Physical parameters of two Compact High-Velocity Clouds
Structure, dynamics and possible origin

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Introduction

Although High-Velocity Clouds (HVCs) were already discovered in 1963 by Muller, Oort and Raimund, their nature is discussed controversially until today. HVCs are gas clouds, in which the baryonic matter consists mainly of neutral atomic hydrogen. They have radial velocities, which are not consistent with a simple galactic rotation model. Both the origin and the spatial distribution of the HVCs are still unknown. The main reason for this is the difficulty to determine the distance of HVCs. A subclass of the HVCs are the so-called Compact High-Velocity Clouds (CHVCs), which were identified by Braun & Burton in 1999. CHVCs are defined by their small angular diameter of $\varphi < 2°$ FWHM. They are spatially and kinematically isolated from the gas distribution in their environment.

Data acquisition

The basis of our analysis are the Parkes and ATCA 21-cm data of two CHVCs (HVC 297+09+253 and HVC 291+26+195), which were observed by Brüns et al. (2005) in the framework of an HI survey of the Magellanic System. The velocity resolution of the Parkes data is 1 km/s and for the ATCA data 0.8 km/s.

The observations of the two clouds with a single-dish telescope on the one hand and with an interferometer on the other hand makes it possible to analyze the total HI masses and the extended structures as well as the small-scale structures within the clouds.

Properties of the two CHVCs

The Parkes data

Fig. 1 shows column density maps of the two CHVCs, based on the Parkes data. The investigation of the line profiles reveals the presence of two line components in the spectra of HVC 297+09+253, which can be identified with a cold and a warm gas phase (Fig. 2).

The two gas phases are partly spatially separated from each other. Fig. 3 shows the column density distribution of the broad and the narrow line component along the major axis of HVC 297+09+253.

Both the distribution of the physical parameters as well as the morphological asymmetry in position-velocity space shows that HVC 297+09+253 reveals a distinct head-tail structure. The presence of a head-tail structure can be explained by an interaction of the CHVC with an ambient medium. Due to friction forces, the diffuse gas component may be stripped off the cold compact core and form the tail. HVC 291+26+195 shows only a cold gas phase.

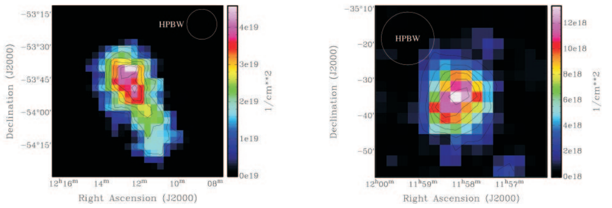

*Fig. 1: Column density maps of HVC 297+09+253 (**left panel**) and HVC 291+26+195 (**right panel**) observed with the Parkes telescope. The contours range from $1\cdot10^{19}$ up to $4\cdot10^{19}$ cm^{-2} in steps of $5\cdot10^{18}$ cm^{-2} and from $2\cdot10^{18}$ up to $1.2\cdot10^{19}$ cm^{-2} in steps of $2\cdot10^{18}$ cm^{-2} respectively. The HPBW of the Parkes beam of 14.1' is shown in both figures.*

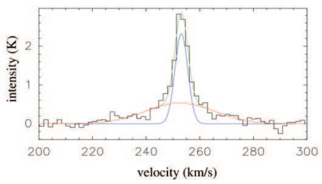

*Fig. 2: One Spektrum of the Parkes data of HVC 297+09+253. Apparently there is a superposition of a narrow and a broad line component. We fitted two gaussians into the spectrum. The resulting fit (**green**) is also shown in this figure.*

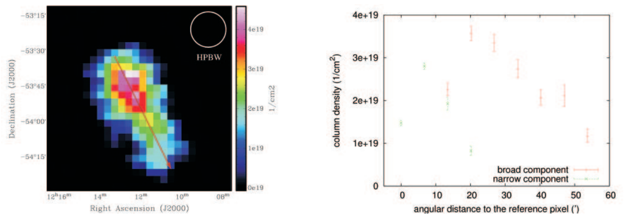

*Fig. 3: **Left panel**: Cut along the major axis of HVC 297+09+253. **Right panel**: Column density distribution along the major axis of HVC 297+09+253 for the cold and the warm gas phase.*

The ATCA data

The investigation of the two clouds with the ATCA reveals the presence of cold compact clumps within both clouds (Fig. 4). These observations are consistent with the concept of a multiphase structure of HVCs. The cold clumps (CNM) are embedded in the diffuse, warm gas (WNM). Because of the small line widths of all investigated clumps ($\Delta v_{\rm FWHM}$ = 2...4 km/s) we obtain a strong limit for the kinematic temperature with 20 K < $T_{\rm kin}$ < 300 K.

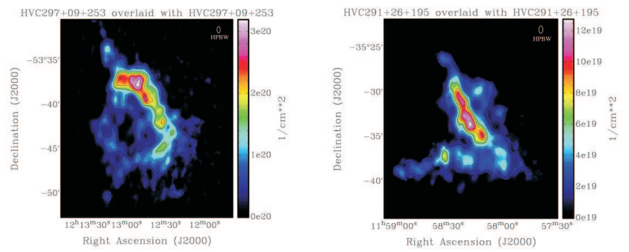

*Fig. 4: Column density maps of the two CHVCs observed with the ATCA. **Left panel**: HVC 297+09+253. The contours range from $5\cdot10^{19}$ to $3\cdot10^{20}$ cm^{-2} in steps of $5\cdot10^{19}$ cm^{-2}. **Right panel**: HVC 291+26+195. The contours range from $2\cdot10^{19}$ to $1.2\cdot10^{20}$ cm^{-2} in steps of $2\cdot10^{19}$ cm^{-2}. The HPBW of the ATCA beams are 58.6" × 36.2" and 74.6" × 38.4".*

Ram-pressure interaction

Since HVC 297+09+253 shows clear signs of a ram-pressure interaction with an ambient medium, it is possible that the cold compact clumps are also generated by an interaction. The clumps can only be found in the head of the cloud (Fig. 5). This may indicate that the highest ram-pressure occurs along the leading edge of the CHVC. Local density fluctuations in combination with cooling processes may then form the cold compact clumps. The fact that HVC 291+26+195 also shows cold clumps, although no diffuse component is observed suggests an interaction of this cloud with an ambient medium. Maybe the diffuse warm component was already stripped off. Its density may be so small that it falls below the detection limit of the Parkes data.

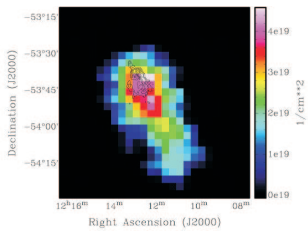

Fig. 5: Column density map of HVC 297+09+253 observed with Parkes. Overlaid are contours of HVC 297+09+253 ($5\cdot10^{19}$ to $3\cdot10^{20}$ cm^{-2} in steps of $5\cdot10^{19}$ cm^{-2}) from the ATCA data.

Distance estimation

A lower distance limit for the two clouds can be obtained by comparing the pressure of some of the clumps of the CHVCs as a function of distance with the pressure of the surrounding Milky Way gas (Fig. 7). In order to investigate how the pressure changes along the line of sight within the Milky Way, a tool developed by Kalberla (2003) was used. A model of the Milky Way is the basis for this tool. The lower distance limit for all clumps of d > 15 kpc resulting from this method is consistent with a connection of both clouds with the Leading Arm.

Based on these results, a distance of the clouds of 50 kpc is assumed, so that we can estimate distance-dependent physical parameters (mass, particle number density, pressure). A comparison of the total HI masses resulting for the Parkes and ATCA data of both CHVCs reveals that the ATCA detected only 36% of the mass of HVC 297+09+253. This result shows that the diffuse expanded gas phase constitutes a major part of the total HI mass. The mass comparison for HVC 291+26+195 confirms the observation that not much diffuse gas is present in this cloud. The ATCA detects 95% of the mass which was measured with Parkes.

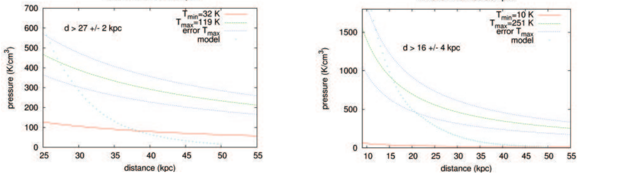

*Fig. 7: Pressure variation as a function of the distance for two cold clumps in HVC 297+09+253 and HVC 291+26+195 and for the gas of the Milky Way derived from a model developed by Kalberla (2003). **Left panel**: Clump A of HVC 297+09+253 and the model. **Right panel**: Clump A of HVC 291+26+195 in comparison with the model.*

Leading Arm

Evidence for an association of both CHVCs with the Leading Arm

Both clouds show evidence for an association with the Leading Arm (LA) in position as well as in velocity. Fig. 6 displays the velocity map of a part of the Magellanic System (MS). In the south-eastern part of LA II the observed velocity range is $v_{\rm LSR}$ = 265...300 km/s (289° < l < 293°, 6° < b < 13°). Thus, HVC 297+09+253 deviates by only 10-15 km/s from the velocities of LA II. In the south eastern area of LA II we observe a velocity dispersion of the gas of 10 km/s.

HVC 291+26+195 lies exactly in the velocity range of the northern part of LA II (190 km/s < $v_{\rm LSR}$ < 275 km/s). Therefore, it is possible to speculate about an origin of the clouds in the interaction of the Leading Arm with the Milky Way. On the other hand it is possible to estimate the distances of these two clouds to 40-60 kpc. This distance range is predicted by simulations of the MS (e.g. Yoshizawa & Noguchi, 2003). If the two CHVCs have the same origin as the Leading Arm the observed head-tail structure and the cold clumps could possibly be explained by a ram-pressure interaction of the clouds with the gas in the outer parts of the Milky Way.

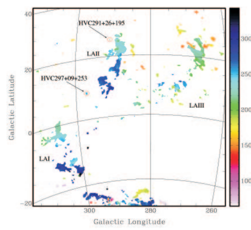

Fig. 6: The figure displays the velocity map ($v_{\rm LSR}$) of a part of the Magellanic system for the velocity range 150...350 km/s. The map shows the three complexes LA I, LA II and LA III which belong to the Leading Arm. The data were observed with the Parkes telescope and processed by Brüns et al. (2005).

Summary and outlook

Both CHVCs reveal a complex structure and show signs of an interaction with an ambient medium. The clouds show cold compact clumps which in case of HVC 297+09+253 are embedded in a diffuse warm envelope. We found evidence for an association with the Leading Arm which allows us to restrict the distance of the CHVCs.

Hydrodynamical simulations would help us to learn more about the generation of cold compact clumps as a result of an interaction of CHVCs with an ambient medium.

References

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