower: 68 and 280 $M_\odot$, respectively.

The Carina dwarf spheroidal is of special interest, however. An extended star formation history calls for gas retention over a long period. The large intermediate-age population of the Carina dwarf makes it the best candidate for a dwarf spheroidal with an interstellar medium. Our upper limit on neutral hydrogen in Carina is reported in this *Letter*.

II. 21 CENTIMETER OBSERVATIONS

The measurements were made with the Parkes 64 m telescope on 1990 February 8. In conjunction with a wide-band horn feed, the telescope has a half-power beamwidth of 15′ and a sensitivity of 0.63 K Jy^{-1} at 1420 MHz. The Parkes 1024 channel one-bit autocorrelation spectrometer (Ables *et al.* 1975) was configured to produce a 10 MHz (256 channel) band for each polarization centered at 230 km s^{-1}. The velocity resolution after Hanning-smoothing was 16.5 km s^{-1}.

The galaxy (R.A. $6^h40^m.4$, decl. $-50°55'$, epoch 1950) was observed for 8 × 5 minutes, alternately with 8 × 5 minutes on a reference sky location 5 minutes of time east of that position under conditions of optimum baseline stability. The separation on the sky of the reference and signal beams was 47′, which should be compared with a tidal radius of 33′ (Demers, Beland, and Kunkel 1983) or 47′ (Godwin 1985) and a core radius of approximately 10′ from the same references.

Flux density calibration was performed using the sources PKS 0915−118 (Hydra A) and PKS 1934−638 by assuming flux densities of 43.5 Jy and 16.4 Jy, respectively. The calibrated 21 cm spectrum of Carina from 115 to 485 km s^{-1} heliocentric velocity is shown in Figure 1. A zero-order baseline, fitted to the data outside the velocity range of the Galaxy and Carina, has been subtracted. Local hydrogen is seen strongly in the difference spectrum at zero velocity and extends as far as $v = 200$ km s^{-1}. However, neutral hydrogen in Carina, whose stellar velocity is 227.9 ± 2.7 km s^{-1} with a dispersion of 8.8 km s^{-1} (Godwin and Lynden-Bell 1987; Seitzer *et al.* 1990), is absent at the level of the baseline noise in the spectrum.

The neutral hydrogen flux integral between 210 and 250 km s^{-1} is $FI = -0.106 \pm 0.096$ Jy km s^{-1}, which is consistent with a nondetection. The error of 0.096 is calculated from $\sigma(FI) = \sigma_v \Delta v N^{1/2}$, where σ_v is the rms flux density error in the rest of the line-free region of the spectrum (7.4 mJy), Δv is the channel spacing (8.2 km s^{-1}), and N is the number of

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[2] If this detection is real, Sculptor may contain $\sim 1.3 \times 10^5\ M_\odot$ of neutral hydrogen. Recent observations we have made at Parkes suggest there is local hydrogen at this velocity, however.

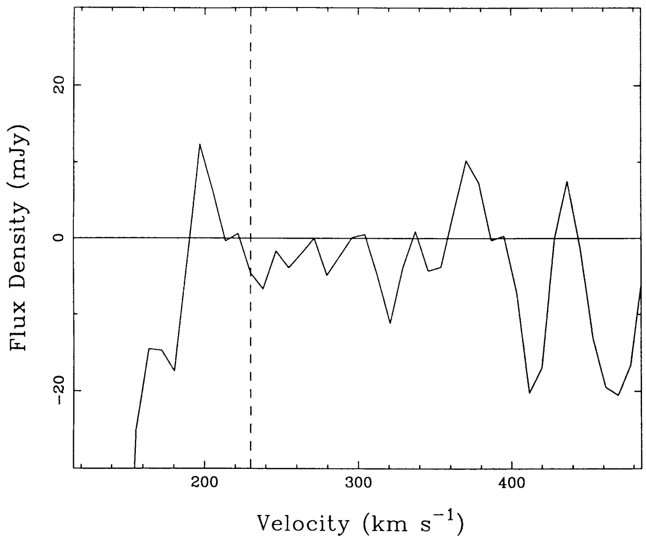

FIG. 1.—Flux density at 21 cm in the location of the Carina dwarf spheroidal galaxy. The optical absorption line velocity of the galaxy is indicated by the vertical dashed line. The velocity zero point is heliocentric.

resolution elements between 210 and 250 km s^{-1} (2.4) (strictly speaking the ratio of the integrated bandwidth to the noise-equivalent bandwidth.) Thus, our 2 σ upper limit is $FI < 0.192$ Jy km s^{-1}, or $F_{\rm H} < 4.5 \times 10^4\ M_\odot$ Mpc^{-2}. Assuming that the projected spatial distribution of any H I present is the same as for the stars, that is a core radius of about 10′ and an ellipticity of $1 - a/b = 0.4$, we estimate a beam correction factor for H I in the core of approximately 2.1. Our limit for the total amount of H I flux coming from the core, with velocities between 210 and 250 km s^{-1}, is therefore $F_{\rm H} < 9.4 \times 10^4\ M_\odot$ Mpc^{-2}, which corresponds to an upper limit to the H I mass of 1040 $M_\odot$ for a distance of 105 kpc (Saha, Monet, and Seitzer 1986). The total mass of the Carina galaxy itself remains uncertain. If we adopt a value of $10^7\ M_\odot$ which lies between the extremes in the literature (Seitzer *et al.* 1990; Aaronson 1985*b*), the upper limit on the fractional H I content of Carina is 10^{-4}.

III. THE INTERSTELLAR MEDIUM

For an old stellar population, the rate of mass return to the interstellar medium from dying stars is 0.015 $M_\odot$ yr^{-1} per $10^9\ L_{B\odot}$ of old stars (Faber and Gallagher 1976). This follows from the observation that intermediate- and low-mass stars end up as 0.6 $M_\odot$ white dwarfs, releasing their envelopes sooner or later to the interstellar medium. This rate is only weakly dependent on the age of the population and almost independent of the initial mass function (Renzini and Buzzoni 1986). Provided the evolutionary endpoints are the same, Population II systems will behave the same way as Population I, although the stellar evolutionary clock runs 14% slower in a very low metallicity system (Renzini 1978). With an absolute visual magnitude of -9.2 (Seitzer and Frogel 1985), Carina should be growing an ISM at the rate of $6 \times 10^{-6}\ M_\odot$ yr^{-1}. Were the gas to cool and recombine, it would reach the present limit of detection in 2×10^8 yr.

What happens to this gas? Is this the gas that fuels ongoing star formation in dwarf galaxies? Mould and Aaronson (1983) show a color-magnitude diagram for Carina with some stars which could be as young as 1×10^9 yr. There is no evidence for stars as young as 2×10^8 yr, although a burst of star formation of $10^3\ M_\odot$ and a normal IMF would produce only a few main-sequence stars at the magnitude of the horizontal branch, which would be difficult to detect.

What seems a more likely fate for this gas, however, is its escape from Carina in a steady wind. If the mass of Carina is mostly in the form of stars, virial considerations dictate that the escape velocity for material from Carina is twice the velocity dispersion of the stars. The outflow velocity in late-type giants ranges from 5 to 25 km s^{-1} in the sample of Knapp and Morris (1985), while Cohen (1976) shows evidence of material escaping from a Population II red giant star at up to 45 km s^{-1}. It follows that Carina is likely to be in a state where some or all of its interstellar medium is steadily flowing out of the galaxy. For a spherically symmetric wind blowing at 10 km s^{-1}, a simple calculation yields a steady state estimate of less than 150 $M_\odot$ of neutral hydrogen within a 15′ beam, well below the limits of detection. The wind hypothesis, of course, shifts the problem of Carina's interstellar medium to the detection of ionized gas, because colliding stellar winds could thermalize the material. Most of the gas would then remain ionized, as the recombination rate is much slower than the mass-loss rate. The present observations, however, limit only the quantity of neutral material, and we conclude that a steady wind is capable of circumventing this limit effectively, whether the wind is neutral or ionized.

The susceptibility of the ISM of the Carina galaxy to mass loss from red giant envelopes, however, poses a problem for our current understanding of the star formation history of Carina. The evidence that there is an old population in Carina is hard to ignore. The RR Lyrae stars detected by Saha, Monet, and Seitzer (1986) are not seen in intermediate-age populations (cf. the cluster Kron 3 in the SMC). Subgiants from an old population together with main-sequence stars of intermediate age have been confirmed by Mighell (1989) and Mateo and Nemec (1990). So, if Carina is now cleansed of an ISM by red giant winds, how did it retain after its initial burst of star formation (accompanied by supernova-driven winds with larger explosive velocities) an ISM capable of fueling a second major burst of star formation? According to Silk, Wyse, and Shields (1987), initially stripped dwarf galaxies may later undergo gas infall and regeneration (see also Dekel and Silk 1986 for some other possibilities.) To explore such a complex history of star formation and gasdynamics, better observational constraints on the age of Carina's stellar populations are desirable, together with a determination of their relative proportions.

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