AN Accurate Distance to HIGH-velocity Cloud COMPLEX C

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ABSTRACT

We report an accurate distance of \( d = 10 \pm 2.5 \) kpc to the high-velocity cloud Complex C. Using high signal-to-noise ratio Keck HIRES spectra of two horizontal-branch stars, we have detected Ca \( \text{ii} \) absorption lines from the cloud. Significant nondetections toward a further three stars yield robust lower distance limits. The resulting \( \text{H} \text{i} \) mass of Complex C is \( M_{\text{H} \text{i}} = 4.9^{+2.9}_{-2.2} \times 10^6 \) \( M_\odot \); a total mass of \( M_{\text{tot}} = 8.2^{+4.6}_{-2.6} \times 10^6 \) \( M_\odot \) is implied, after corrections for helium and ionization. At 10 kpc, Complex C has physical dimensions \( 3 \times 15 \) kpc, and if it is as thick as it is wide, then the average density is \( \log(n) \approx -2.5 \). We estimate the contribution of Complex C to the mass influx may be as high as \( \approx 0.14 \) \( M_\odot \) \( \text{yr}^{-1} \).

Subject headings: Galaxy: evolution — Galaxy: halo — ISM: clouds — ISM: individual (Complex C)

Online material: color figure

1. INTRODUCTION

The halo of the Milky Way (MW) contains clouds of neutral hydrogen (\( \text{H} \text{i} \)) gas representing the flow of baryons into, and out of, the Galactic disk. Identified by their velocities, these high-velocity clouds (HVCs)\(^5\) have been observed in \( \text{H} \text{i} \) 21 cm emission for more than 40 years (Muller et al. 1963). Since their distances cannot be determined by the application of a kinematic model, the mass scale of the flow is uncertain, and the clouds’ origin and impact on the disk are open to speculation.

Since their discovery, many explanations have been offered for the HVC phenomenon, with a corresponding range of distances; most of these explanation can be traced to Oort (1966). One possible origin for some HVCs is a supernova-driven Galactic fountain, in which gas is expelled from the disk into the halo, condenses out of the hot MW halo (Maller & Bullock 2004; Sommer-Larsen 2006; Peek et al. 2008), and hence do not corotate with the Galaxy.

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6.7–11.2 kpc. Here we employ high-quality Keck spectra to determine the most accurate measurement of $d$ for Complex C to date.

2. DATA

Five horizontal-branch stars from the catalog of Sirko et al. (2004) that align with Complex C were observed with the High Resolution Echelle Spectrometer (HIRES; Vogt et al. 1994) on the Keck I telescope on 2007 June 8 and June 9 (UT). We employed the UV cross-disperser to maximize throughput at Ca II K (3933.633 Å) and binned the data 2× in the spatial direction. In this configuration, the Na I D lines are within our wavelength coverage, but are at the extreme edge of the order. The $7'' \times 0.8''$ slit yielded a resolution of $R \approx 48,000$. Over the course of the two nights, the seeing varied from $\sim 1.2''$ to $1.8''$, but we nevertheless obtained excellent quality data. Table 1 summarizes our targets. For these stars, stellar parameters were obtained using the techniques described in Wilhelm et al. (1999). Absolute magnitudes and distances for the stars were determined by comparing $T_{	ext{eff}}$, $\log g$, and [Fe/H] to the run of theoretical isochrones of Girardi et al. (2004) and Dorman (1992); distances are given in the text and in Table 4. External tests of the stellar technique against stars in globular clusters indicate that distances are accurate to $\sim 25\%$ (R. Wilhelm et al. 2008, in preparation). We thus adopt a $25\%$ error as our formal distance error; in all cases, this error is greater than that estimated from the stellar classification, sometimes significantly. Continuing calibration efforts of the Segue Stellar Parameter Pipeline (Lee et al. 2008) should improve this accuracy in the future.

To reduce the data, we used the HIRES Redux pipeline (R. Bernstein et al. 2008, in preparation), which is distributed as part of the xidl package. The package applies standard bias and flat-field corrections, performs a two-dimensional wavelength calibration, and extracts the individual orders to give final one-dimensional spectra and associated errors. For equivalent width measurements, we fit the local continuum with a low-order Legendre polynomial and directly integrate the data, determining error contributions from both the noise and continuum fitting (Sembach & Savage 1992). In general, the HVC Ca II H (3968.467 Å) line is in the wings (and in some cases in the core) of the broad stellar He I (3970.072 Å) line. The He I line is sufficiently broad that it completely dominates the echelle order, and the true continuum cannot accurately be determined. Since we care only about the HVC Ca II H line, we fit a pseudocontinuum along the Balmer line wing, where possible, removing its contribution to the absorption.

H I spectra were primarily drawn from the combined Leiden/Argentina/Bonn (LAB) survey, which has a beamwidth of $\sim 36''$ (FWHM; Kalberla et al. 2005). In one case (S441; see Table 1), an H I spectrum from Effelsberg (9′ beam) is available. Heliocentric radial velocities (RVs) for all five stars were determined by fitting the positions of unblended metal lines in the echelle data. These are also given in Table 1. In most cases $\sim 30$ or more lines were available, but for S139, only 12 unblended metal lines are available in our Keck spectrum. Errors on RVs are the 1σ Gaussian dispersion of the ensemble of measured lines.

Using the absorption-line technique, upper or lower distance limits are placed on the distance to the HVC gas, based on the detection or nondetections of absorption lines due to the gas in the spectrum of stars at known distance. The technique is described in detail elsewhere (Schwarz et al. 1995; Thom 2006); Figure 1 of Schwarz et al. (1995) is particularly enlightening. Since the stars must lie at known (or knowable) distances, horizontal-branch and RR Lyrae stars are the most commonly used, but in principle, any hot star at known distance may be used; hot stars are desirable, to reduce the number of metal lines in the stellar spectrum, which may confuse the HVC absorption. In order to maximize the probability of optical detection, strong resonance transitions are the most appropriate. In the optical, Ca II H and K are the most common, but the Na I D lines may also be used (see, e.g., Thom et al. 2006). Strong UV transitions such as O I have also been used (Danly et al. 1993), and with the scheduled installation of the Cosmic Origins Spectrograph on the upcoming Hubble Space Telescope (HST) servicing mission, Mg II may also prove useful.

3. RESULTS

In the following subsections, we discuss the individual lines of sight, first for the detections, then for the nondetections. We consider the upper distance limits that are set by the detections, and the lower distance limits that can be set by the nondetections. Finally, we summarize our results, both in tabular and pictorial form.

3.1. Detections

S437, $d \sim 11$ kpc.—Toward the star S437 two HVC emission components can be seen in the H I spectrum available from the LAB survey (Fig. 1), at $v_{\text{LSR}} = -115$ km s$^{-1}$ and $-165$ km s$^{-1}$, with corresponding column densities $N$(H I) = $2.1 \pm 0.3$ and $(1.5 \pm 0.4) \times 10^{19}$ cm$^{-2}$. The HVC emission component at $-115$ km s$^{-1}$ is clearly evident in absorption at Ca II K, but the corresponding Ca II H line is lost in the core of the He Balmer line. Since the HVC feature falls in the very core of the He line, we do not attempt to fit the continuum to the Balmer line wings. The HVC component at $-165$ km s$^{-1}$ is lost in the strong stellar Ca II lines. Emission and absorption at $v_{\text{LSR}} = -56$ km s$^{-1}$ from

| Target | $l$ (deg) | $b$ (deg) | $m_0$ (mag) | S/N | $v_{\text{helio}}$ (km s$^{-1}$) | Distance (kpc) | Label |
|--------|-----------|-----------|-------------|-----|----------------|----------------|-------|
| SDSS J173424.01+601735.3 | 89.1 | 32.8 | 15.9 | 60 | $-482.6 \pm 1.4$ | 12.8 \pm 3.2 | S135 |
| SDSS J172009.78+612502.3 | 90.6 | 34.4 | 14.7 | 100 | $-322.3 \pm 3.3$ | 7.8 \pm 2.0 | S139 |
| SDSS J150355.53+623513.5 | 100.7 | 48.4 | 15.6 | 60 | $-201.2 \pm 2.5$ | 11.3 \pm 2.8 | S437 |
| SDSS J153915.24+575731.7 | 91.2 | 47.5 | 15.9 | 80 | $-14.4 \pm 1.5$ | 10.2 \pm 2.6 | S441 |
| SDSS J133654.82+622241.5 | 114.0 | 54.0 | 15.4 | 65 | 26.5 \pm 0.9 | 10.4 \pm 2.6 | S674 |

Note.—SDSS names are created from the right ascension and declination (J2000.0) of the object, truncating coordinates. Galactic coordinates have been rounded to 0.1°. Magnitudes are extinction-corrected g band, taken from the SDSS database. Signal-to-noise measures are given for the continuum region near Ca II K. For convenience, we label each star with a number, corresponding to its numerical position in the catalog of Sirko et al. (2004).
the intermediate-velocity cloud (IVC) known as the “IV arch” can also be seen. This cloud is known to be nearby (0.4 kpc < z < 3.5 kpc; Ryans et al. 1997).

**S674, d ~ 10 kpc.**—The optical spectra of S674, shown in Figure 2, provides a second detection toward the high-latitude part of Complex C. Absorption is detected from Complex C at \( v_{LSR} = -127 \) km s\(^{-1}\), setting an upper distance limit. We also detect the nearby IV arch at \( v_{LSR} = -48 \) km s\(^{-1}\) and the MW disk in absorption. Note that we have fitted the Ca \( \equiv K \) continuum along the wing of the stellar He \( \equiv \) Balmer line, removing it from Figure 2. The falloff in the continuum redward of \( v_{LSR} = 100 \) km s\(^{-1}\) in the Ca \( \equiv \) K line is where the Balmer line transitions from wing to core; since we use only a low-order polynomial and do not attempt to match the entire Balmer line profile, the fit breaks down in this region.

We clearly detect multiple absorption components in the optical spectra that do not always align well with the H \( \equiv \) emission positions. This is present in both the HVC absorption, as well as the IVC and disk gas. Since the H \( \equiv \) data sample 36’ on the sky, while the optical data trace a pencil beam, this may be a consequence of beam smearing. An interferometer map would be required to confirm this. Note, however, that in all cases, the optical absorption falls within the line limits defined by the H \( \equiv \) data.

**3.2. Nondetections**

**S441, d ~ 10 kpc.**—At roughly the same latitude as our two detections and only ~28’ from the Mrk 290 sight line, this line of sight has the most complicated optical spectrum. Figure 3 shows both the optical and radio spectra. Note that for this sight line, the H \( \equiv \) spectrum comes from the Effelsberg telescope, which has a substantially smaller beam than the coarse resolution of the LAB survey.

The optical data in the Ca \( \equiv \) K region show an absorption line slightly to the red (\( v_{LSR} = -125 \) km s\(^{-1}\)) of where we expect the HVC absorption to lie (\( v_{LSR} = -140 \) km s\(^{-1}\)). This line is not HVC absorption, but rather a Ti \( \equiv \) line at a rest wavelength of 3932.020 Å (Meggars et al. 1976). This identification is made based on several factors. First, in the stellar rest frame, a fit to this line only impinges on the wing of the expected HVC Ca \( \equiv \) K absorption to lie (\( v_{LSR} = -140 \) km s\(^{-1}\)). This line is not HVC absorption, but rather a Ti \( \equiv \) line at a rest wavelength of 3932.020 Å (Meggars et al. 1976). This identification is made based on several factors. First, in the stellar rest frame, a fit to this line only impinges on the wing of the expected HVC Ca \( \equiv \) K absorption. Second, the strength of this line is consistent with other Ti \( \equiv \) lines in the spectrum of S441 with similar ionization potential and log \( g_f \). Finally, the strength of this line is \( W_{\lambda} = 25.9 \pm 1.4 \) mÅ. If this was an HVC Ca \( \equiv \) K absorption line that was offset from the H \( \equiv \) profile, the corresponding Ca \( \equiv \) H line would be 13 mÅ. The noise level in the Ca \( \equiv \) K region [\( \sigma(W_{\lambda}) = 2.5 \) mÅ] is low enough that we would detect any HVC absorption at the 5 \( \sigma \) confidence level. We can thus exclude this possibility.

Since the stellar Ti \( \equiv \) line only impinges on the wing of the expected HVC Ca \( \equiv \) K absorption and is well fit by a single Gaussian component, it does not diminish our ability to detect any putative HVC absorption line. Figure 4 shows the result of this fit. We include the strong stellar Ca \( \equiv \) K line and a very weak unidentified line at rest wavelength 3932.25 Å (\( v_{LSR} = -106 \) km s\(^{-1}\)). Both these latter features are well outside the region of interest for HVC absorption. The lower panel shows the residual of the
fit. The expected HVC position is marked by the solid line, while the dotted lines mark the \( \pm 2 \sigma \) line width limits (where \( \sigma \) is the Gaussian width of the H\textsc{i} spectrum). We emphasize that only the high quality of our Keck data allows us to cleanly remove the stellar absorption from the wing of the putative HVC region and place a significant lower distance limit on the cloud.

Since the S441 sight line is very close to the Mrk 290 sight line, this significantly strengthens the conclusions that can be drawn from the nondetection of both Ca\textsc{ii} and Ca\textsc{ii} H, since we can be confident of the level of HVC absorption expected. The worst-case expected HVC absorption toward this line of sight is 38 m\( \text{A} \) (Ca\textsc{ii} H) and 19 m\( \text{A} \) (Ca\textsc{ii} H); both these would be clearly visible. Section 3.4 contains further discussion on the interpretation of nondetections.

S135, \( d \sim 13 \) kpc.—The two stellar probes S135 and S139 are both a few degrees from the edge of Complex C (See Fig. 7), at lower latitude than our earlier targets. For S135, our most distant target, we see no indication of HVC absorption, as shown in Figure 5. Unrelated IVC gas can clearly be seen in both H\textsc{i} and K\textsc{ii} emission at \( v_{\text{LSR}} = -77 \) km s\(^{-1}\) in both Ca\textsc{ii} H and K. This IVC gas can be seen in the LAB data cube to connect smoothly with the Galactic plane at lower latitudes. Although it is not shown in Figure 5, we also see this IVC in the Na\textsc{i} D doublet line, which is the stronger of the two Na\textsc{i} D doublet lines. The lack of HVC absorption sets a lower distance limit of 12.8 \( \pm 3.2 \) kpc.

S139, \( d \sim 8 \) kpc.—The optical spectra of S139 are our highest signal-to-noise data. Figure 6 shows that there is clearly no absorption detected corresponding to the strong HVC emission. The Ca\textsc{ii} H position is at the very core of the H\textsc{II} Balmer line, but the Ca\textsc{ii} K data set a firm lower distance limit if 7.8 \( \pm 2.0 \) km s\(^{-1}\). The Galactic emission shows a broad emission wing at \( v_{\text{LSR}} \sim -50 \) km s\(^{-1}\); Ca\textsc{ii} K absorption components are also seen in this range. There is some evidence of IVC emission, with corresponding very weak absorption, in the range \( v_{\text{LSR}} = 70–100 \) km s\(^{-1}\), but better data are needed to confirm this. The lack of HVC absorption sets a lower distance limit.

3.3. Upper Distance Limits

Table 2 gives the results of the two detections of Complex C in absorption toward background stars. In this table, column (1) lists our target name. Stellar distances and measured H\textsc{i} column densities are given in columns (2) and (3), respectively. Column (4) gives the measured Ca\textsc{ii} equivalent width and its \( 1 \sigma \) error. Column (5) lists the corresponding column density for this equivalent width, \( N(\text{Ca\textsc{ii}}) \), assuming the gas is optically thin. Columns (3) and (5) are combined to give the ratio \( N(\text{Ca\textsc{ii}})/N(\text{H\textsc{i}}) \), which is sometimes called the “abundance” and denoted \( \delta(\text{Ca\textsc{ii}}) \). This is given in column (6). Both sight lines have the same Ca\textsc{ii} abundance to within errors and are also in good agreement with the values observed toward the QSO sight lines Mrk 290 and PG 1351+640, up to 20° away (see below). Such good agreement suggests that there are not large variations of the Ca\textsc{ii} abundance across the cloud.

3.4. Lower Distance Limits

Nondetections are harder to interpret than detections; one must be convinced that the lack of absorption is not a random confluence of bad luck. In general, one predicts the strength of the absorption that should be seen if the star is behind the gas by using the measured \( N(\text{Ca\textsc{ii}})/N(\text{H\textsc{i}}) \) ratio in the cloud and the H\textsc{i} absorption sets a lower distance limit.
which samples 36 which our pencil-beam optical or UV data is difficult, because unresolved both the above cited works have only 8 greater in cloud cores (Wakker et al. 2002) and also note that we refer the interested reader to the Appendix of Wakker (2001) this worst case are deemed "strong" or significant nondetections.

The predicted absorption strength is reduced by all these safety factors to obtain a worst-case absorption strength; only cases in which the noise level is less than this worst case are deemed "strong" or significant nondetections. We refer the interested reader to the Appendix of Wakker (2001) for a more complete discussion of all these effects.

The comparison of large-beam 21 cm measurements of \( N(\text{H} \ i) \) to pencil-beam optical or UV data is difficult, because unresolved small-scale structure can potentially introduce systematic errors. Our \( \text{H} \ i \) column densities are mostly taken from the LAB survey, which samples 36° of sky, or in one case, Effelsberg (9°). Both of these sources have significantly larger beams than the pencil beam of the optical data. This may be clearly seen, for example, in the spectra of S674 (Fig. 2), where the optical data show clear multicompontent absorption structure, yet the \( \text{H} \ i \) emission spectrum does not. Systematic uncertainties are therefore likely to be present, since the radio and optical spectra sample different areas on the sky.

No comprehensive study exists comparing \( N(\text{H} \ i) \) measured at a range of spatial scales toward a large number of sight lines. The best study is that of Wakker et al. (2001), who compared measurements at 36°, at 9°, and pencil-beam UV Ly\( \alpha \) measurements on six QSO and two stellar sight lines (only two toward Complex C). They concluded that most measurements at 9° are accurate to within about 25%, while the larger 36° beam gives an uncertainty of up to a factor of 3. This is in line with the results of Savage et al. (2000), who compared 10 UV Ly\( \alpha \) measurements of \( N(\text{H} \ i) \) to those of the 21' beam of the NRAO 43 m dish, finding that \( N(\text{H} \ i)_{\text{Ly} \alpha}/N(\text{H} \ i)_{\text{21 cm}} \) ranges between 0.62 and 0.91. Thus, we adopt a safety factor of 2\( \times \) for the S441, where 9° Effelsberg data are available. For the other sight lines, a safety factor of 3\( \times \) is warranted. We caution that variations may be still greater in cloud cores (Wakker et al. 2002) and also note that both the above cited works have only 8–10 Ly\( \alpha \) measurements of \( N(\text{H} \ i) \). Clearly, this is the most uncertain aspect of our results, and we are pursuing interferometer data (e.g., with the Allen Telescope Array (ATA)) for our sight lines.

Complex C shows little evidence of dust depletion (Collins et al. 2003), so we do not take into account depletion effects. In the ideal case, the gas-phase abundance toward the stellar sight line will be known from measurements of nearby extragalactic sight lines. This is the case for S441, which is very close (<0.5°) to the Mrk 290 sight line. For the S135 and S139 sight lines, however, we must take into account possible variations in gas metallicity and ionization conditions. Since Ca ii is not the dominant ionization stage of Ca in the interstellar medium (ISM) and HVCs, a safety factor of 2\( \times \) is included to account for this (Wakker 2001). Several authors have shown evidence that the metallicity of Complex C varies from one QSO sight line to another in the range 0.1–0.3 Z\(_{\odot} \), independent of ionization effects (e.g., Gibson et al. 2001; Collins et al. 2007). This may be a result of Complex C mixing with local enriched gas (Gibson et al. 2001; Tripp et al. 2003). Ca ii abundances have been measured toward only two sight lines: Mrk 290 [\( A(\text{Ca} \ ii) = 21 \times 10^{-9} \)] and PG 1351+640 [\( A(\text{Ca} \ ii) = 18 \times 10^{-9} \)] (Wakker et al. 1996; Wakker 2001). Mrk 290 is closest to the S135 and S139 sight lines, so we adopt the measured abundance and include a safety factor of 3\( \times \), line with the metallicity variations.

Table 3 provides a summary of the process used to determine the significance of the nondetections. Column (1) provides target name. Column (2) gives the stellar distance. The measured \( N(\text{H} \ i) \) toward the star is listed in column (3). Column (4) shows the predicted absorption equivalent width, \( W_{\text{equiv}} \). To calculate this value, we assume that the gas is optically thin and adopt \( A(\text{Ca} \ ii) = 21 \times 10^{-9} \). Column (5) lists the safety factor adopted, with column (6) giving the resulting strength of any putative absorption line, reduced by this safety factor. Column (7) lists the 1 e equivalent width error, integrating over a line width determined from the \( \text{H} \ i \) data. Finally, column (8) gives the significance of the nondetection. Following Wakker (2001), a significance greater than 1 is considered a "strong" lower distance limit, with values lower than 1 providing "weak" limits.

Table 3 shows that even under pessimistic assumptions, the excellent quality of the Keck data gives us confidence in our nondetections. For the sight line toward S441, the safety factor according to the above prescription is significantly smaller than the other two sight lines, since the \( \text{H} \ i \) column density is more accurately known, and the Ca ii abundance of the gas in this region is well measured. Nevertheless, a factor of 2\( \times \) is almost certainly too optimistic. In line with this concern, we include in Table 3 a second assessment of the significance of this nondetection, using the same 18° factor as for S135 and S139. Even in this scenario, any putative HVC absorption would still be detected. We conclude that all our nondetections provide strong lower distance limits to Complex C.

### 3.5. Summary of Results

We summarize our results in Table 4. This table gives the Galactic coordinates and stellar distances for each target and indicates whether the target provides an upper (U) or lower (L)
The stellar lines of sight are marked with star symbols in the diagram. Show the HVC detections, S437 and 674. Open circles in Figure 8. This figure shows the position of the gas in relation to the case of detections and crosses in the case of nondetections. The stars be surprising if the lower latitude, lower longitude parts of the complex were more distant, given the large angular size of Complex C. Observations at high latitudes of closer stars in the range 6–8 kpc and of more distant stars in the lower longitude, lower latitude regions are needed to substantiate this speculation. We stress that the ~25% distance accuracy is the current limit of stellar classification techniques for horizontal-branch stars and applies to all results; a systematic calibration effort is required to reduce this uncertainty.

4. DISCUSSION

For ease of discussion, we first consider Complex C to be at a uniform distance of 10 kpc. With such a large projected size, this is unlikely unless Complex C has a curved geometry. Using the total flux for Complex C (Wakker & van Woerden 1991), our distance limit implies a mass for Complex C of \( M = 4.91 \times 10^6 M_\odot \). To calculate the total mass, we include a factor of 1.4 to account for helium and an ionization fraction \( M_{\text{HI}} = 0.18 M_{\text{H}_\odot} \) (Wakker et al. 1999; Sembach et al. 2003). Since there is no indication of molecular gas (Murphy et al. 2000; Richter et al. 2001), we take \( M_{\text{HI}} = M_{\text{H}_\odot} \) and derive a total mass for Complex C of \( M_{\text{tot}} = 8.2 \times 10^6 M_\odot \).

For comparison, Complex C has an H I mass of order the mass that Lockman (2003) derived for Complex H by assuming that it is a satellite of the MW merging with the outer disk. Of the low-luminosity dwarf galaxies recently discovered in the Sloan Digital Sky Survey (SDSS; e.g., Willman et al. 2005a, 2005b; Belokurov et al. 2006, 2007), only Leo T has been shown to have associated neutral gas (Ryan-Weber et al. 2008); the H I mass of Complex C is more than an order of magnitude more than that of Leo T and is comparable to other local group dwarf irregulars, such as Pegasus, DDO 210, and LGS 3 (Mateo 1998). Complex C is also an order of magnitude more massive than the HVCs surrounding the M31/M33 system (Westmeier et al. 2005). Despite the large masses of neutral gas, a variety of searches have failed to find any evidence for an associated stellar content with any HVC (e.g., Willman et al. 2002; Simon & Blitz 2002; Siegel et al. 2005; Simon et al. 2006), and there is no evidence of a connection between Complex C and any dwarf galaxies.

The calculation of the mass flux onto the Galaxy that Complex C provides is hampered by our ignorance of the tangential velocity, which limits our ability to determine the vertical velocity with respect to the disk. We attempt to average over much of our ignorance by considering the average mass flow over the whole accretion timescale (i.e., the time it takes for the whole complex to accrete). The farthest gas from the plane, at highest latitudes, is at between \( b = 55^\circ \) and \( 60^\circ \). We choose a representative direction \((l, b) = (120^\circ, 58^\circ)\). At \( d = 10 \) kpc, this gas is ~8 kpc above the disk and has a line-of-sight velocity \( v_{\text{LSR}} = -126 \text{ km s}^{-1} \). To
Fig. 7.— Location of SDSS stellar targets with respect to H\textsc{i} emission of Complex C. Contours are drawn at log $N$(H\textsc{i}) = 18.2, 19.0, and 19.7.

Fig. 8.— Diagram showing the position of Complex C in relation to the Sun. The inner Galaxy is indicated by the dark region at the bottom. HVC detections are marked by full circles, nondetections by open circles. The positions of stellar targets projected onto the Galactic plane and 1 $\sigma$ distance error bars are also shown. Note that the shape of Complex C here is not an accurate depiction and is indicative only.
remove the disk rotation, we convert to deviation velocity, which is
the amount by which the gas deviates from a model of Galactic rotation (de Heij et al. 2002), giving \( v_{\text{dev}} = -105 \text{ km s}^{-1} \). We consider three cases. First, we assume that the tangential component of the velocity is equal to the radial component and consider both extremes, in which this tangential component is directed toward and away from the disk. This results in a range of vertical velocities \( v_z = -34 \) to \(-145 \text{ km s}^{-1} \), where the negative indicates a direction toward the disk. The case in which the motion is purely radial (i.e., no tangential component) is intermediate to these two extremes, having simply \( v_z = -105 \text{ sin } 58^\circ = -89 \text{ km s}^{-1} \). This range of velocities results in a range of accretion timescales 60–250 Myr and a corresponding mass flux in the range 0.03–0.14 \( M_\odot \text{ yr}^{-1} \). It is worth noting that Tripp et al. (2003) have argued that the lower latitude parts of Complex C show signs of interaction with the thick disk or lower halo.

The condensing-cloud model (Sommer-Larsen 2006; Peek et al. 2008) predicts \( \sim 0.2 \times 10^6 \) \( M_\odot \text{ yr}^{-1} \) of accretion coming from HVCs. Meanwhile, chemical evolution models require such infall to reproduce the observed metallicity distribution in the disk (Alibés et al. 2001; Fenner & Gibson 2003). The most recent calculations suggest an infall rate of \( \sim 0.1 \times 10^6 \) \( M_\odot \text{ yr}^{-1} \) about 5 Gyr ago, falling roughly to half that at the present epoch (Chiappini et al. 2001). Thus, Complex C may provide a substantial amount of the required mass flux on the Galaxy, although the question of how this H I is converted into stars remains.

Now that we have established the distance to Complex C, we can also attempt to put some constraints on physical parameters such as length scales and density. Clearly, the density will vary from sight line to sight line for a large, inhomogeneous structure like Complex C, and the numbers we derive here should be taken as indicative only. For a canonical distance \( d = 10 \text{ kpc} \), simple geometry implies a transverse scale factor \( \sim 0.175 \text{ kpc} \text{ deg}^{-1} \). If we take two representative points on the extreme edges of the cloud, \((l, b) = (90, 50)\) and \((110, 40)\), the maximum angular extent across Complex C is \( \theta \approx 17^\circ \), which corresponds to a physical distance \( L \approx 3.0 \text{ kpc} \). To assess the length of Complex C, we take the points \((l, b) = (30, 15)\) and \((130, 55)\), which correspond to a length \( \sim 15 \text{ kpc} \). Lower latitude and longitude gas is present, but its direct connection with Complex C is ambiguous, since it blends with disk emission. By comparison, the Magellanic Stream is approximately \( 10 \text{ kpc} \times 100 \text{ kpc} \) in size, with a mass of \( \sim 2 \times 10^6 \) \( M_\odot \), for an assumed distance of 55 kpc (Putman et al. 2003). If we further assume that the complex is as deep as it is wide, then the average density, \( \langle n \rangle \), along the line of sight may be computed. Toward the two stars that provide upper limits, S437 and S674, we then have \( \log n = -2.6 \) and \(-2.4 \), respectively.

5. CONCLUSION

We have used the presence and absence of Ca II K absorption in five stars aligned with the high-velocity cloud Complex C to derive a distance to the complex of \( 10 \pm 2.5 \text{ kpc} \). At high latitude, we detect HVC gas in absorption toward stars \( \sim 10 \) and \( \sim 11 \text{ kpc} \) away, setting upper distance limits. At similar latitudes, a nondetection provides a lower limit of \( \sim 10 \text{ kpc} \). Nondetections in stars at \( \sim 8 \) and \( \sim 3 \text{ kpc} \) at lower latitudes are consistent with this distance. Since the stellar distances are accurate to \( \sim 25\% \), a canonical distance of \( 10 \pm 2.5 \text{ kpc} \) is set, but we cannot exclude the possibility of a distance gradient, which would mean larger distances for lower latitude parts of Complex C. Indeed, such a distance gradient would be expected when one considers the large angular size of the complex.

The distance implies an H I mass for Complex C of \( M_\text{HI} = 4.9 \pm 2.3 \times 10^6 \). Applying corrections for helium and ionized gas yields total mass of Complex C \( M_{\text{tot}} = 8.2 \pm 2.6 \times 10^6 \) \( M_\odot \). We derive a mass inflow rate in the range 0.03–0.14 \( M_\odot \text{ yr}^{-1} \), with the uncertainty mostly coming from the unknown tangential velocity of Complex C. If there is no tangential velocity component, this inflow rate is \( \sim 0.1 \times 10^6 \) \( M_\odot \text{ yr}^{-1} \). Thus, Complex C may provide a significant fraction of the inflow rate predicted by the condensing-cloud model. At the measured distance, Complex C is some \( \sim 3 \text{ kpc} \) across, with an average density of order \( \log n = -2.5 \). Our accurate distance contributes to a picture in which the large HVC complexes are nearby Galactic objects, with many of them now known to be within \( d < 10 \text{–} 15 \text{ kpc} \) (van Woerden et al. 1999; Thom et al. 2006; Wakker et al. 2007, 2008). The question of whether the compact HVCs are part of this same population remains open, although condensation models place these small, isolated clouds at larger distances. With the first elements to a solution to the high-velocity cloud distance problem now well established, continuing efforts will provide a more complete census of neutral gas in the Milky Way halo.

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