HIGH-VELOCITY CLOUDS: REVIEW OF OBSERVATIONAL PROPERTIES

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Abstract - Earlier extended surveys with moderate resolution and sensitivity had shown that high-velocity gas can appear as small clouds ($\sim 2^{\circ}$) either isolated, or in elongated complexes with lengths of up to 30°. The profiles were rather broad (halfwidths of 25 km/s). While the brightest HVC's were found in the northern galactic hemisphere, the highest negative velocities were found in the southern latitudes. The only known high-positive velocity objects were a few at low latitudes between $l = 245^{\circ}$ and 330°.

Recent high-resolution observations of a number of individual clouds reveal much small-scale structure. The most conspicuous property is the existence of small (6'), bright (up to 65 K), and narrow (5 km/s) cores, embedded in smooth envelopes (2°, 4 K, 25 km/s). Also sharp gradients, ringlike structures and large velocity gradients (up to 10 km/s/arc-degr.) are reported.

New highly sensitive observations (ΔT_b(rms) = 0.02 K) in the region $l = 100^{\circ}$ to 200° and $b = 0^{\circ}$ to -45° (partly -60°) with a velocity range from -1000 to +1000 km/s show the existence of many small (1°), faint (up to 0.3 K), isolated clouds with very high negative velocities, with the extreme value of -465 km/s ($l = 110\overset{\circ}{.}5$, $b = -7^{\circ}$, $T_b \approx 0.3$ K). A second important result is the existence of high-velocity gas with velocities around -250 km/s, continuing from HVC 160-46-330 to $l,b \approx 188^{\circ},-24^{\circ}$, near the Anticentre complex. No high-positive velocities are found.

CHARACTERISTICS OF HIGH-VELOCITY CLOUDS.

The objects, widely known as high-velocity clouds (HVC's), are neutral hydrogen features exhibiting a velocity not readily explainable by a simple model of galactic structure. In this paper we will confine ourselves to velocities in excess of the largely arbitrary value of 100 km/s. As at lower latitudes the high-velocity gas gets more and more intermingled with the spiral-arm gas we will concentrate ourselves largely on the latitudes above 20° (except when the gas is clearly different from spiral arm gas). An important limitation is that, until now, HVC's can be studied practically only by means of the 21-cm emission line of HI.

W. B. Burton (ed.), The Large-Scale Characteristics of the Galaxy, 525–533.

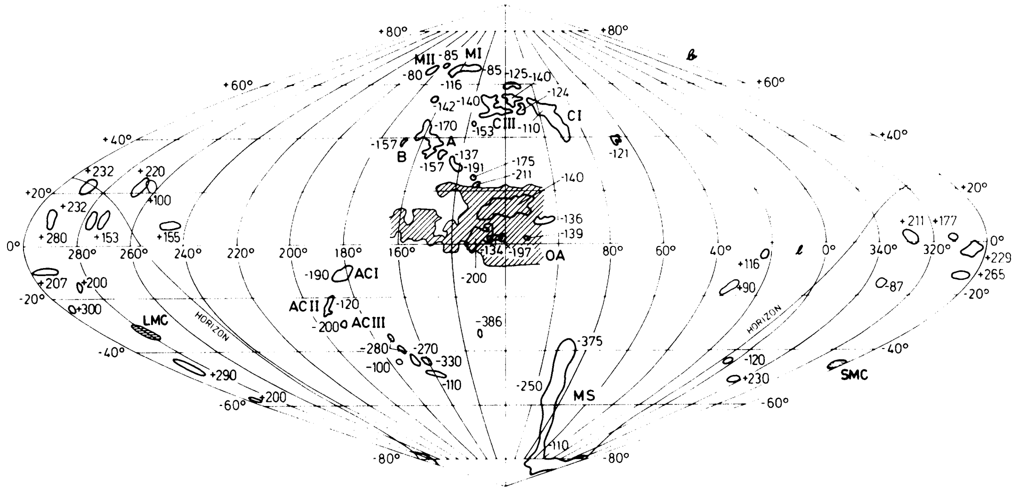

Figure 1 The distribution of features with $|V_{lsr}| > 100$ km/s. The figure is believed to be roughly complete for clouds larger than 2° or 3° over the whole sky above ±20° galactic latitude, for positive as well as negative velocities. The contour level is approximately 2×10^{19} at/cm^2. For references see text.

In the past a number of papers have reviewed the properties of HVC's. In this paper we shall give an overview and add recent new results. Figure 1 shows the distribution of all the more intense HI features with radial velocities $|V_{lsr}|$ higher than about 100 km/s relative to the local standard of rest (lsr). It is thought to be complete in both hemispheres down to galactic latitudes of 20° for clouds larger than 2° or 3° with column densities greater than 2×10^{19} HI atoms per cm^2. This map was taken from Hulsbosch (1975), supplemented for positive velocities and for the southern region (from Wannier et al 1972, Mathewson et al 1974, and Hulsbosch 1978b).

1. The distribution appears to be very uneven.

In the northern galactic hemisphere practically all the known HVC's are confined to a region between roughly 85° and 170° longitude and latitudes below +70°, exept for the small HVC 66+39-121 (the numbers denote respectively longitude, latitude and radial velocity). In the southern latitudes the brighter ones occur between l = 178° and 195°, b = -10° and -32° (the Anticentre complex), in a narrow strip between b = -30° and -85° around l = 80° (the Magellanic Stream), and in a complex around l,b = 165°,-45°. See, however, section 5.

2. There is a preponderance of negative velocities, especially in the northern galactic hemisphere.

Although the search for high-negative velocities has been made in greater detail, figure 1 should be practically complete also for the positive velocities, at least for the more extended objects. It appears that most high-positive velocity gas is found within 20° of the galactic equator in the longitude interval between 245° and 330°; at $b > +25^\circ$ no high-positive velocity gas has been found at all. For $b \geq +15^\circ$ we can make a crude estimate of the masses involved and find $\Sigma_2 Mr^{-2} = 10 \times 10^4 M_\odot kpc^{-2}$ for the negative velocities and $0.5 \times 10^4 M_\odot kpc^{-2}$ for the positive velocities. For $b < -15^\circ$ an estimate is more difficult but we can roughly say that for $100^\circ < l < 200^\circ$ (thus excluding the Magellanic Stream) there is exclusively negative velocity gas, about $0.7 \times 10^4 M_\odot kpc^{-2}$; the mass of the high-positive velocity gas, found near $l = 280^\circ$, amounts to about $0.5 \times 10^4 M_\odot kpc^{-2}$.

It has been suggested that the velocity distribution is affected by the rotation velocity of the lsr. However, it is now clear from figure 1 that galactic rotation, though it may play a role, is not the main determining factor in the distribution, especially of the negative velocity gas. There are more dense HVC's in the Anticentre quadrant than in the quadrants around $l = 90^\circ$ and 270° and the distribution in latitude does not indicate any relation with the rotation.

3. Several high-velocity complexes form long "strings".

Examples of complexes forming long strings are the Magellanic Stream (Mathewson 1974) and complex A (Hulsbosch 1975). The latter extends from $l,b = 160^\circ,+43^\circ$ to $l,b = 132^\circ,+23^\circ$. It is extremely thin, the mean distance of the components to the chain axis being less than 1°. It may extend to still lower latitudes, possibly even $b = 0^\circ$, but there it cannot be unambiguously identified. At the higher latitudes it might be connected with the MI complex via the small cloud HVC 166+56-142 but this is rather uncertain.

Though not nearly so pronounced as string A the CI-CIII complex has likewise a longish shape. Davies (1973) believes that it can be connected with high-velocity hydrogen between $b = +10^\circ$ and $+20^\circ$ around $l = 50^\circ$, but the connection is not convincing. Large velocity jumps are observed in the Anticentre complex, while a considerable velocity gradient is seen in the elongated structure between $l,b = 157^\circ,-46^\circ$ and $188^\circ,-23^\circ$ (see figure 4).

Although in its thinness string A resembles the Magellanic Stream, in many other aspects the latter differs from the other high-velocity features and it was clear from the beginning that the Magellanic Stream is a quite different object (Hulsbosch, 1975). For an elaborate discussion see the papers of Mathewson and of Fujimoto.

4. There appears to be much small scale structure.

Most large scale surveys were performed with medium sized telescopes like that of Dwingeloo, with beamwidths of about $0^\circ.5$, bandwidths of 5 to 10 km/s, detection limits of 0.5 K and observation grids of $1^\circ \times 1^\circ$ or coarser. From these it was inferred that a typical HVC measures 2° to 4°,

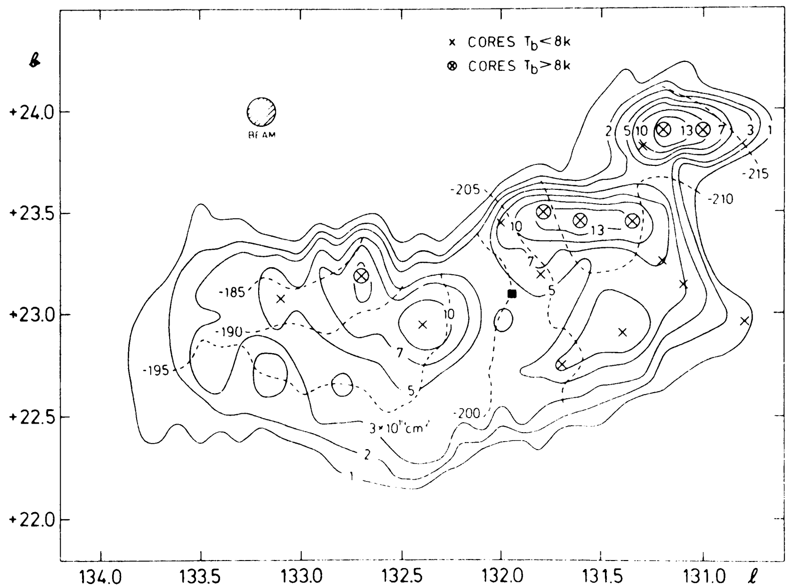

Figure 2 The high-velocity cloud HVC 132+23-211 (from Hulsbosch 1978a). Crosses indicate condensations having diameters of 5' or less.

has a T_b of up to 5 K and a profile halfwidth (W) in general between 20 and 30 km/s (e.g. Hulsbosch 1975).

Observations with higher resolution have shown a wealth of detailed structures. Chain A appears to be extremely clumpy and contains some ringlike structures, while jumps in velocity up to 50 km/s occur between various concentrations (Giovanelli et al 1973, their figure 2).

An important characteristic of several HVC's are their sometimes extremely steep edges, which make the impression of being shockfronts (Giovanelli and Haynes 1977, their figure 1). Several edges appear to be unresolved by 10' beams. Most HVC's contain small condensations, often unresolved, and having velocity halfwidths between 5 and 10 km/s, in contrast to the halfwidths of typically 25 km/s of the clouds in which they lie embedded. The intensities of these condensations may be as high as 65 K at full resolution. (Cram and Giovanelli 1976, Davies et al 1976, Giovanelli and Haynes 1976, 1977, Greisen and Cram 1976, Hulsbosch 1975, 1978a, Verschuur et al 1975). The cores are often numerous. An example is given by the Effelsberg 100-m telescope observations of HVC 132+23-211 (figures 2 and 3) showing the existence of several cores of which at least 6 are brighter than 8 K, have diameters hardly resolved by the 9' beam and profile halfwidths of 5 km/s (Hulsbosch 1978a). Their data, corrected for the beamsmoothing, are collected in table 1. With the spectral line interferometer of NRAO Greisen and Cram (1976) got striking similar results (T_b = 56 K, W = 5 km/s and diameter = 5!3).

https://doi.org/10.1017/S0074180900015035 Published online by Cambridge University Press

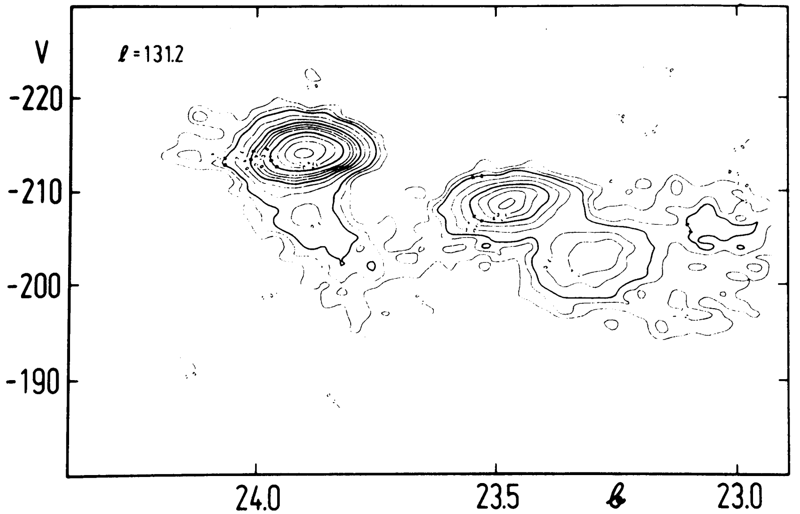

Figure 3 Contourmap of HVC 132+23-211 (from Hulsbosch 1978a). Shown are the T_b contours in the $(b,V)_l$ plane at $l = 131^\circ.2$.

It should be noted that the small-scale structure of HVC's, notably the core-envelope structure and the existence of two velocity-dispersion components might not be typical for HVC's only but a common feature for hydrogen clouds in general, commonly, hidden because they cannot be studied individually.

5. Surveys at greater sensitivity show velocities as extreme as -465 km/s.

Cooled receivers which have become available in recent years have made it possible to observe features an order of magnitude fainter than the limiting contours in figure 1; at the same time searches were extended to higher velocities. Encrenaz et al (1971) had thereby found a "bridge" of weak emission at velocities around -150 km/s extending between CIII and the upper region of A. Faint high-positive velocity hydrogen was found between 252° and 322° longitude and +10° and +30° latitude by Wannier

Table 1 The brightest cores of HVC 132+23-211

l	b	V_r (km/s)	W (km/s)	T_b (K)	$\phi_{\frac{1}{2}}$	N_H (10^{19} cm^{-2})	rn_H (cm^{-3}.kpc)	Mr^{-2} ($M_\odot$ kpc^{-2})
131°.00	23°.90	-213.2	5.7	18	8'.5	20	25	11
131.20	23.90	-214.3	4.5	62	5.4	55	110	12
131.35	23.45	-210.6	4.6	36	7.0	32	50	12
131.61	23.46	-211.4	4.8	58	5.6	54	100	13
131.79	23.50	-210.6	5.0	65	4.5	63	147	10
132.70	23.19	-186.6	5.0	18	9.0	18	21	11

https://doi.org/10.1017/S0074180900015035 Published online by Cambridge University Press

et al. (1972). A large and relatively bright cloud was discovered by Wright (1974) around l,b = 128°,-33°, V = -380 km/s, while Davies (1975) found a small cloud near M31 at a velocity of -447 km/s. Two small clouds, HVC 39+5-353 and HVC 69+4-250 are reported by Shostak (1977, see also Cohen and Mirabel 1978).

A systematic survey of a large part of the southern galactic hemisphere down to a detection limit of $T_b \approx 0.05$ K (corresponding to ~ 3 x 10^{18} at/cm^2) covering a velocity range from -1000 to +1000 km/s has recently been made by Hulsbosch (1978b). The survey will be extended over the whole sky observable from Dwingeloo. Up to the present only the area l = 100° to 200° and b = -45° and -60° to 0° has been covered. Figure 4 shows the results. It is apparent that this part of the southern galactic hemisphere is full of high-velocity features, extending to quite high negative values. Not a single high-positive velocity relative to the lsr has been found. While at the northern galactic hemisphere no velocities lower than -210 km/s are yet known, in the southern latitudes velocities down to -465 km/s are found (HVC 110.5-7-465, see also the detailed observations of this cloud by Cohen and Mirabel 1978). In the region l = 100° to 140° we found 8 objects with $-465 < V < -364$ km/s, including those of Davies (1975) and Wright (1974). The next lowest velocity in this region is "only" -204 km/s (HVC 124-12-204) indicating that the highest velocities may depict the existence of a separate (intergalactic?) stream with a mean velocity of -227 km/s with respect to the galactic centre, possibly associated with the Magellanic Stream (the rotation of the lsr being 250 km/s). At longitudes greater than 140° the picture is dominated by two large complexes, one at l,b = 165°,-45°, V ≈ -330 km/s, discovered by Cohen and Davies (1976), and the Anticentre complex (ACI-ACII-ACIII) with velocities between -100 and -210 km/s. It now appears that the former continues through HVC 168-42-240 (Meng and Kraus 1970) towards l,b = 188°,-23° where it meets the AC complex at roughly a right angle. The same feature runs nearly parallel to a string with velocities around -110 km/s, first reported by Van Kuilenburg (1972). The weakest of the many small clouds found at the southern latitudes is HVC 158-32-318 with a T_b of only 0.06 K. It is confirmed by four independent observations.

REMARKS

An attempt to observe absoption of HVC 131+1-200 against the galactic radiosource 3C58 proved to be unsuccessful, indicating that this cloud either has a spin temperature larger than 200 K or lies beyond 3C58, i.e. its distance is larger than 8 kpc (Westerbork observations of Schwarz and Wesselius 1978).

HVC 132+23-211 has cores with densities of 100 cm^{-3}.kpc. A search for CO by F.P. Israel (private communication) was unsuccessful. This should, however, not be conclusive because, even at a distance as low as a few hundreds pc the HI density is much lower than in an average molecular cloud.

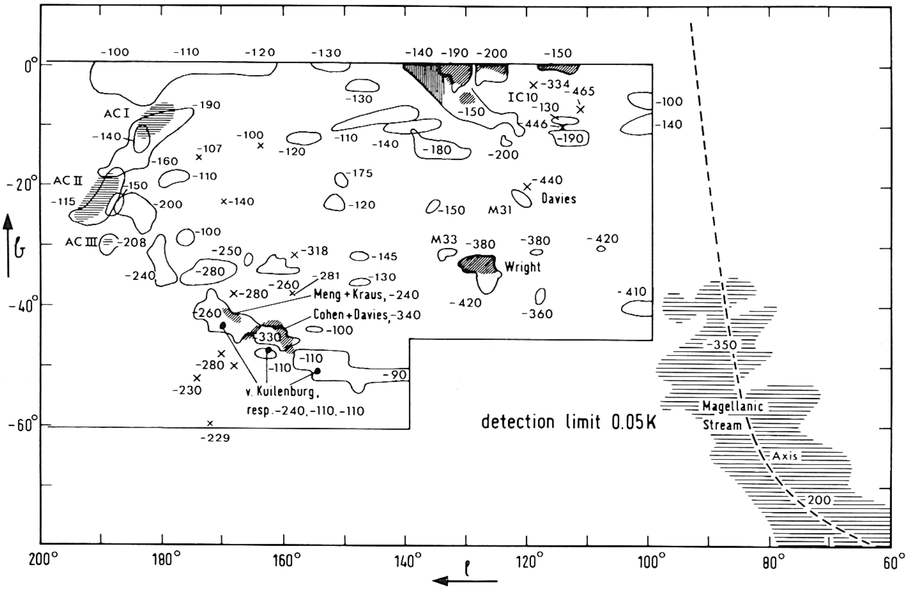

Figure 4 High-velocity features observed in a survey of high sensitivity extending from -1000 to +1000 km/s relative to the lsr (Hulsbosch 1978b, and unpublished data). Shown are the lowest observed contours (~ 0.05 K) of all the objects with $|V_{lsr}| > 100$ km/s, labeled by their radial velocity in km/s with respect to the local standard of rest (for the extended objects rounded to the nearest multiple of 10). Crosses are single positions, shaded areas denote objects already known from previous investigations; for those discovered by others the name of the discoverer is indicated.

In this report we have paid no attention to the distances of HVC's and their nature. Something, however, should be said about this. Let us concentrate on complex A. Its thin structure together with the erratic velocity jumps suggests that the present appearance has been set up only recently (within the last ten million years), most likely as a consequence of its penetration into the Galactic System. The velocity differences would then have been caused by collision of the clumps in the stream with clouds or cloud complexes in the galactic halo. It is possible that steep edges of the clumps are shockfronts associated with such collisions. The distance would be no more than let we say 3 kpc. Following a discussion of Hulsbosch (1975) in connection with the observations of interstellar absorption lines, a minimum distance of roughly 2 kpc can be inferred so that, at least for chain A, we have some idea of the distance. Another case in which a distance can be inferred (a few tens kpc) is the Magellanic Stream. Other nearby intergalactic features might be the group of very-high-velocity clouds on the southern galactic hemisphere between longitude 100° and 140°, and the string connecting HVC 160-46-330 to $l, b = 188^\circ, -23^\circ$.

The HVC's have been enigmatical for many years. At this moment we realize that different kinds of high-velocity gas exist with each its own explanation (e.g. Magellanic Stream, distant-arm extensions to high z, infalling intergalactic gas?). To get a better knowledge further observations are urgently needed. In the next years the search for weak objects in the Dwingeloo sky in the velocity range -1000 to +1000 km/s will be continued. A few bright cores are now being investigated with the new Westerbork line receiver (results are not yet available). The investigations of the small-scale structures with 10'-beam telescopes should also be continued. One of the most important (and difficult!) optical programs is the search for interstellar absorption lines in the spectra of distant stars in order to get some more idea of distances of HVC's (Hulsbosch 1975). Such an investigation should be strongly stimulated.

Acknowledgements - The cooperation of Oort in preparing this paper is gratefully acknowledged. Many of the observations described in this paper have been carried out with the Dwingeloo radio telescope which is operated by the Netherlands Foundation for Radio Astronomy with the support of the Netherlands Organisation for the Advancement of Pure Research (ZWO).

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DISCUSSION

Wollman: Can you estimate the net flow rate of the gas?

Hulsbosch: It depends on a number of unknown factors, including the cloud distances and their thicknesses along the line of sight. If we assume for the gas at $b > +15°$ an average distance of 2 kpc, a layer thickness of 250 pc and a mean velocity of -150 km s^{-1}, the observed total mass of 10^5 $M_\odot$ kpc^{-2} corresponds to an inflow of 0.3 solar masses per year.

Giovanelli: I would like to report negative results of molecular searches in the cores of HVC's, performed with Martha Haynes and Tom Guiffrida. We searched for OH and for CO at, respectively, the 140-ft and the 36-ft telescopes of the NRAO. One of the positions sampled in the OH species, in the denser part of complex A, was observed for a total integration time of 35 hours. Leo Blitz at Columbia has also searched for CO with negative results.

van Woerden: Do your results imply an anomalous abundance of OH in HVC's?

Giovanelli: Not knowing anything about distance and therefore about cloud density and environment, it is hard to set a limit on OH column density.

Felten: You said that the total mass of the clouds is of order 2×10^5 $M_\odot$ if their typical distance is of order 1 kpc. Does the inferred mass scale as the square of the assumed distance?

Hulsbosch: Yes.

van den Bergh: Did your survey turn up any dwarf galaxies?

Hulsbosch: Yes, IC 10 (HVC 119-3-334), but the observed profile was beforehand suspected to belong to such a feature because it showed the exceptionally large width of 65 km s^{-1}.