DISCOVERY OF AN EXTREMELY METAL–POOR GALAXY:
OPTICAL SPECTROSCOPY OF UGCA 292

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ABSTRACT

The results of optical spectroscopy of two H II regions in UGCA 292 (CVn I dwA) are presented. UGCA 292 is a nearby (D=3.1 Mpc) gas–rich dwarf irregular galaxy (M_H/L_B ~ 6.9) which was first discovered in a blind H I survey. The derived oxygen abundance is the third lowest of known star–forming galaxies [12 + log(O/H) = 7.30 ± 0.05], making UGCA 292 one of the nearest metal–poor galaxies known. The derived N/O ratio is similar to that found in other low metallicity galaxies [log(N/O) = −1.47 ± 0.10], and is indicative of a primary origin for nitrogen. The derived oxygen abundance is consistent with closed–box chemical evolution for this low mass galaxy. The observed blue colors, high gas mass fraction, and low metallicity suggest that UGCA 292 is relatively unevolved. The possibility that future blind H I surveys may yield similar low metallicity galaxies is discussed.

Subject headings: galaxies: abundances — galaxies: dwarf — galaxies: evolution — galaxies: individual (UGCA 292)

1. INTRODUCTION

In standard galaxy evolution models, the relative abundances of the elements increase as a function of time, as stars convert pristine (primordial) material into enriched material (e.g., Tinsley & Larson 1978; Chiappini, Matteucci, & Gratton 1997). It is thus of interest to identify extremely low metallicity galaxies at both high– and low–redshift, since these galaxies may be “young,” i.e., galaxies which have not processed much of their gas (e.g., Searle & Sargent 1972; Izotov & Thuan 1999; Kunth & O¨stlin 1999, and references therein).

In addition, low metallicity galaxies provide a unique opportunity to determine the relative abundances of elements in pristine, unevolved, gas, and thus provide critical constraints on big bang nucleosynthesis (e.g., Pagel et al. 1992; Mathews, Boyd, & Fuller 1993; Olive, Steigman, & Skillman 1997; Izotov et al. 1999). However, despite concerted efforts over the last three decades to find nearby galaxies with metallicities similar to I Zw 18 (1/52th of solar), only three other extremely low metallicity star–forming galaxies have been found with [12 + log(O/H)] < 7.35: SBS 033–052 (1/44th of solar, Izotov et al. 1990; Melnick, Heydari–Malayeri, & Leisy 1992), Leo A (1/38th of solar, Skillman, Kennicutt, & Hodge 1989; van Zee, Skillman, & Haynes 2000), and HS 0822+3542 (1/38th of solar, Kniazev et al. 2000). This Letter reports the identification of another nearby metal–poor dwarf irregular galaxy, UGCA 292 (CVn I dwA).

UGCA 292 was observed as part of an on–going survey of elemental abundances in nearby dwarf irregular galaxies (van Zee & Haynes, in prep). Many surveys for low metallicity galaxies target high surface brightness, “star bursting,” dwarf galaxies, in part because their bright H II regions make them easier to identify (e.g., Kunth & Sargent 1983; Terlevich et al. 1991; Masegosa, Moles, & Campos–Aguilar 1994; Thuan et al. 1995). An alternative approach, and the one adopted here, is to focus on extremely low luminosity galaxies, regardless of their current star formation rate (e.g., Skillman et al. 1988; Skillman, Kennicutt, & Hodge 1989; Skillman, Terlevich, & Melnick 1989). The drawback of this approach is that the H II regions tend to be fainter, and thus require significantly longer integration times (or larger aperture telescopes) to reach an acceptable signal–to–noise ratio in the weaker lines. Since the H II regions tend to be faint, Hα imaging observations are a necessary precursor to spectroscopic observations so that the slit can be positioned appropriately. Thus, the present survey for low metallicity galaxies focusses on a subset of the isolated dwarf galaxy sample described in van Zee (2000a), since deep Hα images are readily available. As one of the lowest luminosity galaxies in the imaging sample, UGCA 292 was an obvious target for spectroscopic observations.

UGCA 292 was first discovered by Lo & Sargent (1979) during a search for intergalactic H I clouds in nearby groups of galaxies. UGCA 292 has an extremely low central surface brightness of 27.44 mag arcsec–2 (Makarova et al. 1998) and is only marginally visible on the POSS plates. It is a member of the Canes Venatici cloud, and a distance of 3.1 Mpc has been derived from photometry of its brightest blue stars (Makarova et al. 1998). It has an apparent blue magnitude of 16.10 (M_B = −11.43) and is extremely blue, with a luminosity weighted B–V of 0.08 (Makarova et al. 1998). UGCA 292 has a current star formation rate of 0.0019 M⊙ yr−1, which is typical of the dwarf irregular class (van Zee 2000b). With an integrated H I flux of 17.60 Jy km s−1, corresponding to a neutral hydrogen mass of 4 × 10^7 M⊙ (Young, van Zee, & Lo 2000), UGCA 292 is gas–rich. If UGCA 292 continued to form stars at the present rate, it would take approximately 20 Gyr to deplete the current gas supply. In addition, the derived M_H/L_B of 6.9 is unusually high for a dwarf galaxy,

1Adopting a solar oxygen abundance of 12 + log(O/H) = 8.93 (Anders & Grevesse 1989).
and is comparable to DDO 154 (Hoffman et al. 1993) and H I 1225+01 (Salzer et al. 1991).

Given its low luminosity, blue colors, and relative gas–richness, UGCA 292 was one of the best candidates in the Hα imaging sample to be a low metallicity galaxy. The results of optical spectroscopy of two H II regions in this low luminosity galaxy are presented in this Letter.

![Fig. 1.— Hα image of UGCA 292. The two HII regions are labelled, and the positions and orientations of the spectroscopic slits are shown.](image)

2. SPECTROSCOPIC OBSERVATIONS

Optical spectroscopy of two brightest H II regions in UGCA 292 were obtained with the Double Spectrograph on the 5m Palomar telescope on 2000 January 31; the observations consisted of three 1200 second exposures centered on each H II region (Figure 1). Since the H II regions were not visible on the guider camera, the long slit (2′) was centered on a nearby star and then moved to the H II region. To minimize the effects of atmospheric differential refraction, the observations were conducted near transit and the 2″ wide slit was oriented East–West to match the parallactic angle. The observations of UGCA 292–1 began shortly before transit; the airmass was 1.00 during all three exposures. UGCA 292–2 was observed post–transit when the parallactic angle was 83°; the airmass increased from 1.01 to 1.07 during the observations.

Complete spectral coverage from 3600–7600 Å was obtained by using a 5500 Å dichroic to split the light into two beams (blue and red). The blue camera was equipped with a 600 l/mm diffraction grating while the red camera was equipped with a 316 l/mm grating. Both sides of the spectrograph were equipped with thinned 1024 × 1024 Tek CCDs, with gains of 2.0 e−/ADU and read noises of 8.6 e− (blue) and 7.5 e− (red). The effective spectral resolutions were well matched between the two sides, with a resolution of 5.0 Å (1.72 Å/pix) on the blue side and 7.9 Å (2.47 Å/pix) on the red side. The spatial scale of the long slit was 0.62″/pix on the blue and 0.48″/pix on the red side.

The spectra were reduced and analyzed with the IRAF3 package. The spectral reduction included bias subtraction, scattered light corrections, and flat fielding with both twilight and dome flats. The 2–dimensional images were rectified based on the arc lamp observations and the trace of stars at different positions along the slit. One dimensional spectra of the H II regions were extracted from the rectified images using a 3″ extraction region (slightly larger than the seeing disk at the time of the observation). Relative flux calibration was obtained by observations of standard stars from the list of Oke (1990). Since the night was non–photometric, only the standard stars observed contiguous to the UGCA 292 observations were used to generate the sensitivity function. The optical spectra are shown in Figure 2.

![Fig. 2.— Optical spectra of H II regions in UGCA 292; the major lines are marked. Note the weakness of [NII], which clearly indicates that these H II regions are metal–poor.](image)

3. RESULTS

Derivation of oxygen and nitrogen abundances for the H II regions followed the methods described in van Zee et al. (1998). The reddening along the line of sight to each H II was derived from the observed line strengths of the Balmer emission lines. Since the derived reddening correction is formally zero, the emission line ratios tabulated in Table 1 are the observed line ratios; however, the quoted errors in the emission line ratios include the uncertainty associated with the reddening correction. In addition, while the line ratios for the higher order Balmer lines indicate that there may be as much as 2 Å EW of underlying stellar absorption in UGCA 292–2, the tabulated values do not include a correction for stellar absorption; application of such a correction has only a minor effect on the derived oxygen and nitrogen abundances.

The temperature sensitive line [OIII] λ4363 was de-
ected in both H II regions, so the electron temperature could be determined directly using the emissivity coefficients from a version of the FIVEL program (De Robertis, Dufour, & Hunt 1987). The derived electron temperatures are high, but are similar to those found in other low metallicity galaxies (e.g., Skillman & Kennicutt 1993; Skillman et al. 1994; Thuan et al. 1995). The derived oxygen and nitrogen abundances for the H II regions are listed in Table 1. The derived oxygen abundances are similar for both H II regions, indicating that the overall oxygen abundance in UGCA 292 is 7.30 ± 0.05, or 1/42 of solar. That is, UGCA 292 has an oxygen abundance which is comparable to those of SBS 0335-052 (Izotov & Thuan 1999) and Leo A (Skillman, Kennicutt, & Hodge 1989; van Zee, Skillman, & Haynes 2000), and only slightly higher than that of I Zw 18 (Skillman & Kennicutt 1993). In contrast to SBS 0335-052 and I Zw 18, both UGCA 292 and Leo A are relatively nearby galaxies with only moderate star formation rates.

Table 1

| Ionic Species | Rest Wavelength (μm) | UGCA 292-1 | UGCA 292-2 |
|---------------|----------------------|-------------|-------------|
| [OIII]        | 3728                 | 0.834 ± 0.003 | 0.503 ± 0.022 |
| [OIII]        | 4959                 | 0.832 ± 0.008 | 0.715 ± 0.011 |
| [OIII]        | 4363                 | 0.038 ± 0.007 | 0.043 ± 0.008 |
| [OIII]        | 4959                 | 1.000 ± 0.026 | 1.000 ± 0.027 |
| [OIII]        | 5007                 | 0.492 ± 0.014 | 0.584 ± 0.017 |
| [OIII]        | 5007                 | 1.441 ± 0.003 | 1.341 ± 0.004 |
| [OII]         | 6563                 | 0.011 ± 0.002 | 0.010 ± 0.002 |
| [NII]         | 6563                 | 2.600 ± 0.000 | 2.668 ± 0.003 |
| [NII]         | 6563                 | 0.030 ± 0.003 | 0.021 ± 0.003 |
| [NII]         | 6678                 | 0.022 ± 0.002 | 0.030 ± 0.003 |
| [SII]         | 6736                 | 0.053 ± 0.003 | 0.031 ± 0.003 |
| [SII]         | 6730                 | 0.039 ± 0.003 | 0.024 ± 0.003 |
| [ArIII]       | 7136                 | 0.019 ± 0.002 | 0.028 ± 0.003 |

As one of the two nearest low metallicity galaxies, UGCA 292 provides a unique opportunity to investigate the evolutionary status of gas-rich, metal-poor galaxies in the local universe. A fundamental issue is whether these galaxies represent a population of “young” galaxies, which are undergoing their first episode of star formation at the present epoch. Based on the relative enrichment of oxygen and nitrogen, Izotov & Thuan (1999) argue that metal-poor galaxies are extremely young, with absolute ages less than 40 Myr. However, it is also possible that metal-poor galaxies have faint old stellar populations, but appear to be relatively unevolved because their previous star formation rates were extremely low (e.g., Legrand et al. 2000). Clearly, detailed star formation histories of metal-poor galaxies are necessary to resolve this issue, but most of the starbursting galaxies are too distant to make such an analysis feasible. However, the H II regions in UGCA 292 have similar N/O abundances log(N/O) = -1.46 ± 0.10 as the star bursting dwarf galaxies in Izotov & Thuan (1999), and UGCA 292 is close enough to us that its stellar population should be well resolved by the Hubble Space Telescope. Thus, future resolved stellar photometry of UGCA 292 will provide an important test of the hypothesis that all low metallicity galaxies are young.

An additional concern may be whether the observed elemental abundances in metal-poor galaxies are representative of the chemical evolution which has taken place. For instance, an extremely low mass galaxy may not retain its enriched materials if supernovae ejecta have sufficient kinetic energy to escape the shallow gravitational potential well (e.g., Dekel & Silk 1986; Mori et al. 1997; Sillich & Tenorio-Tagle 1998; Mac Low & Ferrara 1999). In particular, mass loss of enriched material through supernovae “blow-out” may be important for starbursting galaxies, where multiple supernovae can significantly disrupt the interstellar medium (e.g., Martin 1998; D’Ercole & Brighenti 1999). On the other hand, for galaxies with more moderate star formation activity, such as UGCA 292, mass loss is less likely to occur.

To determine if enriched gas outflow has occurred in UGCA 292, the expected metallicity for a simple closed-box approximation was calculated from the observed luminosity and gas content:

\[ Z = y \ln \left( \frac{1}{\mu} \right) \]

where \( y \) is the elemental yield and \( \mu \) is the gas mass fraction, derived from the total baryonic mass. Adopting a stellar mass-to-light ratio of 0.35 and an oxygen yield of 2/3 solar, appropriate for a Salpeter IMF, the predicted closed-box abundance is 12 + log(O/H) = 7.28, in remarkable agreement with the observed abundance. Thus, it appears that UGCA 292 has not lost a significant fraction of its enriched material, and that the low oxygen abundance is representative of the chemical evolution of the galaxy.

4. DISCUSSION

Of a total sample of 25 low luminosity galaxies (van Zee et al. 1996; van Zee, Haynes, & Salzer 1997; van Zee & Haynes, in prep), UGCA 292 was the only extremely low metallicity galaxy that was not previously identified as such. Other surveys of starbursting dwarf galaxies have shown how difficult it is to find metal-poor galaxies (e.g., Terlevich et al. 1991), so the low success rate of this survey was not unexpected. Nonetheless, it is discouraging to note that galaxies of lower luminosity than UGCA 292 were included in the sample, yet no other extremely metal-poor galaxies were found. In particular, if the luminosity-metallicity relation is valid on all mass scales (as indicated by Skillman, Kennicutt, & Hodge 1989; Zaritsky, Kennicutt, & Huchra 1994; Richer & McCall 1995), low luminosity galaxies should have been ideal metal-poor candidates. While a certain amount of scatter may be introduced into the luminosity-metallicity relation as a result of poorly determined distances, it is interesting to note that, with the exception of UGCA 292, all of the extremely low luminosity galaxies observed for this project are relatively gas-poor, and their observed metallicities are higher than predicted from the luminosity-metallicity relation of Skillman, Kennicutt, & Hodge (1989). This suggests that the apparent luminosity-metallicity relation may be a result of selection effects. Most of the galaxies which have measured oxygen abundances are gas-rich, and are actively...
forming stars (i.e., H II regions exist). That is, aside from their luminosity (mass), their other physical parameters (gas mass fraction, surface brightness, etc.) are very similar. Galaxies which are gas-poor at the present time, i.e., galaxies which have processed a large fraction of their materials, are usually excluded from emission-line metallicity studies since it is very difficult to obtain an accurate oxygen abundance for galaxies with faint (or non-existent) H II regions. With the exception of UGCA 292, the other low luminosity galaxies observed for this project appear to have processed a large fraction of their baryonic material, and thus may have enriched their interstellar medium beyond that predicted by the gas-rich luminosity-metallicity relation.

Thus, an ideal survey for low metallicity galaxies should not only target low luminosity galaxies, but should also require that the galaxies be gas-rich, in order to increase the probability that they are relatively unevolved. While it is unlikely that there are many more nearby previously identified galaxies which are metal-poor (like UGCA 292), a viable approach may be to identify new gas-rich galaxies from H I surveys of the local universe. There are several blind H I surveys currently underway that should yield interesting targets for future spectroscopic observations (e.g., Zwaan et al. 1997; Spitzak & Schneider 1998; Banks et al. 1999; Webster et al. 1999). The fact that UGCA 292 was first discovered in such a survey is also suggestive that this may be an efficient means to identify additional metal-poor galaxies.

5. CONCLUSIONS

The results presented here, and those from other surveys, indicate that there are a few galaxies in the local universe which have very low, almost primordial, oxygen abundances. The observed oxygen abundance in UGCA 292 is the third lowest of known star forming galaxies and is consistent with a simple closed-box chemical evolution model. The observed N/O ratio is similar to those found in other low metallicity galaxies, and is consistent with a primary origin for nitrogen in extreme low metallicity galaxies. The identification of another metal-poor galaxy in the nearby universe suggests that there may be several relatively unevolved galaxies at the present epoch. However, the question of whether some dwarf galaxies are “young,” undergoing their first episodes of star formation, is still open. A conclusive answer to this question may be obtained from future observations of the resolved stellar population in UGCA 292.

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