Effelsberg HI Survey of Compact High-Velocity Clouds

Deep follow-up observations of selected objects

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Abstract

Compact high-velocity clouds *(CHVCs) are observed across the entire sky in the 21-cm line of neutral hydrogen. They are thought to represent the missing gaseous Dark-Matter satellites left over from the formation of the Local Group. CHVCs are characterised by small angular sizes of ö ≤ 1° and high radial velocities in excess of any Galactic rotation model. So far, neither stars nor molecular gas have been found in these objects.*
We have investigated a selected sample of 11 CHVCs in 21-cm line emission with the 100-m telescope in Effelsberg. Our observations disclose a complex and inhomogeneous structure of most of these objects. Many of them show clear signs of distortion interpreted as ram pressure interaction with a surrounding medium. As CHVC distances are indirectly estimated, it is not yet clear if this medium is spread more or less homogeneously across the entire Local Group or if it represents an extended Galactic halo. Our results emphasise the importance of high-resolution, single-dish observations of CHVCs to extract the physical conditions within these puzzling objects and their environment.

Introduction

High-velocity clouds (HVCs) were discovered in 1963 by Muller et al. in the 21-cm line emission of neutral hydrogen. They are characterised by **high radial velocities** which cannot be explained by any Galactic rotation model. Some reach radial velocities of $|v_{LSR}| \sim 400$ km s^{-1} in the local standard of rest frame. HVCs can be found all across the sky where they appear in large complexes of tens of degrees in size.
In 1999, Braun & Burton defined a subclass of HVCs characterised by **compactness** as well as spatial and kinematic **isolation** from neighbouring emission. These so-called **compact high-velocity clouds** (CHVCs) have angular sizes of typically ö ≤ 1°. Braun & Burton extracted 66 of them from the Leiden/Dwingeloo Survey of Galactic Hydrogen (Hartmann & Burton 1997) which covers the sky north of ä = –30°.
CHVCs are considered to be the missing gaseous **Dark-Matter satellites** left over from the formation of the Local Group galaxies. The number of satellites predicted by ΛCDM models exceeds the number of observed Local Group dwarf galaxies (Mateo 1998) by a factor of ~5 (Klypin et al. 1999, Moore et al. 1999). CHVCs are the best candidates to solve this so-called missing satellite problem.

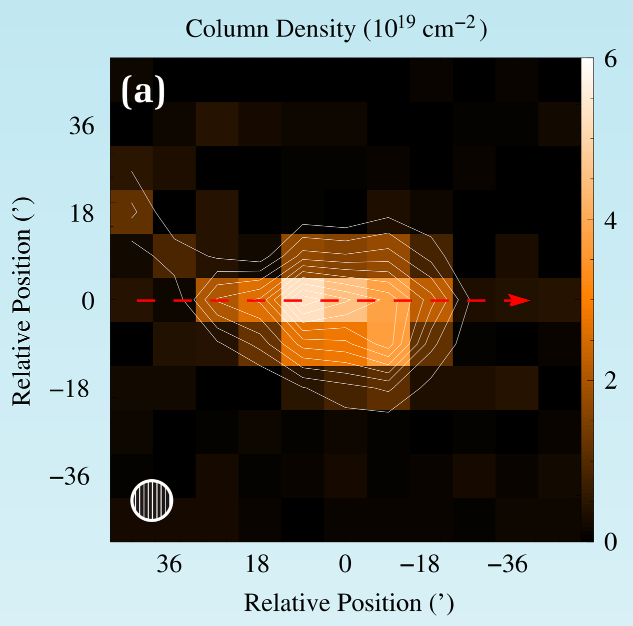
Effelsberg Survey

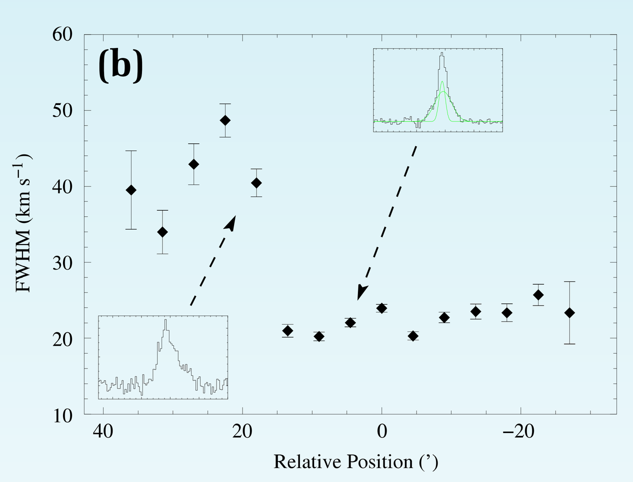
We have observed **11 compact high-velocity clouds** which were chosen from the Braun & Burton 1999 and de Heij, Braun & Burton 2002 catalogues. Each cloud was **mapped** in HI on a 9' grid with 11×11 spectra. The velocity resolution was chosen to be 2.6 km s^{-1}, resulting in a 3ó detection limit in column density of typically $5\cdot10^{18}$ cm^{-2}. Only the most compact object, CHVC 218+29, had to be mapped with 4.5' sampling and 1.3 km s^{-1} velocity resolution.
In addition, we observed a deep **profile** along an appropriate axis of each object on a finer grid and with higher sensitivity. Along this profile we typically reach a 3ó cloumn density limit of $2\cdot10^{18}$ cm^{-2} at 2.6 km s^{-1} velocity resolution. These measurements allow us to obtain the column density profile of each CHVC in great detail and to examine possible line width and velocity gradients with high precision.

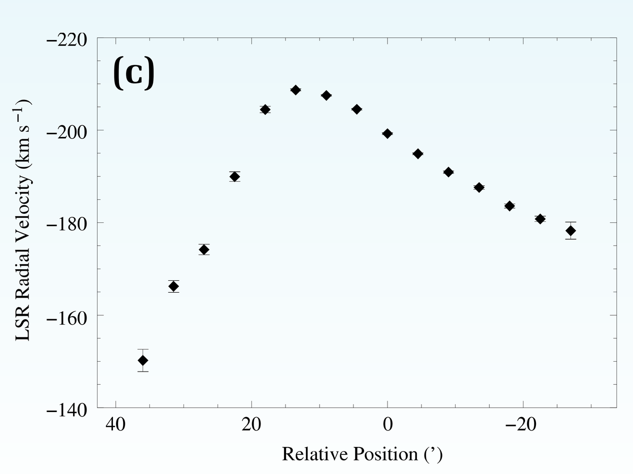
CHVC Properties

Our sample of 11 CHVCs reveals a **complex** and **inhomogeneous** structure and morphology. Only one object, CHVC 148–82, appears spherically-symmetric. All other clouds usually reveal a condensed column density maximum surrounded by an asymmetric, smooth envelope. **Head-tail structures** and **bow-shock shapes** are quite common and are detected in about half of the observed CHVCs (see e.g. CHVC 017–25). Both are traced only by the warm neutral gas. These types of morphologies usually come along with a specific distribution of radial velocities and line widths, indicating that they might undergo **interaction** with a surrounding medium.
Except CHVC 218+29, all investigated objects have a clear **gradient in radial velocity**. The most extreme case is CHVC 050–68. In the eastern part of this cloud, the gradient reaches 60 km s^{-1} on a scale of only 20'. Some of these gradients can be explained by a simple superposition of gas with different velocities along the line of sight. In other cases, the velocity gradient might be real and could be interpreted as a sign of ongoing interaction with a surrounding medium or as rotation of the whole cloud.
The observed **line widths** range from only 4 km s^{-1} FWHM in case of CHVC 218+29 up to about 40 km s^{-1} FWHM for CHVC 040+01. In a few cases, we find a core-halo morphology where a cold neutral medium core with linewidths corresponding to a kinetic temperature of a few 100 K is embedded into a warm neutral medium envelope with temperatures of the order of 10^4 K.

Irregular Objects







CHVC 050–68 is one of the most remarkable objects in our sample. It looks more or less symmetric and undisturbed, but a detailed analysis of spectra taken along the axis indicated by the red arrow in map (a) reveals a more complex picture. Diagram (b) shows the line widths measured along the axis. Over most of the central and western part of CHVC 050–68, line widths are nearly constant with about Δv = 20…25 km s^{-1} FWHM. Furthermore, we can see a clear two-component structure in the HI spectra, indicating the presence of a distinct cold and warm neutral gas (see upper inset in diagram (b)). But towards the eastern edge of CHVC 050–68, line widths suddenly rise substantially above 40 km s^{-1} FWHM. This comes along with complex HI line profiles (see lower left inset in diagram (b)). These complex line profiles seem to trace multiple gas components with different radial velocities and intensities along the line of sight. It seems as if CHVC 050–68 consists of at least two individual objects with different velocities but in nearly the same position on the sky.
The most remarkable feature of CHVC 050–68 is its extremely large velocity gradient. The distribution of radial velocities along the chosen axis ist displayed in diagram (c). In the central and western parts of the cloud, where we find line widths to be very homogeneous, the radial velocity reveals a strong and clear gradient of äv ~ 30 km s^{-1} across 40'. This gradient is very regular and could be caused by a rotation of CHVC 050–68. On the eastern edge of the cloud, radial velocities suddenly decrease by 60 km s^{-1} across only 20'. This extreme gradient strongly supports the idea that there is a second object in the proximity of the main body of CHVC 050–68 which has a significantly lower radial velocity. The superposition of both clouds could have caused the broad and complex line profiles as well as the impression of an extreme velocity gradient towards the eastern edge of CHVC 050–68.

References

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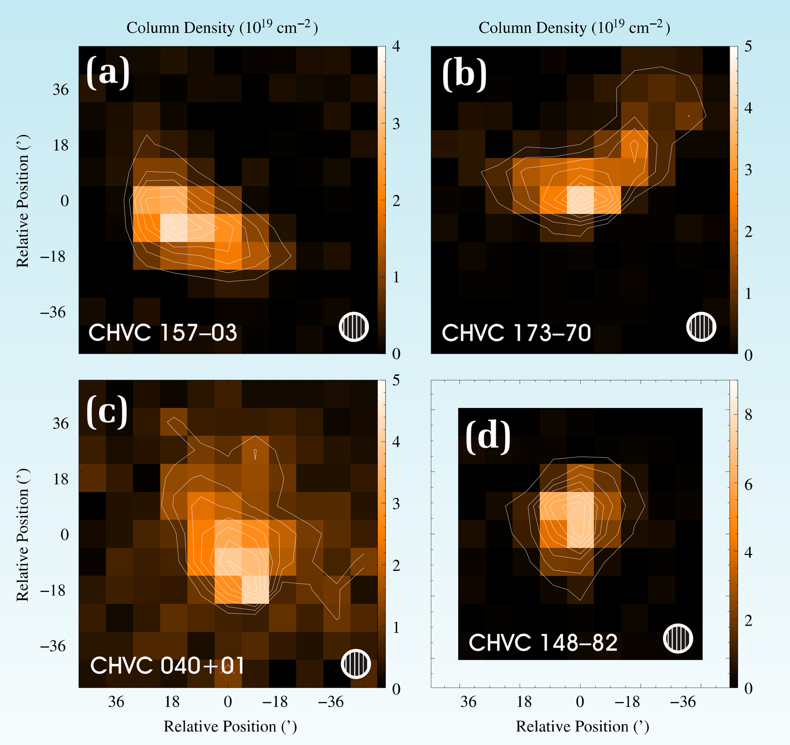
Summary & Conclusions

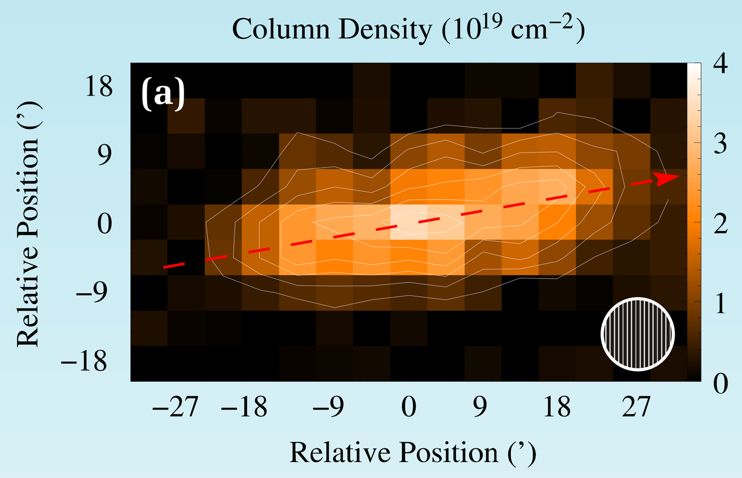
Our results indicate that most CHVCs reveal a complex structure and show signs for ram-pressure interaction with a surrounding medium. They are not as spherically symmetric as one would expect for promordial gas clouds across the Local Group. If CHVCs really are the gaseous counterparts of the missing Dark-Matter satellites in the Local Group we would expect this surrounding medium either to fill the entire Local Group or to trace an extended Galactic Halo gas. The latter is more likely as during the last years there has been more and more support for a circumgalactic distribution of CHVCs with typical distances of the order of about 100…200 kpc (e.g. de Heij, Braun & Burton 2002, Sternberg, McKee & Wolfire 2002).
Our observations demonstrate the importance of studying the warm neutral medium of CHVCs as a tracer for potential interaction effects by a surrounding medium. This will allow us to extract the physical conditions within CHVCs and their neighbourhood in great detail.

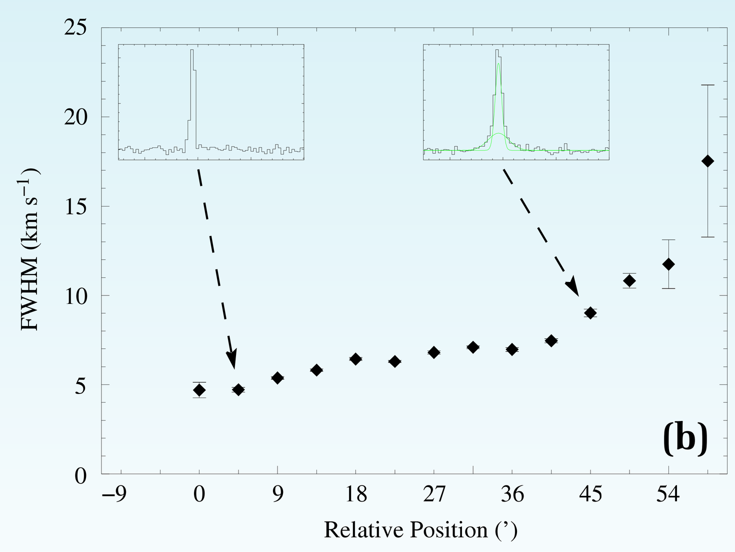
The Appearance of CHVCs



CHVC 148–82 in figure (d) is the only object among our 11 CHVCs with a more or less regular and sperically-symmetric shape. All other CHVCs in our sample reveal a complex morphology. Many of them show clear signs for ram-pressure interaction with a surrounding medium.
The two objects in figures (a) and (b) reveal a bow-shock shape indicating the existence of ram-pressure effects. This interpretation is supported by the distribution of radial velocities and line widths. In both cases, radial velocities of the HI gas decrease towards the presumable front of the cloud by about äv ~ 5 km s^{-1} which indicates that the gas is decelerated by an ambient medium.
CHVC 040–01 in figure (c) is an example for an object with head-tail structure. Again, the distribution of radial velocities and line widths support the idea that this characteristic shape is caused by ram-pressure interaction with a surrounding medium.

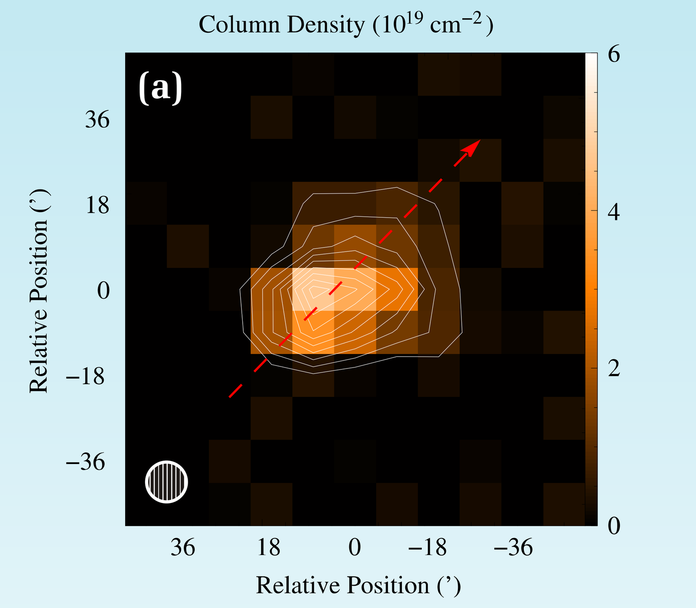
Ram-Pressure Distortion

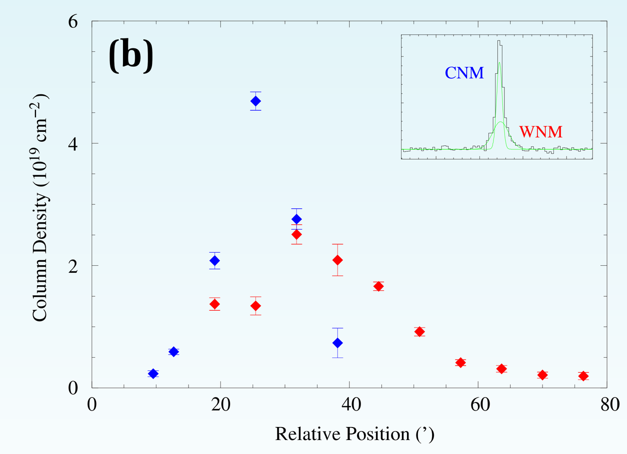




CHVC 218+29 is a prime example for a CHVC being possibly distorted by an ambient medium through which it moves. The map shows the HI column density distribution of the object which is quite compact and extremely elongated. We took spectra along the axis indicated by the red arrow to obtain a deep and detailed profile along the major symmetry axis of CHVC 218+29.
The distribution of line widths along this axis is shown in the diagram below. At the eastern edge of the cloud, line widths of only Δv = 4…5 km s^{-1} FWHM are found. This corresponds to an upper limit in gas temperature of roughly $T < 500$ K which corresponds to a pure cold neutral gas. Towards the western edge, line widths systematically rise above 10 km s^{-1} FWHM. At the same time, a possible two-component structure appears in the central and western parts of CHVC 218+29, indicating the existence of a cold and a warm neutral medium. It looks as if something has swept away the warm gas from the eastern part of the cloud.
Indeed, a detailed analysis reveals that, like in case of CHVC 017–25, cold and warm medium are spacially and kinematically separated with the cold gas showing a higher radial velocity than the warm gas. These results strongly suggest that CHVC 218+29 is distorted by ram-pressure interaction with a potential ambient medium in which the warm gas has been stripped off the eastern edge of the cloud.

Head-Tail Structures





CHVC 017–25 is a good example for a CHVC being disrupted by a surrounding medium. Map (a) on the left shows that the cloud is slightly elongated with extended weak emission towards the northwestern edge. Furthermore, most of the HI lines of CHVC 017–25 show evidence for a two-phase gas. Line profiles consist of a narrow component (Δv < 10 km s^{-1}) of cold neutral medium (CNM) and a broad component (Δv ~ 20 km s^{-1}) tracing a warm neutral medium (WNM). The inset in diagram (b) shows a typical spectrum in which the two components can clearly be seen.
Diagram (b) itself shows the distribution of column densities of both gas components along the axis marked by the red arrow in map (a). Obviously, the distribution of the cold gas is quite compact so that we can speak of a compact cold core of CHVC 017–25. On the other hand, the warm component is much more extended and reveals a weak tail in northwestern direction. Cold and warm gas are spatially separated which indicates that the warm envelope has been stripped off the cold core of CHVC 017–25 by ram-pressure interaction with a surrounding medium.
The results show that although CHVC 017–25 at first glance looks rather symmetric, a more detailed view reveals a head-tail structure. This suggests the existence of an ambient medium enclosing CHVC 017–25. As the CHVC moves through this medium, its diffuse and extended envelope of warm gas seems to be stripped off the compact cold core by ram-pressure interaction.