Observations towards early-type stars in the ESO-POP survey: II – searches for intermediate and high velocity clouds

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ABSTRACT

We present Ca\textsc{ii} K and Ti\textsc{ii} optical spectra of early-type stars taken mainly from the UVES Paranal Observatory Project, plus H\textsc{i} 21-cm spectra from the Vila-Elisa and Leiden-Dwingeloo surveys, which are employed to obtain distances to intermediate and high velocity clouds (IHVCs). H\textsc{i} emission at a velocity of $-117$ km s$^{-1}$ towards the sightline HD 30677 ($l, b = 190.2^\circ, -22.2^\circ$) with column density $\sim 1.7 \times 10^{19}$ cm$^{-2}$ has no corresponding Ca\textsc{ii} K absorption in the UVES spectrum, which has a signal-to-noise ($S/N$) ratio of 610 per resolution element. The star has a spectroscopically determined distance of 2.7-kpc, and hence sets this as a firm lower distance limit towards Anti-Centre cloud ACII. Towards another sightline (HD 46185 with $l, b = 222.0^\circ, -10.1^\circ$), H\textsc{i} at a velocity of $+122$ km s$^{-1}$ and column density of $1.2 \times 10^{19}$ cm$^{-2}$ is seen. The corresponding Ca\textsc{ii} K spectrum has a $S/N = 780$, although no absorption is observed at the cloud velocity. This similarly places a firm lower distance limit of 2.9-kpc towards this parcel of gas that may be an intermediate velocity cloud. The lack of intermediate velocity (IV) Ca\textsc{ii} absorption towards HD 196426 ($l, b = 45.8^\circ, -23.3^\circ$) at a $S/N = 500$ reinforces a lower distance limit of $\sim 700$-pc towards this part of Complex gp, where the H\textsc{i} column density is $1.1 \times 10^{19}$ cm$^{-2}$ and velocity is $+78$ km s$^{-1}$. Additionally, no IV Ca\textsc{ii} is seen in absorption in the spectrum of HD 19445, which is strong in H\textsc{i} with a column density of $8 \times 10^{18}$ cm$^{-2}$ at a velocity of $\sim 42$ km s$^{-1}$, placing a firm although uninteresting lower distance limit of 39-pc to this part of IV South. Finally, no HV Ca\textsc{ii} K absorption is seen towards HD 115363 ($l, b = 306.0^\circ, -1.0^\circ$) at a $S/N = 410$, placing a lower distance of $\sim 3.2$-kpc towards the HVC gas at velocity of $\sim 224$ km s$^{-1}$ and H\textsc{i} column density of $5.2 \times 10^{19}$ cm$^{-2}$. This gas is in the same region of the sky as complex WE (Wakker 2001), but at higher velocities. The non-detection of Ca\textsc{ii} K absorption sets a lower distance of $\sim 3.2$-kpc towards the HVC, which is unsurprising if this feature is indeed related to the Magellanic System.

Key words: ISM: general – ISM: clouds – ISM: abundances – ISM: structure – stars: early-type
1 INTRODUCTION

The Paranal Observatory Project (POP; Bagnulo et al. 2003) provides a wealth of high-resolution \((R \sim 80,000)\) optical spectra towards stars mainly in the Galactic disc that can be used to study subjects such as stellar properties, kinematics and the interstellar medium. In a previous paper (Hunter et al. 2006, hereafter Paper 1) we used a sample of early-type stars in the POP survey in order to investigate the interstellar medium in the Na\textsc{i} UV, Ti\textsc{ii} and Ca\textsc{ii} K lines, using the stars as light sources to probe the material between the star and the Earth. Because these O- and B-type stars are often fast rotators with weak metal lines, they are ideal for probing narrow interstellar features.

In the current paper, we use mainly Ca\textsc{ii} and Ti\textsc{ii} spectra in order to search for Intermediate and High Velocity Clouds (IHVCs) towards the sightlines investigated in Paper 1, plus some additional sightlines for which high S/N data have now become available. Our aim is to improve the distances to these still enigmatic objects by searching for IHVCs in the Villa-Elisa Southern Sky 21-cm H\textsc{i} Survey (Bajaja et al. 2005) or Northern Hemisphere counterpart, the Leiden-Dwingeloo Survey (Hartmann & Burton 1997), and subsequently searching for corresponding absorption in the Ca\textsc{ii} or Ti\textsc{ii} optical spectra. Although the distance to many Intermediate Velocity Clouds (IVCs) is known (e.g. Kuntz & Danly 1996 and references therein), to date there are very few uncontroversial upper distance limits towards High Velocity Clouds (HVCs). Indeed towards the main complexes there are currently only three uncontroversial detections; towards Complex A (van Woerden et al. 1999), Complex M (Danly, Albert & Kuntz 1993) and Complex WB (Thom et al. 2006). Hence it is still unclear whether many of these objects are associated with the Galaxy, for example linked with a Galactic fountain with distances of \(\approx 10\) kpc (e.g. Quillis & Moore 2001), or are failed dwarf galaxies with distances of several hundred kpc (e.g. Braun & Burton 1999). Clearly, as the sample stars in the POP survey were not chosen \textit{a priori} to intersect with known HVC complexes, the majority of the sightlines do not cross known IHVCs. However, serendipitously a few of the sightlines intersect complexes and are studied in the current paper. In addition to the POP data, we include spectra from two recent high spectral resolution observing runs taken using the échelle spectrometer FEROS, plus further UVES observations whose primary aim was to obtain spectra for a stellar library but that are also at high S/N and cover the Ca\textsc{ii} K line (Silva et al. 2007).

The current work complements our previous studies in which we obtained improved distance limits towards IVC complexes gp and K and HVC complexes C, WA-WB, WE, and H (Smoker et al. 2004, 2006), by searching for absorption in high-resolution spectra of mainly B-type stars taken from the Edinburgh-Cape (Stobie et al. 1997) and Palomar-Green Surveys (Green, Schmidt & Liebert 1986). In particular the current sightlines intersect IVC Complex K with previous distance limit of 0.7–6.8-kpc (de Boer & Savage 1983, Smoker 2006), the Anti-Centre clouds with previous distance limit of >0.4-kpc (Tamanaha 1996) and Complex WE with distance limit <12.8-kpc (Sembach et al. 1991).

Finally, one of our current sightlines lies towards the M 15 intermediate velocity cloud lying in the IVC complex gp. This cloud has been studied extensively, in the optical to determine variations in velocity and equivalent width variations (Lehner et al. 1999, Meyer & Lauroesch 1999, Smoker et al. 2002), plus in the H\textsc{i}, infrared and H\alpha (Kennedy et al. 1998, Smoker et al. 2002). An improvement in the current distance limit of 0.8–4.3 kpc (Wakker 2001 and references therein) would be very useful to more accurately define the cloud parameters such as cloudlet sizes and densities and to provide clues to the high metallicity of this IVC (Little et al. 1994).

Sect. 2 describes the sample, provides a table noting the cases where the current sightlines cross known IHVC complexes plus new observations not previously described in Paper I, and shows the optical and H\textsc{i} spectra. Sect. 3 gives the main results, including the cases where the current optical sightlines intersect IHVCs and an attempt to obtain improved distance limits towards these clouds. Sect. 4 discusses the most interesting lower limits to IHVCs and finally Sect. 5 gives a summary of the main findings.

2 THE SAMPLE, OBSERVATIONS AND DATA REDUCTION

The list of sample stars is shown in Table 1. The table includes all stars for which new observations were taken, plus sightlines that lie towards IHVC complexes that are discussed in Sect. 4, but does not include the POP paper 1 objects that have no IHVC detection. Further information concerning the POP objects is given in Paper I. They are all O- and B-type stars with \(2.3 < m_v < 7.9\) mag. For these POP optical spectroscopic data, we used the on-line versions of reduced data from the Paranal Observatory Project (Bagnulo et al. 2003). These are spectra taken with the UVES échelle spectrometer mounted on the 8.2-m Kueyen telescope at the Very Large Telescope at a spectral resolution of 80,000 or \(3.75\) km\(s^{-1}\) and S/N pixel\(^{-1}\) ranging from 190–770. In this paper we concern ourselves with the Ca\textsc{ii} K (\(\lambda_{\text{air}}=3933.66\)Å) and Ti\textsc{ii} (\(\lambda_{\text{air}}=3883.76\)Å) species only. A further 9 stars were observed with FEROS on the ESO 2.2-m on La Silla during observing sessions in Oct. 2005 (FER1 in Table 1) and May 2006 (FER2 in Table 1). These stars are all B-type post-AGB stars or Planetary Nebulae and have fainter magnitudes than the POP stars, with 9.4 < \(m_v < 13.3\) mag. The S/N ratios pixel\(^{-1}\) at Ca\textsc{ii} K range from \(\sim 40–120\) and the resolution is \(R=48,000\). The spectra shown in this paper are the quick-look pipeline products. As a check of their reliability, during each of the FEROS runs a bright B-type star from the POP survey was observed and the velocities and equivalent widths of some of the absorption lines were compared between the two datasets. Agreement was found to be excellent. Finally, 12 stars were taken from the dataset of Silva et al. (2007; S07 in Table 1). These are UVES spec-
extra of early-type stars with $5.9 < m_V < 11.3$ mag., observed at a spectral resolution of $\sim 40,000$ with $S/N = 100$–620 pixel$^{-1}$, and were reduced using the ESO pipeline (MIDAS context) with calibrations taken the morning after the observations. For the H$\alpha$ 21-cm spectra, we used either the Southern Villa-Ehilda H$\alpha$ survey data (Bajaja et al. 2005), corrected for the effects of stray radiation or the Leiden-Dwingeloo survey for sightlines with Dec. $> -20^\circ$ (Hartman & Burton 1997). Both surveys have been merged to form the Leiden/Argentine/Bonn (LAB) H$\alpha$ line survey (Kalberla et al. 2005) which has a velocity resolution of 1 km s$^{-1}$ and brightness temperature sensitivity of 0.07 K.

In Table 1 the columns are as follows. Columns 1–5 give the star HD name, alternative name, Galactic coordinates and V-band magnitude taken from SIMBAD. Columns 6–7 give the estimated stellar distance and $z$-height above or below the Galactic plane. These distances were primarily estimated using the method of spectroscopic parallax from the spectral type, apparent magnitude and reddening to obtain the S/N per resolution element this needs to be taken from Schmidt-Kaler (1982) with colours from Wegner Absolute magnitudes as a function of spectral type were the signal-to-noise (S/N) ratio pixel magnitude calibration of our sample, the distances have an particular the Wolf-Rayet stars, peculiar objects and Post-AGB stars, distances were taken from the reference given at the foot of the table. For example for HD 179407 the distance is given as 7600$^\circ$ where the suffix refers to reference number 1 where the distance of 7600-pc was given. Column 8 gives the signal-to-noise (S/N) ratio pixel$^{-1}$ in the Ca$\Pi$ spectrum; to obtain the S/N per resolution element this needs to be multiplied by $\sqrt{2}$.

If the coordinate of the sightline lies within any of the figures of Wakker (2001) which display H$\alpha$ column densities towards IHVCs, this name is given in Column 9. We must stress that although more than 35 of our stars lie within the boundaries of these figures, often they are in regions where no IHVC is observed in H$\alpha$, for example because the stars lie in holes in the H$\alpha$ distribution. Columns 10 and 11 give the minimum and maximum expected LSR velocity for gas orbiting the Galactic Centre, based on the direction of the sightline and the distance to the stellar target. To calculate the velocity range for "normal" gas, we use the methodology of Wakker (1991), in that we assume a flat rotation curve with $v_{rot} = 220$ km s$^{-1}$ at $r > 0.5$ kpc, decreasing linearly towards the Galactic Centre, together with equations from Mihalas & Binney (1981). A deviation velocity for interstellar components occur.

3 RESULTS
In this section we discuss those cases where the stellar sightlines intersect with known IHVCs, and hence determine improved distance estimates towards a handful of objects.

Fig. 1 shows the optical and H$\alpha$ spectra towards the sightlines where a distance limit has been determined towards an IHVC. Fig. 2 (available online) shows the remaining sightlines. Two plots are shown for each sightline in order to emphasise both weak and strong features. The majority of the optical spectra are in the Ca$\Pi$ K line; where this was not available the Ti$\Pi$ line is shown. The horizontal line at the top of the first of the optical plots shows the extent of the full width half maximum of the stellar line. In most cases, these lines are wide, hence there is no possibility that stellar lines could be misidentified as interstellar features, which tend to be much narrower. If the stellar lines have a FWHM exceeding $\sim 100$ km s$^{-1}$ they were removed in the normalisation process to facilitate visualisation of the interstellar lines in all cases apart from HD numbers 115363, 136239 and 142758 where too much overlap of stellar and interstellar components occur.

3.1 Methodology of estimating distances to IHVCs
The method of estimating distances to IHVCs is discussed fully in Schwarz, Wakker & van Woerden (1995). For an upper distance limit, detection of optical absorption, in association with an H$\alpha$ detection, is sufficient to provide an upper distance limit, being the distance of the stellar probe. Lower distance limits are more problematic. A firm lower distance limit can only be set if no optical absorption is seen at a sufficient S/N ratio, the abundance of the optical element is known (generally from observations of the same part of the complex towards QSOs), and the H$\alpha$ column density is accurately defined using a pencil beam. For the current sample, the chemical abundance of the IHVC is often not known, and the observations in H$\alpha$ only have a spatial resolution of 0.5$^\circ$, which means that care must be taken in ascribing a lack of optical absorption as due to the stellar probe being closer than the IHVC. However, these factors are somewhat ameliorated by the fact that the optical spectra have high S/N, frequently being >500 per resolution element and with a median of 410 in the sightlines with a detected IHVC.

3.2 Distance limits towards individual complexes
A number of the current sightlines either intersect with known IHVC complexes, or have gas present at IHVC velocities in the Villa-Ehilda or Leiden-Dwingeloo H$\alpha$ spectra. These cases are discussed below, and lower distance estimates towards five IHVCs are determined. Table 2 summarizes these cases. Columns 1–6 gives the star name, stellar distance, previous IHVC distance limit, IHVC complex, observed H$\alpha$ velocity and corresponding log of the H$\alpha$ column density. Columns 7–8 give the previously-known abundance in Ca$\Pi$ taken from Wakker (2001) and limiting 5$\sigma$ Ca$\Pi$ column density estimated from the current spectra. This was derived using the observed S/N ratio and instrumental resolution, assuming the the optically thin approximation. Finally, column 9 gives the predicted Ca$\Pi$ column density de-
The Complex has LSR velocities of +1.1 km s\(^{-1}\) and brightness temperature integrals of 1.7 \pm 1 K km s\(^{-1}\), corresponding to a H\(\alpha\) column density of 1.1 \pm 0.2 \times 10^{19} cm\(^{-2}\). Although weak, this should have been detected in our UVES spectrum which has a S/N = 500 per resolution element. The star has a distance of 700-pc, which is similar to the distances for previous objects towards which there were non-detections. In Complex gp we also observed HD 179407 (l = 24.02\(^\circ\), b = -10.4\(^\circ\), distance = 7600-pc) at a S/N \text{pixel}^{-1} \approx 120 in Ca\(\Pi\) K. At the current position, there are two weak H\(\alpha\) velocity features, at v = +50\(\kms\) and v = +97\(\kms\) with FWHM values of 26\pm2 and 42\pm4 km\(\kms\) and brightness temperature integrals of 1.7\pm0.2 and 1.7\pm0.2 K km\(\kms\) respectively, corresponding to column densities of \approx 3 \times 10^{19} cm\(^{-2}\). There is obvious detection of Ca\(\Pi\) in the +50 \kms \text{ feature (as in the Ca\(\Pi\) spectrum of Sembach & Danks 1994)} but no detection of the v = +97 \kms \text{ feature, perhaps due to clumpiness in the H\(\alpha\) or ionisation issues; a higher S/N Ca\(\Pi\) spectrum would be useful. Given the weak nature of both H\(\alpha\) features a higher spatial-resolution and sensitivity H\(\alpha\) spectrum would be useful at this position although in any case the star lies at a distance exceeding the current upper limit of the cloud. Although HD 179407 was
Figure 1. Optical Ca ii K and 21-cm H i spectra towards early-type stars for which a lower distance limit towards an IHVC has been determined. Two plots are shown per sightline in order to emphasise weak features. Further details are given in the text.

Table 2. IHVC sightlines where H i is detected at intermediate or high velocities. Complex WEM is in the same part of the sky as complex WE of Wakker (2001), but at higher velocities. See Sect. 3.2 for details.

| Star     | d (pc) | d_{prev}^{HVC} (pc) | IHVC complex | \( v_{HVC}(H\text{ i}) \) km s\(^{-1} \) | \( \log(N_{HVC}(H\text{ i})) \) \( (\log(cm^{-2})) \) | \( A_{HVC}^{\text{H i}} \) (log(cm\(^{-2}\)) | \( \log(N_{\text{lim}}(Ca\text{ ii})) \) \( (\log(cm^{-2})) \) | \( \log(N_{\text{pred}}(Ca\text{ ii})) \) \( (\log(cm^{-2})) \) |
|----------|--------|---------------------|--------------|---------------------------------|---------------------------------|---------------------------------|---------------------------------|---------------------------------|
| HD 196426  | 700    | 800-4300            | gp           | +78                             | 19.06                           | -7.42                           | 10.20                           | 11.65                           |
| HD 179407  | 7600   |                     | gp           | +50                             | 18.49                           | -7.42                           | 10.60                           | 11.07                           |
| "         | "      | gp                  | +50          | 18.49                           | -7.42                           | 10.60                           | 11.07                           |
| HD 19445   | 39     | gp                  | +78          | 18.49                           | -7.42                           | 10.60                           | 11.07                           |
| "         | "      | gp                  | +78          | 18.49                           | -7.42                           | 10.60                           | 11.07                           |
| HD 30677   | 2700   | gp                  | +78          | 18.49                           | -7.42                           | 10.60                           | 11.07                           |
| HD 115363  | 3200   | gp                  | +78          | 18.49                           | -7.42                           | 10.60                           | 11.07                           |
| "         | "      | gp                  | +78          | 18.49                           | -7.42                           | 10.60                           | 11.07                           |
| HD 46185   | 2900   | Other               | +78          | 18.49                           | -7.42                           | 10.60                           | 11.07                           |

also observed in the FUSE spectrum by Zsargo et al. (2003), the presence of a complex stellar continuum meant that no interstellar O vi was observed. Finally, although EC 20485-2420 lies in the general direction of this complex, no H i is obvious in the Villa-Elisa spectrum.

3.2.2 IV South

IV South is a group of IVCs that extend over much of the southern sky, with velocities of \( \sim -85 \) to \(-45 \) km s\(^{-1}\). Towards HD 19445 \((l,b=-157.48^\circ, -27.20^\circ)\), no IV absorption is seen in the Ca ii spectrum at a S/N of 280 per resolution element, thus placing a rather uninteresting firm lower distance limit of 39-pc to this part of the IVC that has two components with \( v= -45 \pm 0.5 \) km s\(^{-1}\), \(-40.2 \pm 0.5 \) km s\(^{-1}\), FWHM values of \(8\pm 1\) km s\(^{-1}\) and \(22\pm 2\) km s\(^{-1}\), peak \( T_B \) values of \(2.1 \pm 0.2 \) K and \(1.2 \pm 0.2 \) K and brightness temperature integral of \(17 \pm 2 \) K km s\(^{-1}\) and \(28 \pm 3 \) K km s\(^{-1}\). The combined H i column density in these two features is \( \sim 8 \times 10^{19} \) cm\(^{-2}\) which should have been easily detected in the current optical spectrum if the cloud were closer than the star.
3.2.3 Complex K

Complex K is a Northern-Hemisphere cloud with LSR velocities ranging from ~65 to ~95 km s\(^{-1}\). Its previous distance bracket was ~700–6800-pc (Smoker et al. 2006 and refs. therein). One of our sightlines towards G169-28 (l,b=+41.83\(^\circ\),+36.06\(^\circ\)) lies in the general direction of Complex K, but no H\(^i\) emission is visible in the Leiden-Dwingeloo spectrum and there are many stellar lines. Thus the current observations do not add anything to our knowledge of this IVC.

3.2.4 Anti-centre HVCs

Seven of our sightlines lie in the region of the Anti-Centre HVC (Fig. 9 of Wakker 2001). No upper distance limit is available for this HVC and the previous lower-distance limit towards Cloud ACI is only 0.4-kpc (Tamanaha 1996). We only detect H\(^i\) at high velocity towards one of the current sightlines which lies towards ACII, namely HD 30677 at a velocity of ~117±1 km s\(^{-1}\), peak brightness temperature of 0.40±0.04 K, FWHM of 23±2 km s\(^{-1}\) and integrated brightness temperature of 9.5±1.0 K km s\(^{-1}\), corresponding to an HVC column density of 1.7±0.2×10\(^{19}\) cm\(^{-2}\). Assuming that the HVC has a similar abundance to the relation described by McLure-Griffiths et al. (2001). At a velocity of ~117±1 km s\(^{-1}\), putting an upper distance limit of 12.8 kpc. Eighteen of our sightlines lie within the general area of WE as defined in Fig. 11 of Wakker (2001). One of the sample stars HD 115363 (l,b=328.68\(^\circ\),−14.52\(^\circ\)) is detected towards this parcel of gas that lies within ~20\(^\circ\) of the Anti-Centre Shell (Fig. 8 of Wakker 2001) but is at different velocities and probably unrelated.

3.3 IHVCs detected in Ca\(^{ii}\) absorption

A number of sightlines were already flagged in Paper I as having IHVC components detected in the optical spectra. These include the Wolf Rayet stars HD 94910 and HD 163758 and the sightline HD 72067 which lies towards the Vela Supernova remnant. No H\(^i\) is detected towards any of these sightlines. In the first two cases this implies the presence of circumstellar lines and in the latter case lines within the SN remnant. Similarly, towards HD 171432 many IVCs are detected in the optical. This sightline lies towards the Scutum Supershell mapped in H\(^i\) by Callaway et al. (2000) and with a distance of ~3000-pc. Although towards HD 171432 there is a dearth of H\(^i\) detected in the Callaway maps, there is H\(^i\) in our H\(^i\) spectrum up to a velocity of ~90 km s\(^{-1}\), coincident with our detections of Ca\(^{ii}\). No H\(^i\) is seen in our highest-velocity Ca\(^{ii}\) component of ~120 km s\(^{-1}\), perhaps due to S/N limitations. The detections in Ca\(^{ii}\) and H\(^i\) are consistent with the supershell being closer than our stellar distance of ~4000 pc and with
the previous observations, but add nothing to the distance bracket.

4 DISCUSSION

Table 3 gives a summary of the distance limits to IHVCs set by the current observations, plus existing limits to the clouds where available. Particularly interesting is the improved lower limit towards part of the Anti-Centre complex ACII which has firm lower-distance limit of \(>2.7\)-kpc. This compares with the indirect distance estimate of a part of the complex at \(t \sim 60^\circ, b \sim 45^\circ\) derived from morphological and kinematical arguments of \(\sim 4\)-kpc (Peek et al. 2007), and an \(\mathrm{H}\alpha\) estimated distance of between 8 and 20-kpc (Weiner et al. 2001) which is based upon the observed ionisation being caused by the Galactic radiation field. Although a big improvement on the previous lower-distance limit of \(\sim 0.4\)-kpc (Tamanaha 1996), the current observations cannot discriminate between the indirectly-estimated distances and clearly searches for more distant probe stars in this part of the sky would be useful. Other less interesting results are the consolidation of the lower-distance limit towards complex gp and the first lower distance limit towards the WEM complex. The \(z\)-distance of the former IVC is now constrained to \(\sim 300\)-1700-pc which compares to the \(\mathrm{H}\) \(i\) massheight of \(<200\)-pc at Galactocentric radii of \(<10\)-kpc (Narayan, Saha & Jog 2005). Further progress on this sightline should involve performing obtaining a high-resolution spectrum of the star HD 357657 and associated model atmosphere calculation and abundance analysis. Although Smoker et al. (2006) estimated a distance of \(\sim 2.0\)-kpc for this object on the line of sight to Complex gp and found no associated Ca\(\text{ii}\) absorption, the distance of the star remains uncertain. If a firm lower distance limit of 2-kpc were confirmed, cloud parameters such as the clotud sizes, cloud electron density, fractional \(\mathrm{H}\) \(i\) to \(\mathrm{H}\) \(ii\) ratios and ionizing radiation field could be better constrained (c.f. Smoker et al. 2002), and the position of the cloud relative to the \(\mathrm{H}\) \(i\) disc of the Galaxy confirmed.

Finally, the lower distance limit of 3.2-kpc towards HVC WEM is consistent with both a Magellanic origin as proposed for example by Putman (2000), or a ‘classical’ high velocity cloud, \(\mathrm{H}\) \(i\) synthesis mapping towards other HVCs in this part of the sky (e.g. Bekhti et al. 2006) have provided evidence from cloud structure and linewidths of distances of \(\sim 10\)-60-kpc, consistent with a Magellanic origin, and the same observations could be performed for the present sightline in order to obtain an indirect distance estimate, perhaps in conjunction with \(\mathrm{H}\) \(\alpha\) mapping. However, in the absence of early-type stars present in the leading arm as present in the Magellanic Bridge (Rolleston et al. 1999), obtaining a firm upper distance limit will be difficult although perhaps possible due to the offset in velocity from the stellar and interstellar Ca\(\text{ii}\) K lines (c.f. Smoker et al. 2002).

5 SUMMARY

We have correlated optical spectra in the Ca\(\text{ii}\) K and Ti\(\text{ii}\) lines observed towards early-type stars in the POP Survey, plus other optical data, with 21-cm \(\mathrm{H}\) \(i\) spectra taken from the Villa-Elisa and Leiden-Dwingeloo Surveys, in order to determine the distances to Intermediate and High Velocity Clouds. The lack of Ca\(\text{ii}\) K absorption at \(\sim 117\) km s\(^{-1}\) towards HD 30677 at a \(S/N\) ratio of \(\sim 610\) has set a firm lower distance limit towards Anti-Centre cloud ACII which previously had a lower distance limit of 0.4-kpc. Likewise, towards HD 46185 no Ca\(\text{ii}\) K absorption at \(+122\) km s\(^{-1}\) is seen at a \(S/N\) ratio of \(\sim 780\), hence placing a lower distance limit of 2.9-kpc towards this gas that is perhaps an IVC. Towards Complex gp no Ca\(\text{ii}\) K absorption is seen in the spectrum of HD 196426 at a \(S/N\) of \(\sim 500\), reinforcing the assertion that this IVC lies at a distance exceeding 0.7-kpc. Likewise, towards the nearby star HD 19445 at 39-pc in the line of sight to IV South no Ca\(\text{ii}\) K absorption is seen setting a firm but uninteresting distance limit towards this part of the complex. Finally, no HV Ca\(\text{ii}\) K absorption is seen in the stellar spectrum of HD 115363 at a \(S/N\) of 410, placing a lower distance of \(\sim 3.2\)-kpc towards the IVC gas at velocity of \(\sim +224\) km s\(^{-1}\). This gas is in the same region of sky as the WE complex of Wakker (2001), but at higher velocities. If related to the Magellanic system (Putman 2000) then a distance limit of 3.2-kpc is not unexpected.

A future paper will describe the use of new FEROS observations combined with UVES archive data to provide improved distance limits to complex EP, the Cohen Stream, IV South and the Anti-Centre shell. Concerning the POP data, future papers will investigate the neutral species of Ca\(\text{ii}\), Fe\(\text{i}\), Na\(\text{ii}\) D and K\(\text{i}\) as well as molecular line species CH, CH\(^+\) and CN in order to better understand the local interstellar medium.

### Table 3. Distance limits and probe stars towards the IHVCs studied in this paper.

| IHVC   | \((l, b)\) | \(v_{\text{HVC}}(\text{H}i)\) \(\text{km} \text{ s}^{-1}\) | Probes | \(D_{\text{HVC}}\) \(\text{pc}\) |
|--------|------------|---------------------------------|--------|------------------------------|
| gp     | \(-46, -23\) | +78                             | HD 196426 | 800-4300\(^{1,2}\) |
| IVS    | \(-157, -27\) | \(-45, -40\)                   | HD 19445 | > 39\(^{1}\) |
| ACHII  | \(-190, -22\) | \(-117\)                        | HD 30677 | > 2700\(^{1}\) |
| WEM    | \(+306, -1\) | \(+224, +240\)                  | HD 115363 | > 3200\(^{1}\) |
| Other  | \(+222, -10\) | \(+122\)                        | HD 46185 | > 2900\(^{1}\) |

Reference codes: (1) This paper, (2) Little et al. (1994).

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Figure 2. Optical (CaII K or TiII) and 21-cm H\textsc{i} spectra towards early-type stars. Two plots are shown per sightline in order to emphasise weak features. In the cases where the FWHM of the stellar profile exceeded $\sim$100 km s$^{-1}$ it has been removed in the normalisation process to emphasise the interstellar line features. This affects the stars with HD numbers 480, 2857, 2913, 61429, 74966, 76131, 90882, 100841, 115842, 122272, 145482, 156575, 163745, 186837, 188294, 344365, plus ROA 5701. For HD 2857 some residuals are left by this process at $\sim$ –160 km s$^{-1}$.
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