Effelsberg HI Survey of Compact High-Velocity Clouds

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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 satellites left over from the formation of the Local Group. CHVCs are characterised by small angular sizes 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 12 CHVCs in the 21-cm line emission with the 100-m telescope in Effelsberg. Our observations reveal a rather complex and inhomogeneous distribution of warm and cold gas within most of these clouds suggesting they are highly disturbed either by ram-pressure or by tidal interaction. Therefore, CHVCs are presumably located in the neighbourhood of the Milky Way rather than distributed across the entire Local Group. Our results emphasise the importance of high-resolution, single-dish observations of CHVCs to extract the physical conditions within these puzzling objects and their surroundings.

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}. HVCs can be found all across the sky where they appear as large complexes of tens of degrees in size.
In 1999, Braun & Burton defined a subclass of HVCs defined by **compactness** as well as spacial and kinematic **isolation** from neighbouring emission. These so-called **compact high-velocity clouds** (CHVCs) have angular sizes of typically 1°. Braun & Burton extracted 66 of them from the Leiden/Dwingeloo Survey of Galactic Hydrogen which covers the sky north of –30° declination.
CHVCs are believed to be the missing gaseous **dark-matter satellites** left over from the formation of the Local Group. 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 **12 compact high-velocity clouds** with the 100-m telescope in Effelsberg (Germany) in greater detail. These objects have been selected by two criteria. First, they must still be defined as compact high-velocity clouds in the improved CHVC catalogue by de Heij, Braun & Burton 2002. A comparison between peak column densities obtained by Dwingeloo and Effelsberg measurements reveals the existence of small-scale structure which is not resolved by the Leiden/Dwingeloo Survey, making a reinvestigation of these CHVCs reasonable and interesting. We selected those clouds which have a column density ratio of $N_{Eff} / N_{LDS} > 3$.
Each of the 12 clouds was **mapped** on a 9' grid, resulting in a field of usually 1.5°×1.5°. The velocity resolution was chosen to be 2.6 km s^{-1} resulting in a 3σ detection limit in column density of typically $5 \cdot 10^{18}$ cm^{-2}. Only the most compact object, CHVC 218+29, had to be mapped with 4.5' angular sampling and 1.3 km s^{-1} velocity resolution.
In addition, we observed a **deep profile** along an appropriate axis of each cloud, usually along the symmetry axis of the column density distribution, with higher resolution. Each spectrum along this profile was integrated for 10 minutes, leading to a 3σ column density limit of about $2 \cdot 10^{18}$ cm^{-2} at a velocity resolution of 2.6 km s^{-1}. These measurements allow us to obtain the column density profile across the object in great detail and to examine possible velocity and line width gradients.

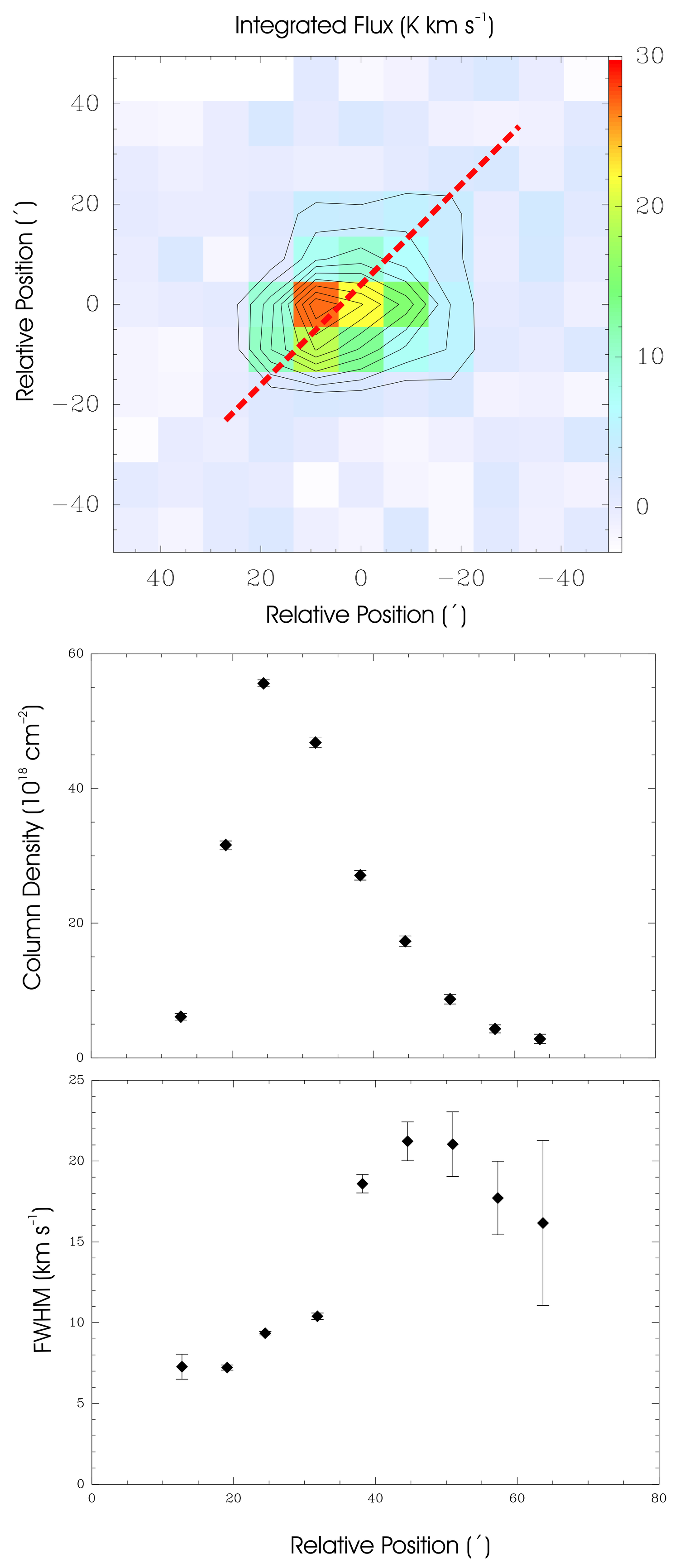

Figure 1: *CHVC 017–25 as an example for a CHVC with head-tail structure. Along the eastern edge there is a steep and sudden increase in column density while in the western part of the cloud the column density profile shows a rather smooth decline (upper diagram). This goes along with a clear gradient in line width (lower diagram). Profiles were taken along the axis indicated by the red arrow.*

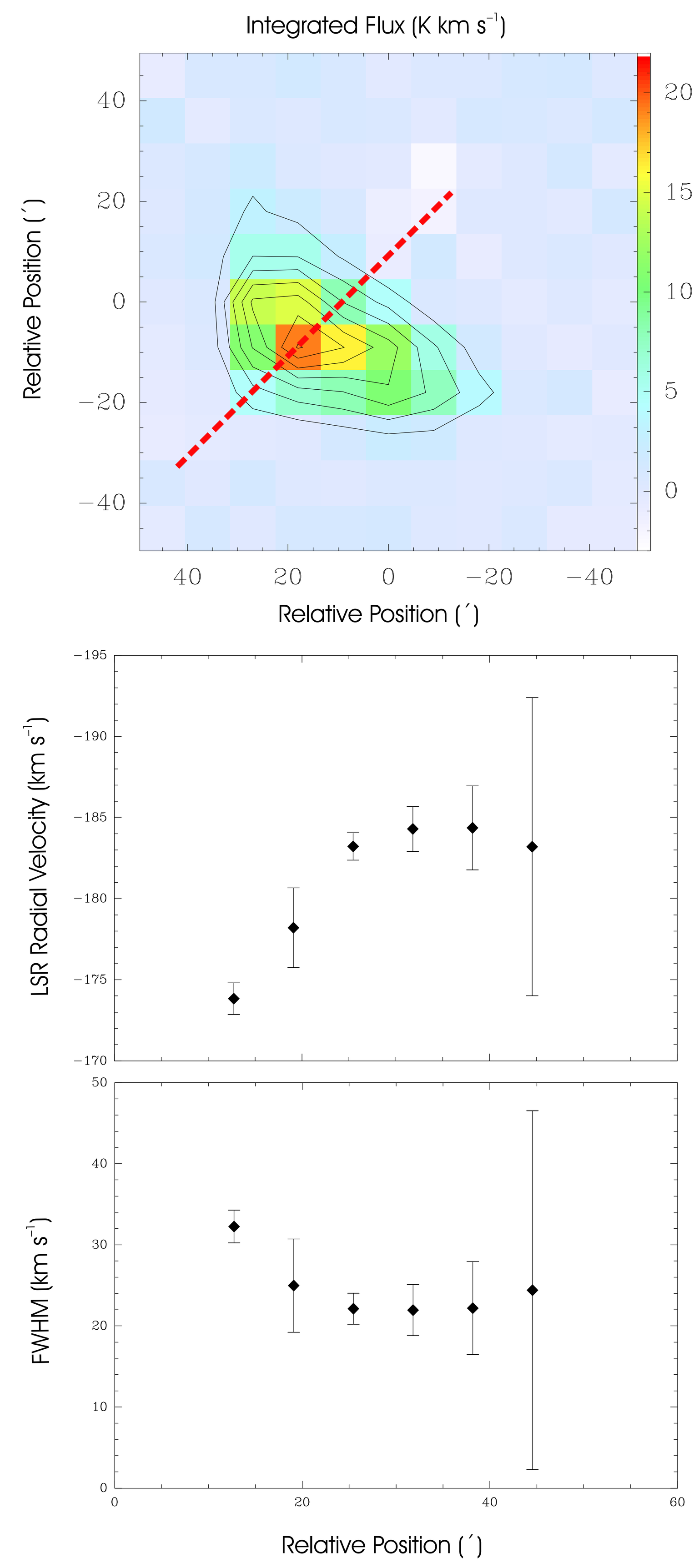

Figure 2: *CHVC 157+03 as an example for a bow-shock-shaped CHVC. The characteristic shape indicates a possible interaction with a surrounding medium. This is supported by the observed decrease in velocity (upper diagram) and increase in line width (lower diagram) along the symmetry axis of the object, indicated by the red arrow.*

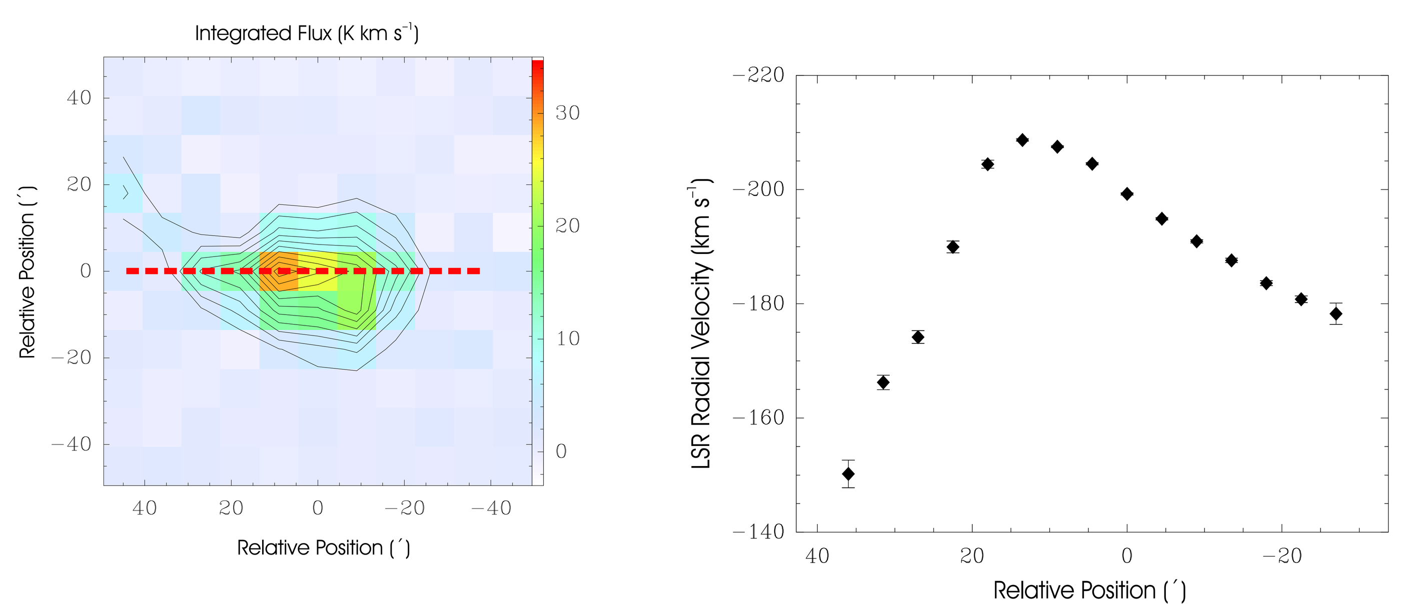

Figure 3: *CHVC 050–68 reveals a very strong gradient in radial velocity along its major axis. In the eastern part of the object a sudden drop of 60 km s⁻¹ across only 20´ is observed. This goes along with extended, weak emission towards the left border of the map which shows much larger line widths than the main part of CHVC 050–68. The velocity profile was taken along the axis indicated by the red arrow.*

Properties of our CHVCs

Our sample of 12 CHVCs shows a **complex** and **inhomogeneous** structure and morphology. Only one object, CHVC148–82, shows a more or less spherical symmetry (figure 6). All other clouds have a quite complex appearance, usually revealing a condensed column density maximum surrounded by an asymmetric, smooth envelope of warm neutral gas. **Head-tail structures** and **bow-shock shapes** are quite common and are detected in about half of the observed CHVCs. 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. Two examples are shown in figures 1 and 2.
Except CHVC 218+29, all investigated objects have a clear **gradient in radial velocity**. The most extreme case is CHVC 050–68 which is shown in figure 3. In the eastern part of the 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 individual clouds 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 (figure 4) 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 (figure 5).

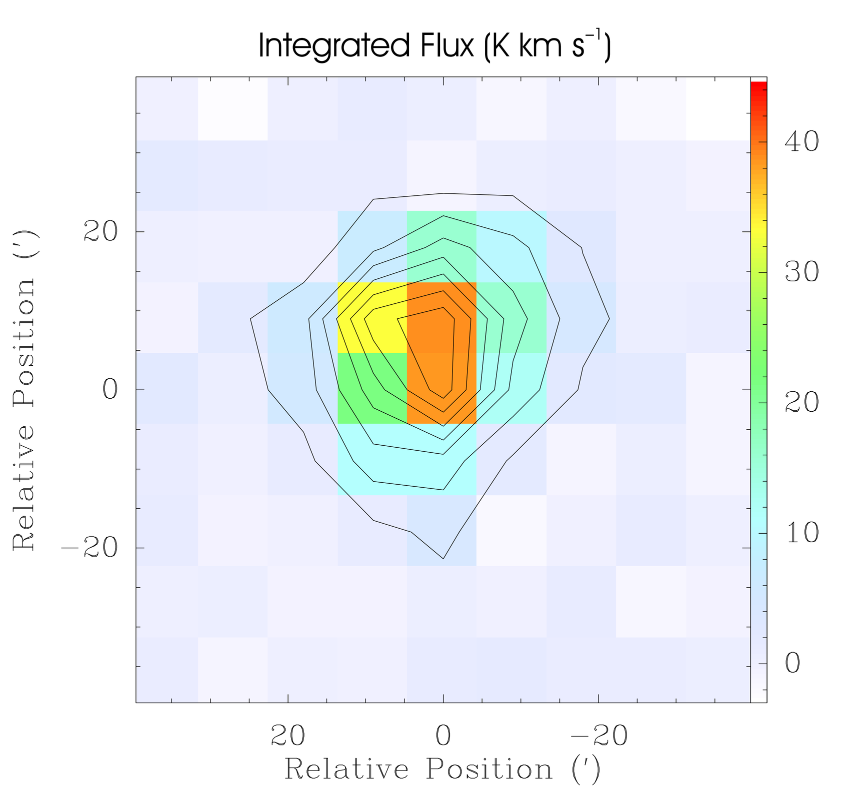

Figure 6: *Column density map of CHVC 148–82. This is the only cloud in our sample which has a more or less spherical appearence.*

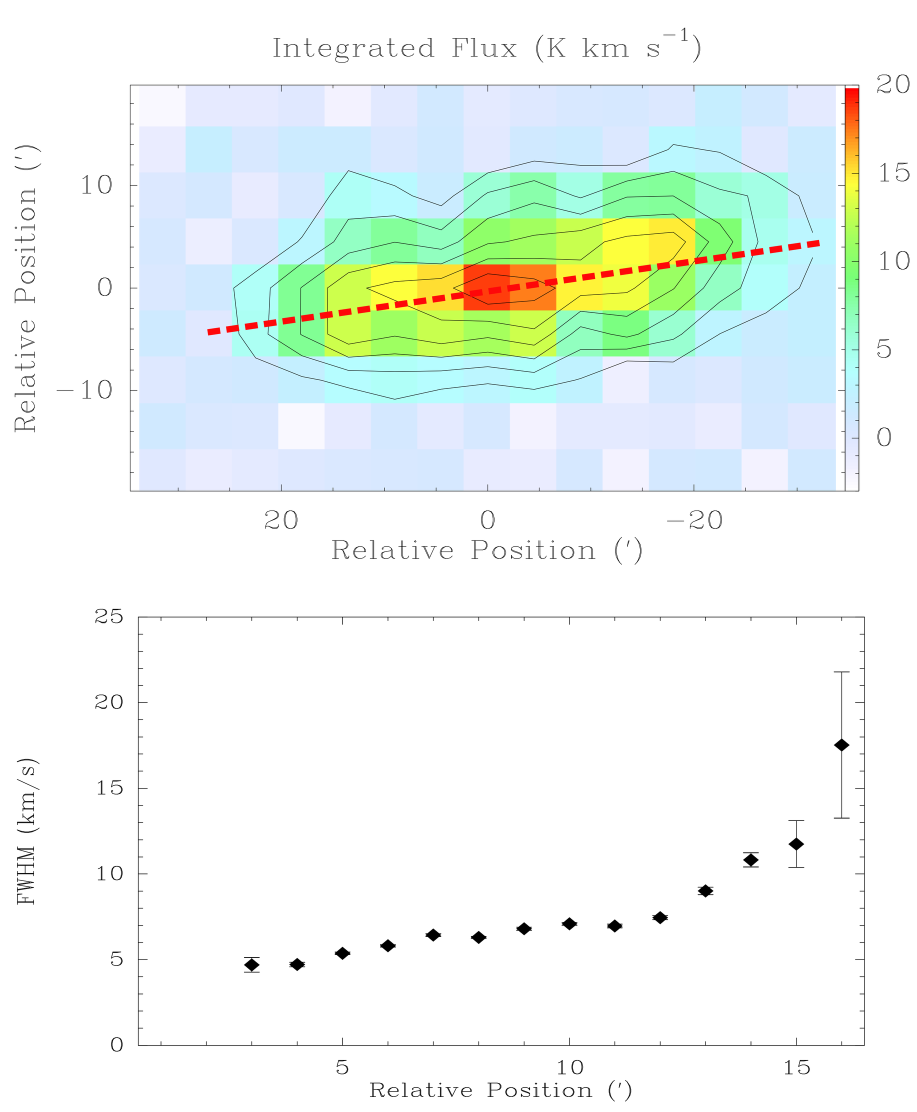

Figure 4: *The upper image shows a map of CHVC 218+29. This object is quite compact and extremely elongated. It is the only CHVC in our sample which does not show a clear velocity gradient. On the other hand, it reveals the narrowest lines reaching only 4 km s⁻¹ FWHM along the eastern part of the cloud. Line widths increase systematically above 10 km s⁻¹ towards the western edge. The diagram displays the linewidth gradient along the red arrow indicated in the map.*

Summary & Conclusions

Our results clearly show that the observed sample of CHVCs is quite inhomogeneous. The complex morphology and structure of most of the objects is a sign of disturbance by either **ram pressure** or by **tidal interaction**. The CHVCs from our sample are, therefore, presumably located in the neighbourhood of the Milky Way where the higher density of the ISM could possibly be responsible for the observed effects. This is in contrast to a distribution across the entire Local Group as predicted in the literature.
Our observations demonstrate that the **warm neutral medium** of CHVCs has to be studied in detail to extract the physical conditions within these objects and in their neighbourhood. This is only possible by using large single-dish telescopes which have a sufficient sensitivity and resolution and which are able to detect the warm neutral component of CHVCs in contrast to interferometers which are mainly sensitive for the compact and cold cores.

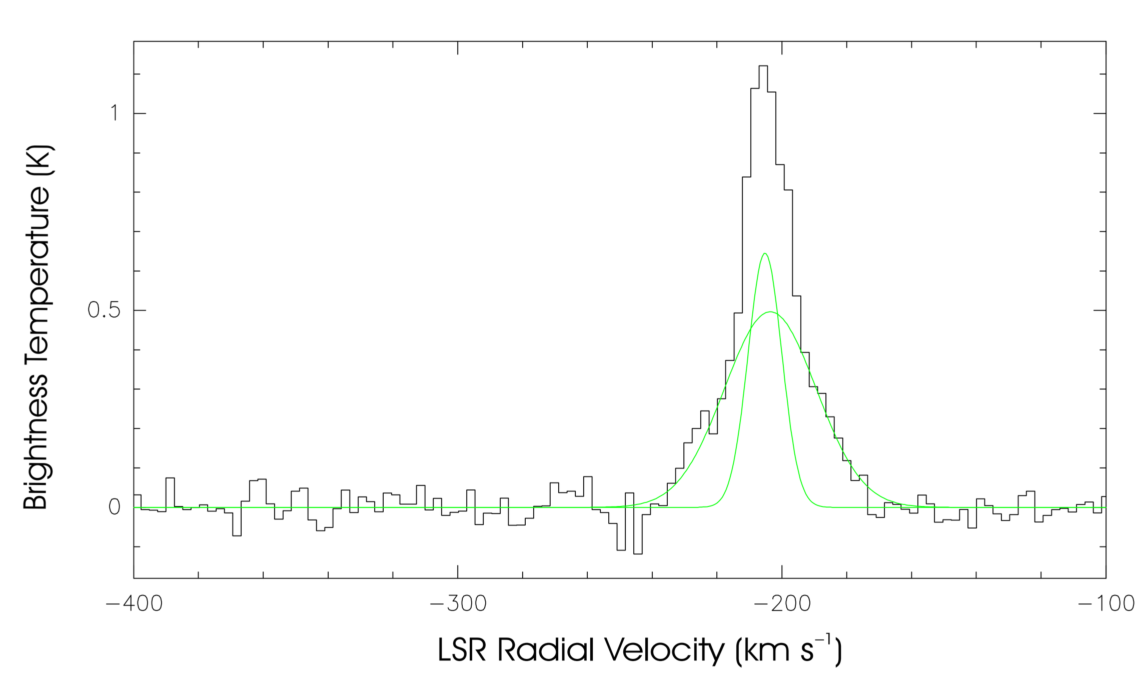

Figure 5: *Typical spectrum of CHVC 050–68. One can clearly distinguish a narrow component indicating the existence of a cold core (some 100 K) and a broad component representing an envelope of warm neutral gas (~10⁴ K).*

References

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