Structure of the Intermediate and High Velocity Clouds towards the LMC and SMC

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Introduction

High velocity clouds were originally discovered nearly 50 years ago (Muller, Oort & Raimond 1963). Originally observed in H I, they comprise parcels of gas with velocities not compatible with Galactic rotation; in practice this means HVCs have $|v_{\rm LSR}|$ >90–100 km s^{-1} if they lie at at high Galactic latitudes.

Recently it has become clear that at least some of the clouds lie within the halo of the Milky Way (Thom et al. 2006; Wakker et al. 2008, 2009; Lehner & Howk 2011). Other HVCs may lie at extragalactic distances (Blitz et al. 1999; Braun & Burton 1999), although non-detections of HVCs in some external galaxy groups (Pisano et al. 2004), and the lack of stars in many HVCs (e.g. Hopp, Schulte-Ladbeck & Kerp 2007), indicate that many clouds lie in the halo of the Galaxy.

IHVCs are important to study as they may provide fuel for star formation in the Milky Way (see the review by Wakker & van Woerden 1997), put constraints on Λ Cold Dark Matter theory (e.g. Maller & Bullock 2004; Connors et al. 2006), and provide information on close encounters and/or winds from the SMC and LMC (Olano 2008; Lehner, Stavely-Smith & Howk 2009).

We present interstellar absorption-line spectroscopy of early-type stars in CaK and NaD towards the Large and Small Magellanic Clouds (taken from the ESO archive) to investigate the large- and small-scale structure in foreground Intermediate and High Velocity Clouds (IHVCs). The data include FLAMES-GIRAFFE observations of 403 stars in four open clusters (Fig. 1) plus FEROS spectra of 52 in the LMC and 8 in the SMC (Fig. 2).

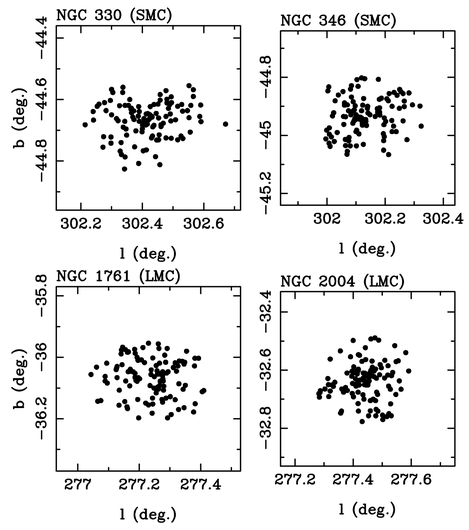

Figure 1: FLAMES/GIRAFFE sightlines taken from the ESO archive. The field of view is 30 arcminutes and minimum separation between the stars around 12 arcseconds. The spectral resolution is 16 km s^{-1}.

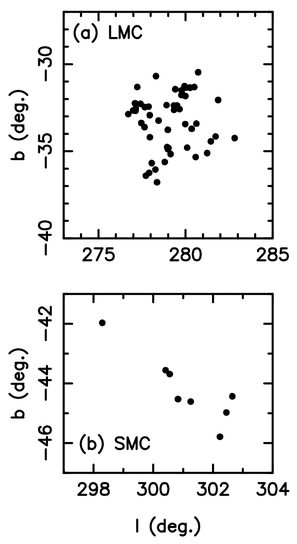

Figure 2: FEROS sightlines taken from the ESO archive towards the LMC and SMC. The spectral resolution is 6.3 km s^{-1}.

Results - small-scale structure

Figures 3 and 4 show how the FLAMES-GIRAFFE observations pick out structures in velocity. The fact that these variations exist in material far away from supernova remnants, has been taken to imply that this small-scale structure is either continuously regenerated or persists for long periods of time (e.g. van Loon et al. 2009). Figure 5 shows GIRAFFE Ca II K spectra towards the four Magellanic clusters studied, showing two or three sightlines with the minimum (top panels) and maximum (bottom panels) equivalent width in the IHVC components. The maximum star-to-star separation on the sky is 27 arcminutes (the size of the FLAMES plate). It is apparent that the variation in the strength of the low-velocity Ca II component is smaller than those of the IHVC and Magellanic components.

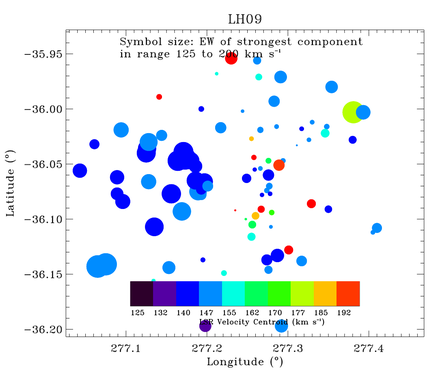

Figure 3: GIRAFFE velocity map towards NGC 1761.

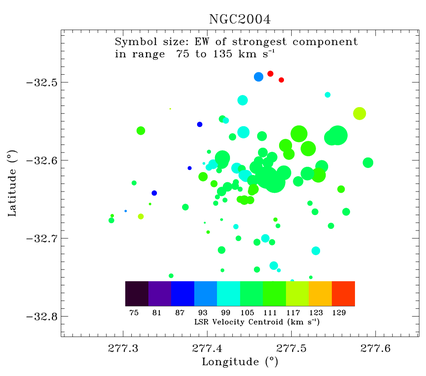

Figure 4: Ditto for NGC 2004.

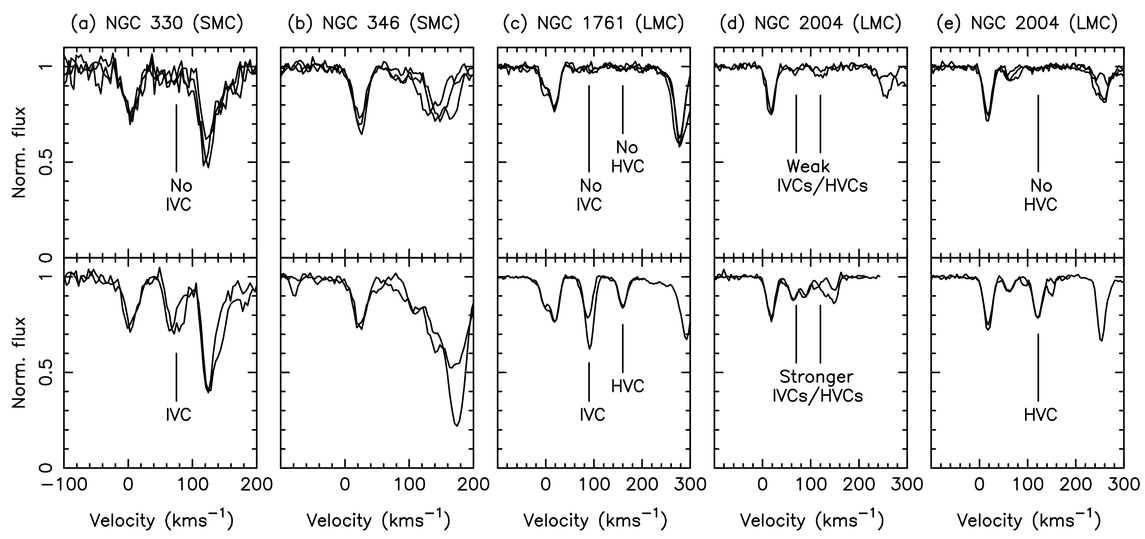

Figure 5: FLAMES-GIRAFFE example sightlines in Ca II K showing the variation in absorption line strength over scales of ∼20 arcseconds.

Results - Velocity field of LMC IHVCs

Figure 6 shows the velocity of high velocity components in the LMC standard of rest plotted against their RA. The solid line is the best-fit relationship of Lehner et al. (2009) who found a good correlation between RA and position, which they ascribe to the clouds being formed by an energetic outflow from the LMC. In six of seven sightlines where we have measured the velocity of the *main* HVC component in Ca II and H I, the values for both elements agree within the errors, providing evidence that at least in these cases the Ca II and H II sample the same phase of the interstellar medium. The discrepant case is towards SK-69 214 where the velocities are different by 5.4 km s^{-1}, although low S/N ratio in the H I observations.

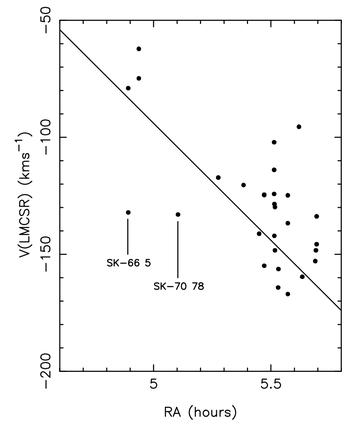

Figure 6: LMC standard of rest velocity of IHVCs against RA for FEROS targets.

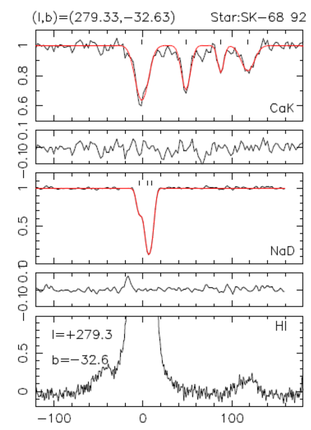

Figure 7: FEROS sightline with IHVC CaK but no NaD.

Results - Abundance ratios of IHVCs

The vast majority of sightlines (Fig. 7) show only Ca II in absorption and no Na I D at intermediate or high velocities, although there are a few exceptions (Fig. 8). The range in the Ca II/Na I ratio in the IHVCs is large, with values from –0.45 to more than +1.5 dex, illustrating the Routly-Spitzer effect and similar to previous values observed in other IHVCs (e.g. Ben Bekhti et al 2008). Both Ca II and H I data are available for six sightlines, with most IHVCs showing similar Ca II/H I ratios to the general IHVC population (Fig. 9).

In four sightlines with previous O I measurements, we find Ca II/O I ratios in the LMC gas ranging from 0.23 to 1.3 dex below the solar value, indicating either dust or ionisation effects.

Finally, no Ca I, CH^+ or CH is visible in IHVCs of the current dataset, although the latter has been seen towards other LMC IHVCs (Richter et al. 1999).

Data taken from the ESO archive, programmes
078.C-0493(A) and 171.D-0237(B).

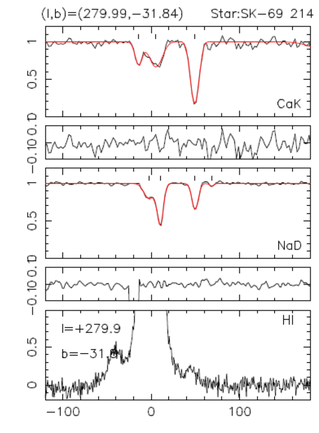

Figure 8: FEROS sightline with IHVC CaK and NaD detected at intermediate velocities.

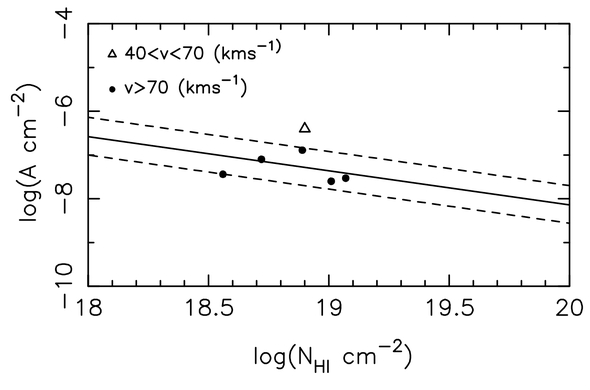

Figure 9: CaII/HI ratio for FEROS sightlines with a detection in both species. The full and dashed lines are from Wakker & Mathis (2000).

Future work

Future work will include CLOUDY modelling of the current sightlines in order to obtain more information about the gas densities and temperatures.