ULTRAVIOLET INTERSTELLAR ABSORPTION LINES TOWARD THE STARBURST DWARF GALAXY NGC 1705

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ABSTRACT
Archival Goddard High Resolution Spectrograph (GHRS) low-resolution spectra of NGC 1705, with wavelength ranges of 1170.3–1461.7 Å and 1453.5–1740.1 Å and a velocity resolution of ~120 kms⁻¹, have been used to derive the velocity structure and equivalent widths of the absorption lines of Si ii λλ1190.42, 1260.42, λλ1304.37, and λ1526.71, S ii λ1253, Al ii λ1670.79, and Fe ii λ1608.45 in this sight line. Three relatively narrow absorption components are seen at LSR velocities of ~20 kms⁻¹, 260 kms⁻¹, and 540 kms⁻¹. Arguments are presented to show that these absorption features are interstellar rather than stellar in origin on the basis of a comparison with the C iii λ1175.7 absorption feature. We identify the ~20 kms⁻¹ component with Milky Way disk and halo gas and the 260 kms⁻¹ component with an isolated high-velocity cloud, HVC 487. This small HVC is located ~10° from the H i gas that envelops the Magellanic Clouds and the Magellanic Stream (MS). The Si/H ratio for this HVC is greater than 0.6(Si/H)₀, which with velocity agreement suggests association with the Magellanic Cloud and MS gas.

Hα emission line kinematics of NGC 1705 show the presence of a kiloparsec-scale expanding supershell of ionized gas centered on the central nucleus with a blueshifted emission component at 540 kms⁻¹. We identify the 540 kms⁻¹ absorption component seen in the GHRS spectra with the front side of this expanding, ionized supershell. The most striking feature of this component is strong Si ii and Al ii absorption but weak Fe ii absorption. The low Fe ii column density derived is most likely intrinsic since it cannot be accounted for by ionization corrections or dust depletion.

Because of their shallow gravitational potential wells, dwarf galaxies have small gravitational binding energies and are vulnerable to large mass losses from strong winds driven by the supernovae from the first generation of stars. Galactic winds from dwarf galaxies occur at timescales less than 10⁸ yr, which is less than the timescale required to produce Type Ia supernovae. Consistent with our observations, shells produced by galactic winds are expected to be enriched with Type II supernova products like Si, Al, and Mg and should be deficient in the products of Type Ia supernovae, like Fe and iron-peak elements.

Subject headings: galaxies: evolution — galaxies: individual (NGC 1705) — galaxies: ISM — galaxies: starburst — ISM: abundances — ultraviolet: ISM

1. INTRODUCTION
NGC 1705 is a nearby, H i-rich dwarf galaxy with a systemic heliocentric velocity of 628 ± 9 kms⁻¹ derived from the peak of the H i profile, which corresponds to vLSR = 610 kms⁻¹ (Meurer et al. 1992, hereafter MFDC). Hα continuum-subtracted images are striking: NGC 1705 is dominated by major loops and arcs that have been cataloged from the Hα continuum-subtracted images of NGC 1705 is dominated by extended loops of Hα emission (see Fig. 2 of MFDC). The continuum image shows a major axis extent of ~40° and a minor axis extent of 20°, while the Hα loops extend beyond 40° in the direction perpendicular to the minor axis. At least eight major loops and arcs have been cataloged from the Hα images by MFDC and are reminiscent of H i supershell structures seen in our Galaxy (Heiles 1990). A superstellar cluster NGC 1705A, with a mean spectral type B3V, is present in the center of the galaxy (Melnick, Moles, & Terlevich 1985). The presence of the extended H i loops and the central superstellar cluster point to the existence of a supernova-driven galactic wind in NGC 1705.

Previous studies with the IUE revealed the presence of prominent absorption lines in the ultraviolet spectrum of NGC 1705, which York et al. (1990) argued were of an interstellar origin. However, the data were at the sensitivity limit of IUE, and so we have used better quality spectra in the Hubble Space Telescope (HST) archive to reinvestigate their nature. As we shall show, the features are indeed (predominantly) interstellar in origin and can be identified with three separate environments, namely, gas in our Galaxy, in NGC 1705 itself, and in a probable Magellanic Stream (MS) cloud near the sight line. The large velocity range inherent in the absorption lines explains why they were so prominent in the lower resolution IUE spectra. Discovery of the MS component was unexpected. However, our most intriguing result concerns the component attributed to NGC 1705, which shows an underabundance of Fe compared with Si, S, and Al. We discuss this underabundance in the context of supernova-driven galactic wind evolution of dwarf galaxies.

2. THE DATA
Two GHRS spectra of NGC 1705 taken through the small science aperture with the G140L grating were retrieved from the HST data archives: the first extending from 1170.3 to 1461.7 Å and the second from 1453.5 to 1740.1 Å. The observations were made on 1994 November 12 and obtained with a comb addition of 4 to reduce detector fixed-pattern noise. The shorter wavelength spectrum (filename Z2J70107T) has an exposure time of 1196.8 s, while the other
The NGC 1705 sight line intercepts a region that is approximately 10° away from the outermost H I contour that envelops both the Large and Small Magellanic Clouds (Mathewson & Ford 1984). We checked the southern 21 cm survey of high-velocity gas between −650 and 650 kms$^{-1}$ by Bajaja et al. (1985) for H I gas at velocities corresponding to any of the UV absorption components. These authors reported the detection of an isolated cloud HVC 487 at (l, b) = (258°03, −39°15) and $v_{LSR}$ = 232 kms$^{-1}$, which is only ∼2° away from the sight line to NGC 1705. We attribute the 260 kms$^{-1}$ absorption component to the isolated HVC. Since this H I survey has a spectrum (filename Z2JTO109T) has an exposure time of 2393.6 s. The spectra were reduced with the standard pipeline software available in the STSDAS high-resolution spectrograph (HRS) package together with the most recent calibration files. Individual wavelength calibration (WAVECAL) exposures were taken before the science exposures and, since no FP-SPLIT was used, the ZWAVCAL task was used with the WAVEOFF task to give an average wavelength offset value and improve the wavelength calibrations. For the G140L grating, the dispersion is 0.57 Å per diode, which corresponds to a velocity resolution of ∼140 kms$^{-1}$ at 1200 and ∼100 kms$^{-1}$ at 1700. The wavelength accuracy is ∼40 kms$^{-1}$. The signal-to-noise ratio ($S/N$) in the continuum ranges from ∼7:1 at 1670 Å to 16:1 at 1400 Å. There is good velocity agreement between the galactic component of the Si II 1190 and λ1526 lines present in separate spectra, which suggests that the relative velocity scales of the two G140L spectra are consistent. The continuum is smooth and slowly varying, and spectra were normalized by fitting low-order polynomial functions.

Both spectra show complex, multicomponent absorptions from all the common interstellar species. Table 1 contains the ion name, vacuum wavelength ($\lambda_{vac}$), oscillator strength, measured equivalent widths (EWs) and their uncertainties, and the $S/N$ in the continuum. The equivalent width uncertainties quoted include contributions from the continuum-placement uncertainties and noise. We have performed an iterative, nonlinear least-squares fit to the observed profiles (see Blades et al. 1997). Figure 1 shows the continuum-normalized profiles of the Si ii, C III, S II, Fe ii, and Al ii absorption lines plotted as histograms against LSR velocity, with model fits plotted as continuous lines. Other species are seen in the spectra, including C i, C i*, O i, Si iv, and C iv. A detailed line list and atlas of UV absorption lines for the NGC 1705 sight line will be published elsewhere.

### 3. DISCUSSION

#### 3.1. Interstellar Origin of the Absorption Lines

York et al. (1990) considered the prominent absorption they found in NGC 1705 to be interstellar. The superior HST data are compelling on this point. First of all, we note that the C III λ1175.7 absorption feature is broad (EW = ∼1.8 Å) and centered at ∼620 kms$^{-1}$, close to the LSR velocity recession of NGC 1705. This C III absorption feature, commonly seen in spectra of OB stars, is a photospheric line and originates from the massive stars in the central superstar cluster NGC 1705A.

The Si ii λ1526.71 absorption is unaccompanied by Si ii λ1533 and must be interstellar (Walborn et al. 1995). This line has three narrow components: a strong feature centered at −20 kms$^{-1}$, a relatively weak feature centered at 260 kms$^{-1}$, and a strong feature centered at 540 kms$^{-1}$. The other lines in Figure 1 show a similar velocity structure. Their velocities are not consistent with the systemic velocity of NGC 1705, nor do any of the profiles show asymmetric or P Cygni shapes characteristic of stellar mass loss. Hence, apart from the C III feature, we can attribute the other lines to an interstellar origin without ambiguity. In the next section we discuss where the individual components arise.

#### 3.2. Curve-of-Growth Analysis

We have performed a curve-of-growth (cog) analysis for the three components at −20 kms$^{-1}$, 260 kms$^{-1}$, and 540 kms$^{-1}$ and obtained best-fitting $b$-values of ∼25 kms$^{-1}$, ∼50 kms$^{-1}$, and ∼30 kms$^{-1}$, respectively. Details of the cog analysis will be presented elsewhere. Only lines with optical depth at the center of the line, $\tau_{c} \leq 1$ in Table 1, were used for column density determinations; stronger lines provide lower limits. We note that the three components have large $b$-values compared with those of single, cold components seen in the ISM and must be due to successive overlapping components. In our analysis we are interested only in the contribution to the column density from the large $b$-value components.

#### 3.3. Origin of the Absorption Features

We attribute the absorption feature centered at −20 kms$^{-1}$ to Milky Way disk and halo gas. This component shows strong Si ii, Fe ii, and Al ii absorption and relatively weak S ii absorption.

### 3.3.1. The 260 kms$^{-1}$ Feature

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NGC 1705 is known to have strong outflows of gas: MFDC found the Hα and [O III] λ5007 Å nebular emission lines to be double peaked with a separation of ≈100 kms\(^{-1}\) over most of the face of the galaxy. The kinematics of the ionized gas are best represented by a homogeneously expanding ellipsoidal shell and are plotted in Figure 14 of MFDC. The blueshifted emission component of this kiloparsec-scale expanding super-shell is at 540 k.ms\(^{-1}\), the \(v_{\text{LSR}}\) velocity of our UV absorption feature.

The most interesting property of this 540 k.ms\(^{-1}\) supershell component is strong Si II and Al II absorption but relatively weak Fe II absorption. We find that \(N(\text{Si II}) \approx 7.9 \times 10^{14}\) cm\(^{-2}\), \(N(\text{S II}) = 9.1 \times 10^{14}\) cm\(^{-2}\), \(N(\text{Fe II}) = 2.5 \times 10^{14}\) cm\(^{-2}\), and \(N(\text{Al II}) \approx 1.5 \times 10^{14}\) cm\(^{-2}\). The Si/S for this component is \(\approx 0.4\) (Si/S)\(\odot\), which suggests low dust depletion in this supershell component. For the 540 k.ms\(^{-1}\) component, ionization corrections cannot explain the observed low Fe II column density because both Al and Fe have similar ionization potentials for the ionization \(X^2\rightarrow X^1\) (18.83 and 16.16 eV, respectively), and both Al and Fe have small cross sections for this ionization stage. Further, using the mean spectral type of B3V (Melnick et al. 1985) for the central superstar cluster NGC 1705A, the photoionization code CLOUDY (Ferland 1993), and a plane-parallel slab cloud with solar metallicity, we estimate that Al II/Al III > 500 and Fe II/Fe III > 50. We conclude that the presence of gas in unobserved stages of ionization is not a significant factor. Second, dust depletion can not explain the low Fe abundance. Al and Fe have similar condensation temperatures (Jenkins 1987), similar first ionization potentials (5.99 and 7.87 eV, respectively), and similar logarithmic gas-phase depletion in the diffuse ISM, with \(D(\text{Fe})\) and \(D(\text{Al})\) ranging between −3.0 and −1.0 (Barker et al. 1984; Jenkins 1987; Savage & Sembach 1996). Moreover, in a given cloud with an overall level of depletion, the change in element-to-element depletion is less than 0.16 dex and significantly less than the element-to-element variation (Joseph 1988; Welty et al. 1997). The logarithmic depletion factor \(D(X) = \log (X/S) - \log (X/S)_{\odot}\) for the supershell component is \(D(\text{Fe}) = -0.87\), which should be equal to \(D(\text{Al}) \pm 0.16\), making the \(\tau_{\odot}\) for the Al II line significantly lower than what is observed (Table 1). The low Fe II column density for the 540 k.ms\(^{-1}\) cloud must therefore be intrinsic. We have illustrated this point further by using the N(S II) for the 540 k.ms\(^{-1}\) component and solar Fe/S to estimate the column density, \(N\), for the same \(b\)-value. This estimated profile is plotted in long-dashed lines in Figure 1 over the Fe II \(\lambda 1608\) profile. The column density estimated in this manner is a greater by a factor of \(\approx 10\) than the observed Fe column density. Unfortunately, the \(\lambda 1608\) line is the only Fe line in the spectra, and it will be extremely important to reobserve this sight line to confirm whether the other Fe lines show this underabundance.

3.4. Gas Expelled from NGC 1705 through Supernova-driven Galactic Winds—An Overabundance of \(\alpha\)-Process Elements?

Could overabundance of Al, Si, and S and \(\alpha\)-process elements with respect to iron-peak elements (Fe, Cr, and Zn) in the gas expelled from a dwarf galaxy by a supernova-driven galactic wind explain the weak Fe II line? Larson (1974) has argued that dwarf galaxies, because of their shallow gravitational potential wells, have small binding energies and are vulnerable to huge mass losses through winds driven by...
supernova explosions from the first generation of star formation. Dekel & Silk (1986) have shown that galaxies with velocity dispersions less than 100 km s$^{-1}$ would lose much of their gas because of strong galactic winds. Galactic winds from dwarf galaxies (with total mass $\sim 10^{11} M_\odot$) occur at timescales less than 10$^8$ yr (Nath & Chiba 1995), which is less than the time required to produce Type Ia supernovae (SNs; Wheeler, Sneden, & Truran 1989). Type Ia SNs, which produce nearly 2/3 of the Fe and iron-peak elements (Truran & Bunkert 1993) cannot contribute to the metallicity of this gas, which has been produced by the first generation of stars and expelled from the dwarf galaxy. Shells produced by galactic winds are therefore expected to be enriched with Type II supernova products like Si and Al and deficient in Fe and other iron-peak elements that are produced mainly by Type Ia supernovae. The underabundance of Fe for the supershell component in the GHRS spectra is consistent with this interpretation.

In addition, the 540 km s$^{-1}$ absorption component in the UV spectra provides evidence that superwinds from dwarf galaxies could account for some types of QSO absorption lines, as suggested by York et al. (1986). Further HST Space Telescope Imaging Spectrometer observations of other strong Fe and iron-peak element lines and $\alpha$ elements in wavelength ranges $\lambda 1750$–$\lambda 3000$ (not covered by our GHRS spectra) would be extremely useful in confirming this result.

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