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Complex H: a case of HVC-galaxy collision?*

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Abstract. This work has been undertaken with the intention of studying the interaction between HI high velocity clouds (HVCs) and the galactic HI. For this purpose we have selected the HVC complex known as Complex H, which includes HVC131+1-200, because its low galactic latitude and its size make such interaction very likely. Furthermore, the low latitude lessens the uncertainty about its vertical height above the plane. In order to verify the existence of such interaction, we studied the available observations of the complex and we observed, in the HI 21 cm line, a region centered on HVC131+1-200 with the 100 m Effelsberg telescope. Our map for the distribution of the high velocity HI shows, within the observed region, four peaks, two of them not seen before, and, in some places, steep gradients in the column densities. The latter suggests the existence of shocks which might represent the effects of the interaction on the high velocity cloud. We studied the distribution of the HI at low and intermediate velocities, using the existing surveys of galactic HI covering the region of Complex H, and we found a hole, approximately constant in size and position, within the velocity range of -109 to -98 $\mathrm{km\,s^{-1}}$. Determining kinematical distances, the hole appears to be at about 22 kpc from the galactic center and 15.4 kpc from the Sun. We present arguments that suggest that this hole and Complex H are the results of the collision of a HVC with the galactic HI in a warped region of the Galaxy.

Key words: ISM: HVC Complex H – ISM: clouds; kinematics and dynamics; bubbles – radio lines: ISM

1. Introduction

The high velocity HI clouds (HVCs) were discovered by Muller et al. (1963) and since then their nature and origin remained an enigma, mainly because of the difficulty in determining the distances to the clouds. Several models and interpretations have been tried during the more than thirty years of study of these objects. They have been considered either as intergalactic gas, as galactic gas expelled from the disk by some sort of galactic "fountains", or as z-extensions of the outer galactic disk. Bajaja et al. (1989) and Wakker & van Woerden (1991), however, have shown that the HVC complexes do not seem to form a homogeneous group of objects but rather a superposition of groups of quite different origins.

Whatever the origin, from the work of Mirabel & Morras (1984), it has become evident that some HVCs are flowing in toward the Galaxy. The existence of this inflow means that we may expect some kind of interactions with the disk gas when the infalling HVCs are close enough to the galactic disk. In fact it has been already suggested that this kind of interaction could be the origin of large HI holes and shells ("supershells") observed in the Galaxy (Heiles 1984) and in other galaxies like M31 (Brinks & Bajaja 1986), M33 (Deul & den Hartog 1990), NGC 4631 (Rand & Stone 1996). Evidence for high-velocity gas drizzling to the plane of a galaxy has been apparently found by Rubin & Graham (1990) in the case of NGC 4258.

Some authors have reported observations that they interpret as evidence of penetration of HVCs in several regions of the Galaxy. They have been found by Mirabel (1982), Mirabel & Morras (1990) and Tamanaha (1997) for the anticenter region, by Rohlfs et al. (1989) in the Draco Nebulae and by Meyerdierks (1992) around HVC132+23-211. Alfaro et al. (1991) suggested a HVC-disk collision as the energy source for the prominent depression, named Big Dent, at $l \sim 240°$ and at a distance of about 1.8 kpc from the Sun. Stark et al. (1994) suggested the same type of collision to explain the large variation in the observed HI gas kinetic temperatures, found in high latitude cirrus clouds, on scales as small as 9 arc minutes. Franco et al. (1988), Lepine & Duvert (1994) and Cabrera-Caño et al. (1995) have put forward arguments for explaining the displacement, with respect to the galactic plane, of some nearby star-formation regions in terms of such a collision. Recently, Kerp et al (1996) found direct evidence that a large part of Complex C is colliding with the galactic disk.

In this work we continue the search for such kind of interactions in the Galaxy, but selecting HVCs at low galactic lati-

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*** Member of the Facultad de Ciencias Astronómicas y Geofísicas of the Universidad Nacional de La Plata tudes and with negative velocities. The idea is that such clouds, if their velocity components on the plane of the sky are small, necessarily will have to interact sometime with the galactic disk, increasing the chances of finding a case in which the interaction has indeed occurred. The condition of low latitude also lessens the uncertainty about their vertical height above the plane, and gives the possibility, by looking at lower-velocity gas and stars, of determining their locations in the Galaxy.

One of the most interesting HVCs at low galactic latitudes is HVC131+1-200. It was discovered by Hulsbosch (1971) and also found by Dieter (1971). A map at low angular resolution of this object can be found in Hulsbosch (1975) on which it appears as the brightest part of a larger HI complex which includes other HVCs as, for example, HVC122+1-197. Even though projection effects cannot be ruled out, all these clouds are supposed to be part of the same complex, called Complex H (after Hulsbosch) by Wakker & van Woerden (1991), because of both the regularity in the distribution of the gas and in the velocity field. The complex has a size of about $15° \times 10°$ and velocities which deviate by at least 70 $\mathrm{km\,s^{-1}}$ from the highest negative velocity expected, in the direction of the complex, assuming a normal galactic rotation. Due to its galactic latitude, its size and its velocities, we selected this object for further study.

We shall refer to HVC131+1-200 as the core of Complex H as Wakker & Schwarz (1991) did. They observed it at Westerbork, with angular and velocity resolutions of $1'$ and 1 $\mathrm{km\,s^{-1}}$ respectively. In their maps, the core breaks up into two patches at slightly diferent average velocities (-204 and -198 $\mathrm{km\,s^{-1}}$). In one of these, there is a very smooth velocity gradient (9 $\mathrm{km\,s^{-1}}$ over $10'$). On a larger scale, the velocities in Complex H gradually drop outwards from the core (Fig. 6 in Hulsbosh 1975) suggesting an expanding shell. Hulsbosch mentioned that there is, presumably, no relation between this high velocity HI complex and the gas which forms part of the Outer Arm feature O* (Kepner 1970). In the region where both features overlap, Hulsbosch saw a doubly peaked velocity profile with maxima at V = -140 and -170 $\mathrm{km\,s^{-1}}$ corresponding to feature O* and Complex H, respectively. With the data of the survey made by Burton (1985), kindly provided to us by the author, we have produced l-b contour maps for the HI distribution at several velocity ranges. The distribution for the range -220 to -180 $\mathrm{km\,s^{-1}}$ is shown in Fig. 1. The arc-like feature in the figure, connecting several peaks, is well defined. At higher velocities the HI behaves as in the case of an expanding shell till it merges with the galactic gas at -140 $\mathrm{km\,s^{-1}}$.

In both of the patches seen by Wakker et al. (1991) at the core, they detected a 21-cm absorption line in the spectrum of a background source (probably extragalactic) showing that the HI spin temperature is of the order of 50 K. Schwarz & Wesselius (1978) and Roberts et al. (1993) did not detect absorption lines against the radiosource 3C 58 at the velocities of the HVC. Furthermore, Roberts et al. were able to estimate the distance of 3C 58 as 3.2 kpc. Wallerstein (private communication to Hulsbosch 1975) did not detect absorption lines against objects at distances between 0.9 and 3.6 kpc. Lilienthal (private comunication to Wakker & Schwarz 1991) did not detect absorption lines against early type stars located at about 1 kpc. Centurion et al. (1994) found strong indication that Complex H is located at distances larger than 2 kpc. Finally, in the results of IUE observations of OB stars, Wakker et al. (1998) did not detect absorptions against four stars at distances from 3.4 to 5.0 kpc. The conclusion, from all these results, is that Complex H is located beyond the Perseus arm.

In view of the characteristics of Complex H we decided to carry out our work on this object in two ways, namely: a) by observing the HI 21 cm line, with the Effelsberg 100 m radiotelescope, on a region centered on the core of Complex H, and b) by analyzing the available previous HI observations, covering the region of the Complex H at high, intermediate and low velocities. In Table 1 are listed the references of the main HI observations made on regions which include Complex H and which have been used for our purpose.

Our aim has been to study the structure of Complex H, concentrating particularly on its core, trying to find the evidence of an interaction between the complex and the lower-velocity gas, which is almost certainly part of the normal galactic disk. In the following two Sections we describe our observations (Section 2) and the results of these observations (Section 3), and, in Section 4, we discuss the possible interpretations.

2. The observations with the Effelsberg telescope

The HI 21-cm line observations were made with the Effelsberg 100-m telescope, between May and July 1991, using a two-channel HEMT receiver with a system temperature of the order of $\sim$ 28 K in both channels. A 1024-channel autocorrelator, split into two sets of 512 channels, one for each receiver, was used as backend. The frequency switching technique, with a spacing of $\sim$ 2.6 MHz ($\sim$ 550 $\mathrm{km\,s^{-1}}$) between the signal and reference bands, was used. The signal band was centered at a velocity of -200 $\mathrm{km\,s^{-1}}$ (LSR) covering a velocity range of $\sim$ 530 $\mathrm{km\,s^{-1}}$. The velocity resolution was 1.27 $\mathrm{km\,s^{-1}}$. For an integration time of 125 seconds, the rms-noise of individual spectra was measured to be 0.1 K in brightness temperature. The brightness temperature scale was derived from observations of S7 (l = 132° , b = -1°) (Williams 1973). The overall brightness temperature scale is accurate to within 2-3%. The region defined by 129° $\leq l \leq$ 133° and -2.5° $\leq b \leq$ 5.3° was observed at $20'$ grid spacing. An inner rectangular grid, defined by 129° $20' \leq l \leq$ 132° and -0° $10' \leq b \leq 1°$ $50'$, was observed at a grid spacing of $10'$.

3. Results

The region observed by us, indicated in Fig. 1, covers the core and the eastern part of Complex H. The contour map in Fig. 2 shows the HI distribution in the region, as obtained from our observations, for the velocity range -220 to -180 $\mathrm{km\,s^{-1}}$. The highest column density in this distribution, with a peak value of 2.2×10^{20} cm^{-2}, is at l = 130° $30'$, b = 1° $10'$. There are other relative maxima, with lower peak densities, in the field as well as an extended weaker component as is the case in other

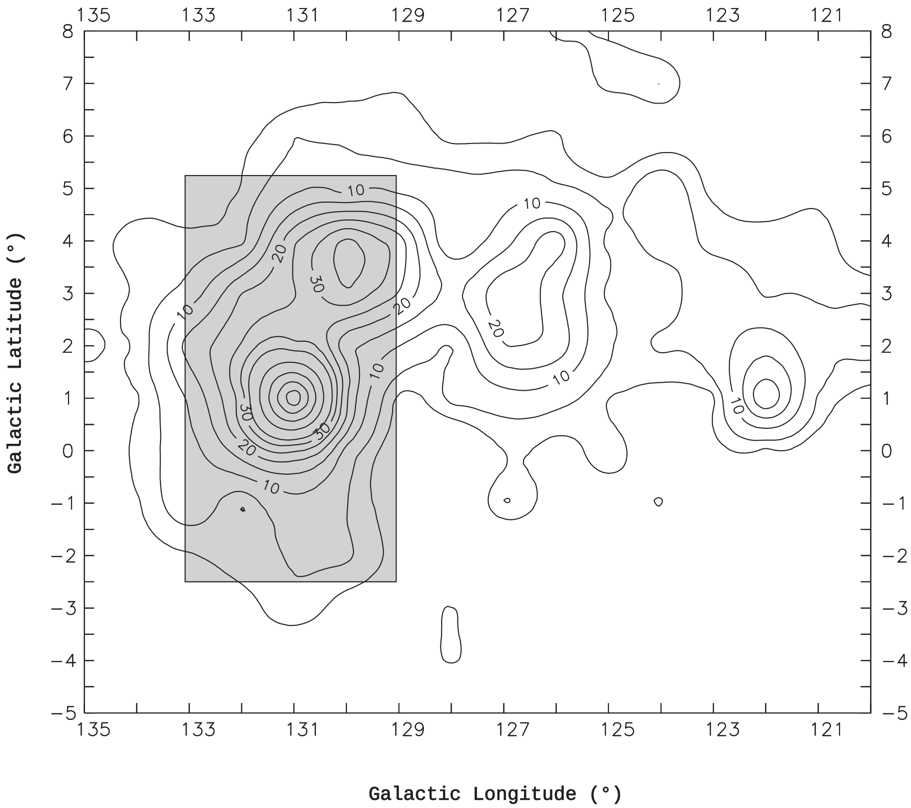

Fig. 1. HI distribution in Complex H, for the velocity range -220 $\leq V \leq$ 180 $\mathrm{km\,s^{-1}}$, in units of K $\mathrm{km\,s^{-1}}$(or 1.8 × 10^{18} $\mathrm{cm^{-2}}$ assuming it optically thin). The data were obtained from Burton (1985). The shaded area indicates the region observed by us with the Effelsberg telescope

Table 1. HI surveys containing the region of Complex H

Reference	Telescope	HPBW (′)	Vel. res. $\mathrm{km\,s^{-1}}$	Vel. range $\mathrm{km\,s^{-1}}$	rms noise K	grid (°)
Hulsbosch (1975)	Dwingeloo 25 m	34.8 × 37.8	5	-240 to -20	0.11	1 × 1
Burton (1985)	NRAO 43 m	21	1	-264 to 264	0.06	1 × 1
Hulsbosch & Wakker (1988)	Dwingeloo 25 m	35.2	8.25	-950 to 750	0.01	1 × 1
Wakker & Schwarz (1991)	WSRT	0.6 × 0.9	1.03	-227 to -163	–	–
Weaver & Williams (1973)	Hat Creek 25	35.5	2.11	-180 to 80	0.38	0.5 × 0.25
This paper	Effelsberg 100 m	9.3	1.3	-400 to 130	0.1	0.33 × 0.33 (0.16 × 0.16)

HVCs. There is another feature in Fig. 2 that is noticeable: the rather strong HI surface density gradient in the SW boundary, at around $l = 130°$, $-1° \leq b \leq 2°$, which is usually interpreted as evidence for the presence of shock fronts. The contour interval is regular and almost 20 times the r.m.s. noise in the column density data, so the high gradient seems to be real.

Fig. 2 should be compared with the maps produced with the Dwingeloo telescope (∼36′ beam) (Hulsbosch 1975; Wakker & van Woerden 1991) and with the WSRT (1′ beam) (Wakker & Schwarz 1991). Our beam, having a HPBW four times smaller than the Dwingeloo beam, provides a more detailed picture of the HI distribution than the one obtained with the Dwingeloo telescope. Two of the secondary peaks and the density gradients

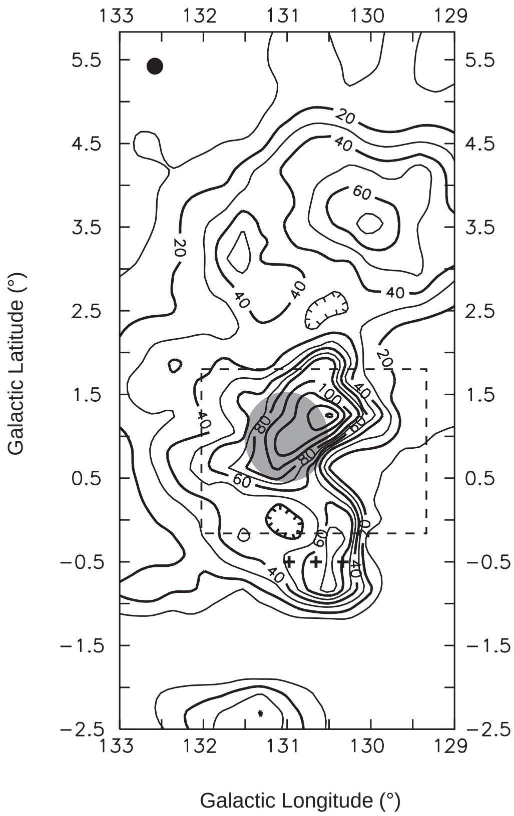

Fig. 2. As Fig. 1, with data obtained with the 100 m Effelsberg telescope. The filled circle in the upper left corner represents its HPBW. The shaded area near the center indicates the region observed by Wakker & Schwarz (1991) with the WSRT. The area delimited by the dashed line has been observed with a grid spacing of 10′. The grid spacing for the rest of the region was 20′. Crosses indicate the positions for which the velocity profiles are shown in Fig. 5

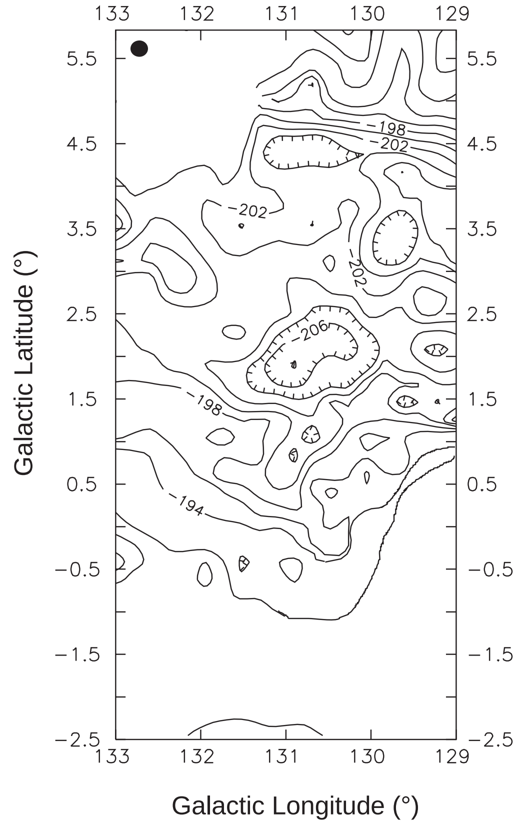

Fig. 3. Mean velocity field, for the same velocity range as in Figs. 1 and 2, produced with the data obtained with the 100 m Effelsberg telescope.

have appeared thanks to this higher angular resolution. On the other side, the angular resolution in our map is certainly much lower than that of the WSRT maps but the region observed by Wakker & Schwarz (1991) (indicated with a shaded circle in Fig. 2) is much smaller than the one observed by us.

Wakker & Schwarz (1991) did not find the gradients in the HI surface density that we see in Fig. 2 mainly because their field covers only marginally the region with those gradients. Instead, they found a series of smaller interconnected clouds and they concluded that these were, probably, instabilities in the front shocks. Furthermore, even if the regions were comparable in size, a smoothing of the WSRT map, to match our angular resolution, would not reproduce completely our map due to the missing extended component in the WSRT maps. In fact, both observations are complementary.

Fig. 3 shows the mean velocity field, for the velocity range -220 $\leq V \leq$ -180 $\mathrm{km\,s^{-1}}$, obtained with our data. It shows that the highest negative velocities ($\sim$ -206 $\mathrm{km\,s^{-1}}$) occur at the core of the complex. From there, the velocities gradually drop outowards. This behaviour is present also in the rest of Complex H, as was noted by other authors (Hulsbosch 1975; Wakker & van Woerden 1991), suggesting, as quoted before, an expanding shell. The highest peak temperature, within the velocity range mentioned above, is 13.5 K at *l* = 130° 20′, *b* = 1° 20′. The high velocity component of the HI velocity profile at this position can be fitted with two gaussian components whose halfwidths are 7 and 17 $\mathrm{km\,s^{-1}}$ centered at -197 and -200 $\mathrm{km\,s^{-1}}$, respectively.

Wakker & Schwarz (1991) measured in the core a peak brightness temperature of 22.6 K which indicates that the source is not resolved by our beam. In fact, even with an angular resolution of 1′ it is still not completely resolved (Wakker et al. 1991). In the region 130° $\leq l \leq$ 131° , *b* = -0° 30′ and at velocities between -200 and -180 $\mathrm{km\,s^{-1}}$, the HI velocity profiles show two narrow components whose widths, at 50% level, vary between 5 and 6 $\mathrm{km\,s^{-1}}$. Both components are separated by 10 $\mathrm{km\,s^{-1}}$ and both show a velocity gradient of 15 $\mathrm{km\,s^{-1}}$ per degree, the velocity increasing with l. Fig. 4 shows a few representative spectra in the region, at the positions indicated in Fig. 2, with the characteristics mentioned above.

The HI mass in the region observed by us, within the velocity range -220 to -180 $\mathrm{km\,s^{-1}}$, has been estimated as 2.6 $\times$ $10^3 D^2$ $\mathrm{M_\odot}$, where *D* is the distance in kpc (for the HI mass determinations in this paper, the optically thin condition will be assumed in all cases). Wakker & van Woerden (1991) estimated for the whole complex a total HI mass of 1.9 $\times$ $10^4 D^2$ $\mathrm{M_\odot}$ so we have observed $\sim$14% of the total HI mass. For the core itself, the estimated mass within the contour level of 7.3 $\times$ 10^{19} $\mathrm{cm^{-2}}$ (contour level 40 in Fig. 2) is 6 $\times$ $10^2 D^2$ $\mathrm{M_\odot}$.

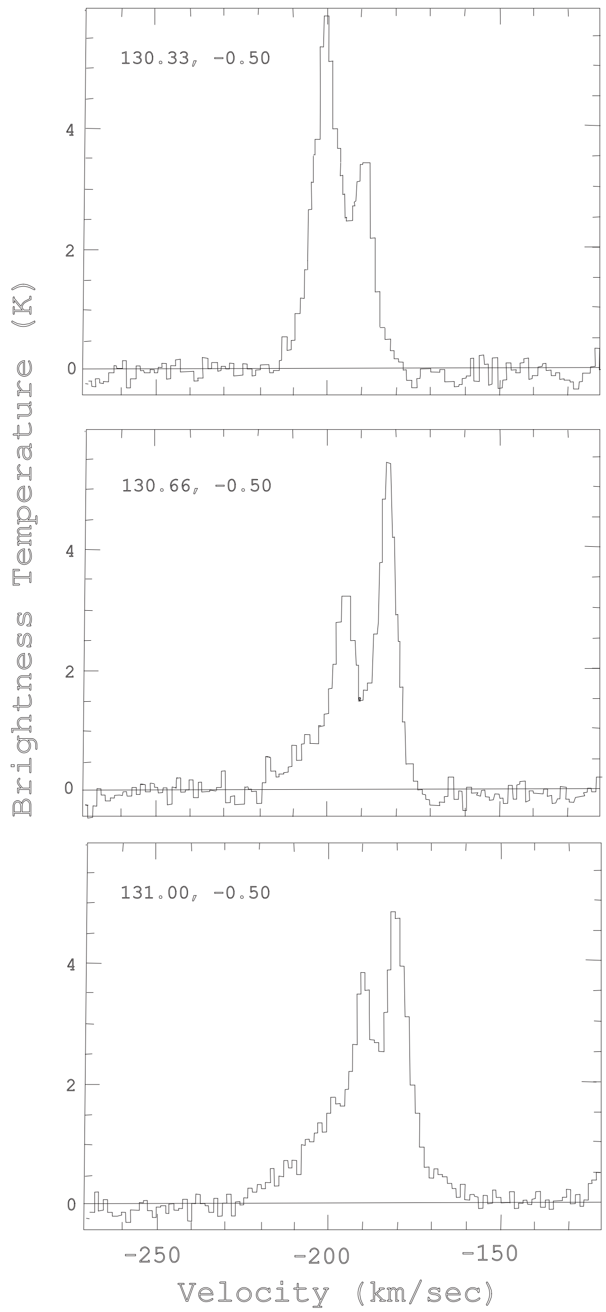

Fig. 4. HI velocity profiles, at the positions indicated in Fig. 2, as obtained with the 100 m Effelsberg telescope

4. Discussion

Analyzing their WSRT high resolution map, Wakker & Schwarz (1991) concluded that the environment of the complex must be tenuous. If this were the case, they foresee two possibilities: either the feature was originated by an explosion near the edge of the local bubble or it is located at the edge of the Galaxy. Even if the first possibility may not be totally discarded, a strong argument against it is the fact that no absorption, at the velocities of the complex, has been seen against 3C 58 or against early type stars present in the region (Section 1) which implies that the distance should be $D \geq 5$ kpc. This would favor the possibility that the Complex H is in the outskirts of the Galaxy. We might discriminate between both possibilities if an interaction with the galactic HI has indeed occurred and determining where it has taken place. The effects of such interaction should be evident in both the complex itself and in the galactic HI layer.

4.1. A shell in the outskirts of the Galaxy

In order to find the effects on the galactic HI layer, we analyzed the previous HI observations listed in Table 1, and also the maps in the paper by Burton & te Lintel Hekkert (1985, 1986), at different velocity ranges. We found a cavity surrounded by a shell at velocities of the order of -100 $\mathrm{km\,s^{-1}}$ centered at l = 129° , b = 1° . In Fig. 5 are shown the contour maps for six consecutive channels, between -109.6 and -98 $\mathrm{km\,s^{-1}}$, as obtained from the data of the HI survey of Weaver & Williams (1973), and in Fig. 6 these maps have been added to produce the HI distribution map for the whole mentioned velocity range. The shell is elongated along the plane and its size is about 7° × 3.°5. In Fig. 7 is shown, for the same velocity range, the HI distribution on the part of the shell seen with our Effelsberg data in which the higher angular resolution becomes evident.

This shell has been already identified as a stationary one by Heiles (1979) who catalogued it as GS128+1-105. Its size and position, as depicted by the peak intensities around the cavity in each panel of Fig. 5, remain approximately constant over the whole velocity range. This seems to indicate that the cavity is rather cylindrical. In Fig. 8, HI velocity profiles at several positions along the shell, covering the velocity range between -140 and -40 $\mathrm{km\,s^{-1}}$, are shown. These profiles indicate that on the shell the profiles are, in general, quite broad as the result of the presence of several components along the line of sight. This is a necessary but not a sufficient condition for a cylindrical shape.

A velocity of -100 $\mathrm{km\,s^{-1}}$, according to models for the rotation curve in the outer part of the Galaxy (for example, Brand & Blitz 1993), is not forbidden in the direction of the shell. The HI at this velocity can be attributed to the (assumed as external) arm Feature γ (Verschuur 1973) or to Feature A (Cygnus Arm) in Kulkarni et al. (1982).

The models for the rotation curve may be used to estimate the kinematic distance to the shell. This procedure has been justified by Heiles (1984) for shells having fairly large radial velocities. The reliability of this distance depends on how well the galactic rotation curve itself is known and on local irregularities of the galactic velocity field. The uncertainties in the rotation curve at large galactic radius are due mainly to the small number of optically visible HII regions, necessary for its determination, in the outer part of the Galaxy, and to the errors in the determination of their distances (about 30%). Velocity dispersion and streaming motions contribute to the irregularities in the galactic velocity field. Therefore, the large perturbations in the velocity field, originated by the formation of the shell, makes the velocities in the shell unsuitable for distance determinations. We have to use, for this purpose, the velocity of the HI in the center of

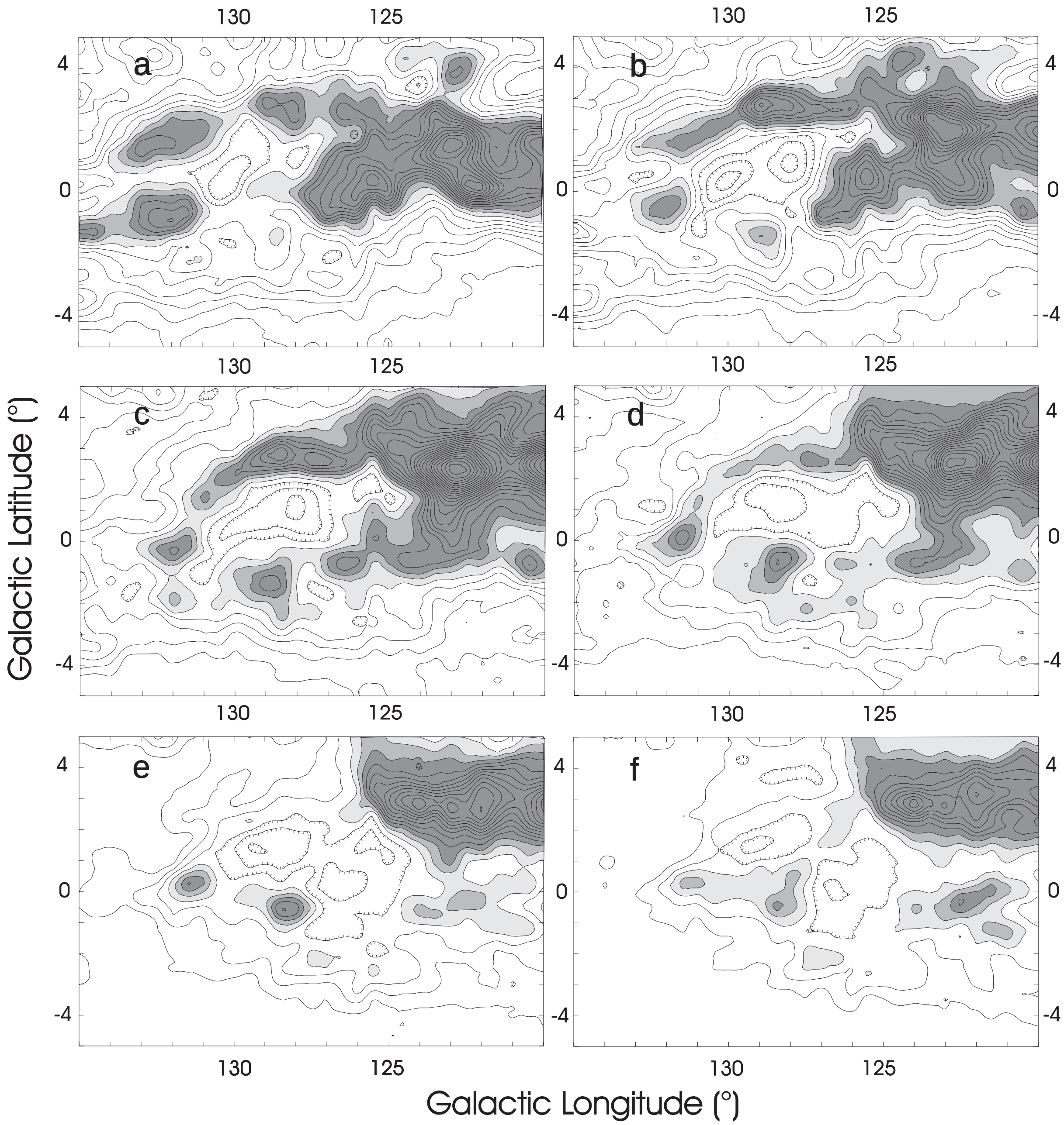

Fig. 5a–f. Contour maps for six consecutive velocity ranges as obtained from the data of Weaver & Williams (1973). The velocity ranges, in $\mathrm{km\,s^{-1}}$, are: **a** -98.0 to -99.1, **b** -100.1 to -101.2, **c** -102.2 to -103.3, **d** -104.3 to -105.4, **e** -106.5 to -107.5 and **f** -108.6 to -109.6

the cavity before its formation using the surrounding HI and to assume, in the absence of better data, that in the studied region the galactic velocity field, before the formation of the hole and the shell, was due to pure galactic rotation.

Adopting for the center of the shell the coordinates l = 129° , b = +1° and a LSR velocity of -100 $\mathrm{km\,s^{-1}}$, for the Sun a distance of 8.5 kpc to the galactic center and a rotation velocity of 220 $\mathrm{km\,s^{-1}}$, and using the galactic rotation curve of Brand & Blitz (1993), we estimated for the shell a distance of 15.4 kpc from the Sun and 22 kpc from the galactic center. This galactocentric distance is the same as the one derived by Digel et al. (1994), using a flat rotation curve, for their molecular cloud No. 1 which happens to coincide with the shell in position and velocity range (see below). Analyzing the possible sources for errors in the derived distances, they conclude that the uncertainties in galactocentric distances larger than 20 kpc, are probably 20% to 30% which, in our case, means 4.4 to 6.6 kpc. For the distance to the Sun this uncertainty amounts to 4.6 to 7 kpc.

In spite of this uncertainty in the distance, the important point is that the shell seems to be in the outskirts of the Galaxy. The galactic HI and the hole associated to the shell are visible in Figs. 3(12) to 3(14) of Burton and te Lintel Hekkert (1986). The rotation curve used by these authors to calculate the kinematical distances was not, obviously, the same as the one used by us but

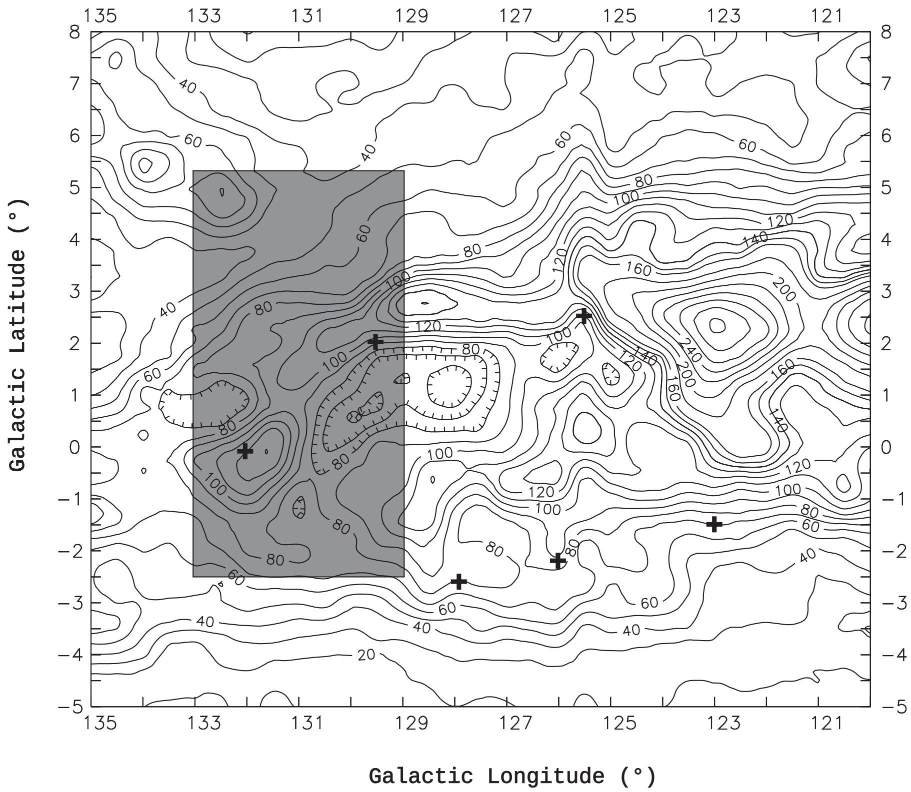

Fig. 6. As Fig. 1 but for the velocity range -108.6 $\leq V \leq 98\ \mathrm{km\,s^{-1}}$(sum of the channel maps of Fig. 6). The shaded area indicates the region observed by us with the Effelsberg telescope and the crosses indicate the positions for which the velocity profiles are shown in Fig. 8

the figures are valid to show the shape and the relative position of the hole.

At the estimated distance, the mass of the gas in the shell determined from the contour map of Fig. 6, using as limiting contour level 80 K $\mathrm{km\,s^{-1}}$(1.46 $\times$ 10^{20} $\mathrm{cm^{-2}}$) and assuming solar abundances, would be 7.3 $\times$ 10^6 $M_{\odot}$. If we assume that the gas in the shell is gas displaced from the place where the cavity was formed, the average volume density of the gas before the formation of the cavity, assumed as spherical with a mean radius of 670 pc, was 0.23 $\mathrm{cm^{-3}}$. This value would be a lower limit because a) part of the gas could remain ionized; b) some clouds could be optically thick, and c) part of the gas could be ejected to higher z values. The assumption of a spherical shape for the cavity is the simplest one we can make. The velocities of the components in the velocity profiles along the shell, as those seen in Fig. 8, may be not used to derive a "kinematical volume" for a cylindrical shape because of the perturbation of the velocity field mentioned above.

The energy which would be required to produce the cavity by a sudden explosion, estimated in the same way as was done by Heiles (1979) but using the distance and HI volume density as derived by us, would be $\sim 10^{53}$ erg. The size and the energy allow us to refer to this structure as a supershell. If this shell were related to the Complex H, then the kinematical distance would also favor the possibility of the Complex H being in the outskirts of the Galaxy.

4.2. The origin of the shell

4.2.1. The shell as result of the evolution of massive stars

Before attempting to relate Complex H to the genesis of the supershell, however, we have to discard other possibilities for the origin of this shell. Processes related to the evolution of massive stars (ionizing radiation, stellar winds, supernovae) are usually thought to be responsible for most of the shells, supershells and bubbles observed in the interstellar medium. Let us assume that only stellar winds have played a major role in shaping the -100 $\mathrm{km\,s^{-1}}$ feature. Following McCray (1983) (his formula 4a), the age of the shell may be of the order of 40 $\times$ 10^6 yr (assuming a shell expansion velocity of 10 $\mathrm{km\,s^{-1}}$) and, with the mean volume density of 0.23 $\mathrm{cm^{-3}}$ derived above, the mechanical power needed to create the -100 $\mathrm{km\,s^{-1}}$ HI hole amounts to $\sim$ 3.4 $\times$ 10^{37} erg in the energy conserving case, or $\sim$ 13 $\times$ 10^{38} erg in the momentum conserving case.

For illustrative purposes, this mechanical power is $\sim$ 0.7 (energy conserving case) and $\sim$ 20 (momentum conserving case) times the mechanical power injected into the ISM by the open cluster Tr 16, known to contain several O3 stars which are the earliest and most massive stellar species in the MK classification scheme (Walborn 1982). For this comparison, the tabulation of Vacca et al. (1996), for O type stars, the mass loss rates given by Lamers & Leitherer (1993), and the escape wind velocities calculated by Leitherer et al. (1992) were used.

Since the age of $\sim 40 \times 10^6$ yr is much larger than the typical main sequence lifetime of O type stars, it could be argued that all the massive stars in this hypothetical stellar aggregate should

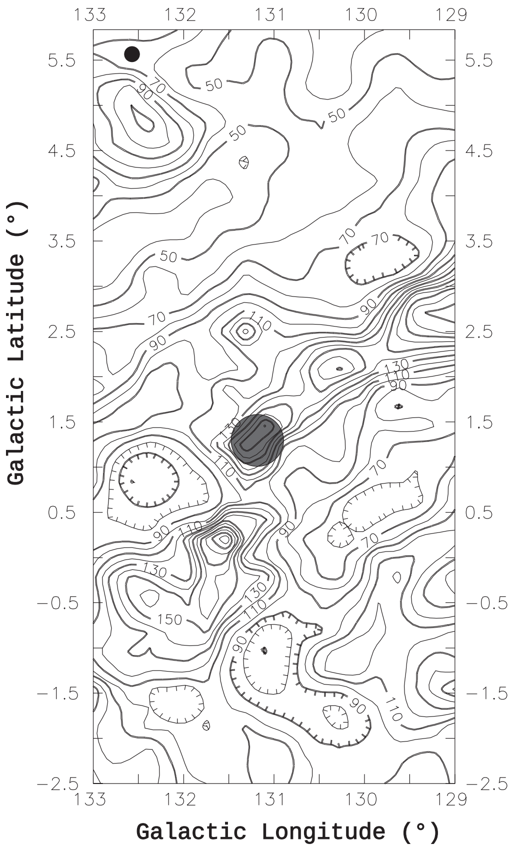

Fig. 7. As Fig. 6 but with data obtained with the 100 m Effelsberg telescope. The shaded area indicates the region in which Diegel et al. (1994) detected a molecular cloud

have undergone a supernova explosion, each releasing $\sim 10^{51}$ erg of energy (McKee 1990). In this way, the -100 $\mathrm{km\,s^{-1}}$ shell could have been created by the combined action of stellar winds and supernova explosions (SNe). Therefore, if stellar winds and SNe have contributed to the creation of the HI shell, in spite of the large uncertainties of the numbers mentioned above, it is inescapable that a conspicuous stellar aggregate had to exist at a galactocentric distance of $\sim$ 22 kpc.

Although the shell might conceivably be formed by the stellar winds and explosion of a large number of massive stars, a couple of arguments may conspire against such interpretations, namely:

a) Although Mead et al. (1990) showed that massive star formation seems to be only less active at about 15 kpc from the galactic center than in the inner part of the Galaxy, no observational evidence exists that such type of star formation activity occurs indeed in its outermost part.

b) Another indication of star formation activity in the area might be the presence of IR sources associated with molecular clouds. Wouterloot & Brand (1989) observed the ^{12}CO(1-0) transition line in the direction of 1302 sources included in the IRAS point sources catalogue (*IRAS* Explanatory Supplement 1985), within 10° of the galactic plane and at galactic longitudes between 85° and 280° . These sources had the infrared colors which characterize regions where star formation is taking place within a molecular cloud. No IRAS point sources at galactocentric distances $R > 18$ kpc, in the direction of Complex H, were observed (Digel et al. 1994).

c) In 40×10^6 years the shell would move about 23.°5 in its orbit (assuming a rotational velocity of 220 $\mathrm{km\,s^{-1}}$) and the differential rotation would produce a severe distortion of its shape.

In consequence we believe that these arguments lessen the chances of finding such kind of massive star aggregate in the outskirts of the Galaxy and considerably reduce the possibility of a galactic internal violent event as the origin of the shell at $V \sim$ -100 $\mathrm{km\,s^{-1}}$.

4.2.2. The shell as a result of the collision of a HVC with the galactic disk

We shall consider now the possibility that the supershell was originated by a collision of a HVC with the galactic disk. Such kind of collisions may take place anywhere without restrictions of mass and energy (Tenorio-Tagle et al. 1987). The observation of HVCs falling down toward the Galaxy indicates that this interaction may take place indeed and that it can be quite violent, depositing large amounts of energy in a short lapse. The modeling of the collision of HVCs with the gas of the galactic disk, under a variety of conditions, has been carried out, among others, by Tenorio-Tagle et al. (1986, 1987), Meyerdierks (1991), Comerón & Torra (1992, 1994) and Rand & Stone (1996).

Head-on and oblique collisions of a large HVC (diameter $\sim$ 500 pc) with the galactic disk were studied by Comerón & Torra (1992). They showed that it is possible to produce, through these collisions, an important re-distribution of the gaseous mass and gas phase transitions and be able to originate extended, dense and cold regions where star formation may take place. In their models, the compressed material lying between the two shock fronts remains trapped and, in the case of head-on collision, they can escape very slowly. In an oblique collision, instead, because the material entering the shocks has a velocity component parallel to the shock surfaces, there is an appreciable flow of compressed material escaping from the shock layer (see their Figs. 1a and 2a) and it can reach sizes larger than 2 kpc. They found that this material is slowed down by the surrounding unperturbed galactic disk gas and finally it appears as roughly outlining the path followed by the shocked region through the galactic disk. The final velocities of the shocked regions, with respect to the rest of the galactic disk, are much smaller than the initial cloud velocity.

Wakker & Schwarz (1991) mentioned that a possible explanation for the origin of Complex H could be that a high velocity dense cloud hit the disk sideways and accelerated the gas by means of shock waves. In this case, the center of Complex H would consist of the remains of the original cloud while the rest of the object would consist of gas ”originally present but now pushed aside” (it is not clear whether the authors meant that it was ”present” in the HVC or in the galactic disk). We believe that the observational results, in the case of Complex H, are consistent with this interpretation and with some of the

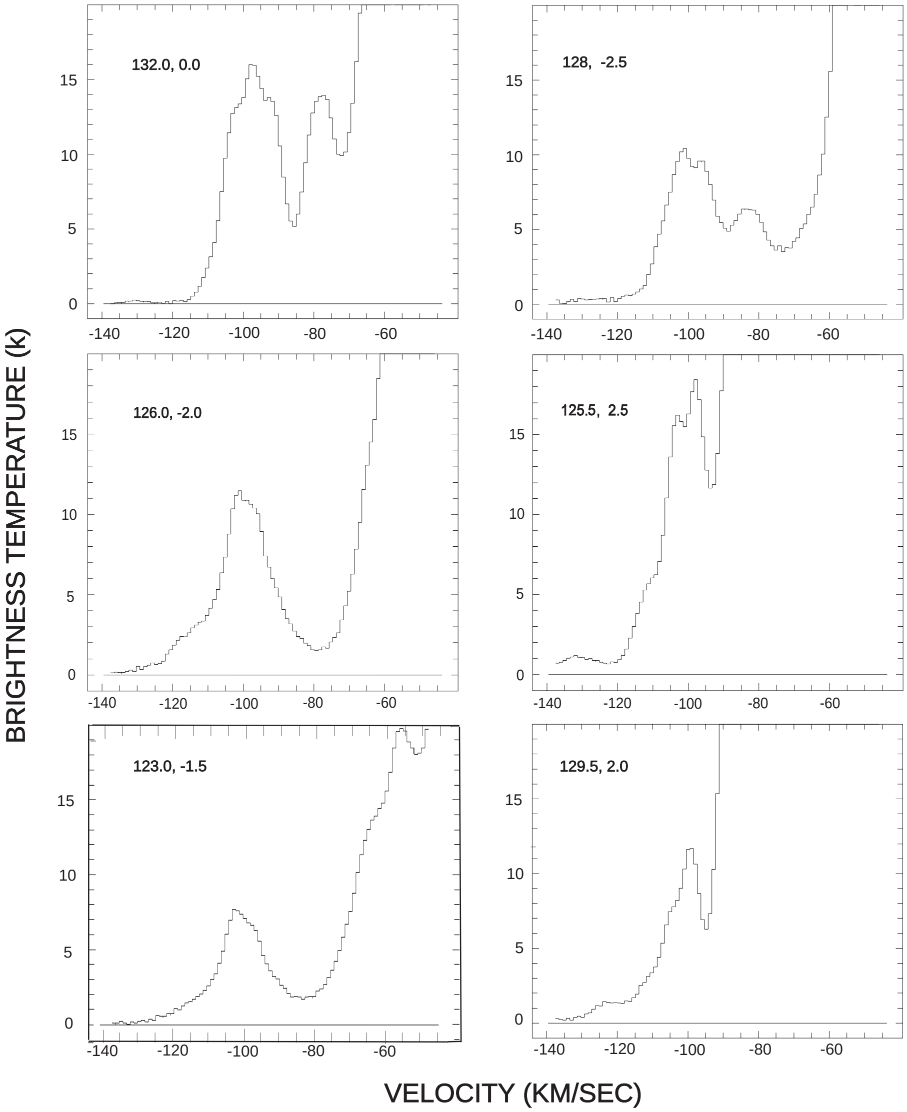

Fig. 8. HI velocity profiles along the shell at the positions indicated in Fig. 6

results produced by the models described above. Since we do not intend to build a particular theoretical model for Complex H, we use those results only for a possible interpretation of the observational data.

4.3. *Interpretation of Complex H and of the shell*

On the basis of our Figs. 1, 5 and 6 and Fig. 3 of Burton & te Lintel Hekkert (1986) we suggest, as Wakker & Schwarz (1991) did, that a HVC hit the galactic disk on the side but, more specifically, along a line parallel to the galactic plane and 0.3 kpc above it. The collision would have occurred at $R \sim 22$ kpc, $\theta \sim 140°$ (θ = 180° at the anticenter), where the galactic HI layer is about 1 kpc above the plane. The results of this collision depend on the relative value of the volume densities in the HVC and in the disk. We assume that Complex H is one of the results of this collision, the one that consists of the remains of the original HVC plus the material that might have carried along. We also assume that the HVC remains should be found in the place where the volume densities are highest, i.e., in the core. The volume density in this place, however, most probably will be not the same as the original one, before the collision. The estimation made by Wakker & Schwartz (1991) for the highest densities in the core, as seen in their WSRT map, at a distance of 20 kpc from the galactic center, is $\sim 5\,\mathrm{cm}^{-3}$. If the original density was of this order, it was much higher than that of the disk gas with which it interacted ($< 0.5\,\mathrm{cm}^{-3}$) and, according to Tenorio-Tagle et al. (1986), the HVC was able to generate a cylindrical hole in the disk gas and be little perturbed during this process.

This hole would be the other result of the collision and would be originated by the sweeping of the gas by the HVC and by some expansion due to the thermal energy generated in the shock. According to Franco (1996), this thermal energy would be short lived so soon after the interaction there would be low pressure in the cavity and it should contract laterally. The fact that the hole is still so large would indicate, in this case, that it is relatively young. The galactic HI and the hole produced in it by the HVC are depicted in the mentioned Figs. 3(12) to 3(14) of Burton & te Lintel Hekkert (1986).

The less dense and more extended regions of Complex H would consist of the gas swept from the disk, from the place where the cavity was formed by the shock front, and observed as a shell expanding in less dense regions of the Galaxy. The two velocity peaks, observed in the HI velocity profiles of Fig. 4, are indicating two different components of the gas in the region near the core of Complex H. These components could correspond to a) the rest of the high velocity HI infalling cloud, and/or b) part of the Complex H itself.

The whole picture of the hole and of Complex H, as results of a collision of a HVC with the galactic disk, sketched above is consistent with the results of Comerón & Torra (1992) as shown in their Fig. 2a for an oblique impact. The precise location of Complex H is not well defined but in view of the apparently recent origin of the cylinder and the fact that the hole is not seen to continue in the galactic HI along the path, it should be between the inner end of the cavity and the Outer arm. We shall adopt 14 kpc for its distance to the Sun.

If the origin of the shell is effectively related to the HVC, we can use its distance for mass determinations. Using the expressions derived in Section 3 we estimate the upper limits of the HI mass in the core of the complex as 1.2×10^5 $M_\odot$ and the HI mass in the whole Complex H as 4.0×10^6 $M_\odot$. The relative velocity between the HVC and the supershell would be ~ 100 $\mathrm{km\,s^{-1}}$, and the upper limit of the kinetic energy of the core, in the radial direction would be $1.2\,10^{52}$ erg. No information exists about the velocity component in the plane of the sky. If we assume that the core is only part of the original HVC, the mass and the kinetic energy of the latter would be larger than the values estimated for the core.

Digel et al. (1994) showed the existence of molecular clouds in the outermost parts of the Galaxy. Their Cloud 1 overlaps in position with part of the shell, at around l $\simeq$ 131°.1, b$\simeq$ 1°.5, as can be seen in Fig. 7, and also in velocity (between -107 and -98 $\mathrm{km\,s^{-1}}$). The column densities are $\sim 3.4 \times 10^{20}$ and 0.5×10^{20} $\mathrm{cm^{-2}}$ for the HI and and the H_2, respectively. This correlation seems to indicate a physical relation between the molecular gas and the supershell at $\sim$ -100 $\mathrm{km\,s^{-1}}$as the model of Comerón and Torra (1992) predicted. No other observational data exist for a better correlation. No IRAS point source, which could be associated with this molecular cloud, has been found by Digel et al. (1994). As they mentioned, this lack of association can strictly rule out the presence of embedded OB stars.

Recently, Ivezic & Christodoulou (1997) found a close correspondence between the source IRAS 01572+6248 and the HI in the core of Complex H as mapped by Wakker & Schwarz (1991). The dependence on the wavelength of the emission of this IRAS source indicates that it is a young stellar object (YSO). IRAS 01572+6248 is also seen projected on the ridge of the -100 $\mathrm{km\,s^{-1}}$HI shell (Fig. 6 and 7), which might indicate an association with this shell (instead with the core of Complex H) as we suggested for the molecular cloud in the previous paragraph. The possibility of a chance coincidence, however, may not be discarded.

4.4. Very high velocity clouds in the region

About the material which might have caused the original shock front, it should have had a velocity equal or larger than the core. We searched for HVCs with higher velocities in the HI survey made with the Bell Lab by Stark et al. (1992). In this region of the sky, this survey lists HI detections at velocities between -400 and -300 $\mathrm{km\,s^{-1}}$. The high velocity HI survey of Hulsbosch & Wakker (1988), however, does not confirm these detections. We extended the comparison between both surveys to a larger region of the Galaxy (150° $\leq l \leq$ 200° , -20° $\leq b \leq$ 15°), in which Stark et al. detected, apparently, tens of very high velocity clouds (VHVC) but none of them could be confirmed with the data of Hulsbosch & Wakker. The sensitivity of both surveys are similar (r.m.s. = 0.017 and 0.01 K, respectively) although the beams and the velocity ranges are different. Some of the detections of VHVCs by Stark et al. are well above the noise and seen in several observations so they appear to be real. It could be possible that sistematic errors in the process of correcting the baselines might have produced some artifact in the data that later on could be interpreted as real HI features. The same, however, could be said about the spectra of Hulsbosch and Wakker in the sense that the lack of detections might be due to overcorrections. Another possible explanation for not seeing the VHVCs in the survey of Hulsbosch and Wakker could be the fact that, in this one, the sky has not been fully sampled but this would require that all the VHVCs happen to be in the the not sampled areas of the sky, something that we consider highly unlikely.

The recently published HI survey of Hartmann and Burton (1997) is much less sensitive (r.m.s.= 0.07 K) to use it for comparison. The question of whether the existence of the VHVC is real or not deserves to be confirmed by new observations.

5. Summary

We have observed a region of Complex H, centered on HVC131+1-200 (or core), in the HI 21-cm line with the 100 m Effelsberg telescope. Its 9′.3 beam is intermediate between the usual beam for large surveys (about 30′) and the synthesised beam of large arrays which is much smaller but unable to map features on scales corresponding to spatial frequencies smaller than those measured by the shortest interferometer spacing. Our results show the presence of several peaks in the HI distribution and regions with enhanced density gradients which, we believe, are indicative of shock fronts. The regularity and the gradients in the velocity field show that all components are part of an expanding structure (the Complex H).

Different observations of absorption lines in the area, against radiosources and early type stars, indicate that the Complex H is located at more than 5 kpc from the Sun. The analysis of the galactic HI distribution at lower velocities, in the same region of the sky, showed the presence of a hole and a shell, stationary at velocities between -108 and -99 $\mathrm{km\,s^{-1}}$, which correspond, apparently, to a cylindrical cavity. Assuming that the rotation curve in this region is as given by Brand & Blitz (1993), its kinematical distance is $\sim$ 15.4 kpc from the Sun and 22 kpc from the galactic center. The energy input required to generate this cavity is of the order of $\sim 10^{53}$ erg. There is no evidence that the source of energy injection could be stellar.

The cylindrical shape for the cavity and the energy involved in its formation is consistent with the model of Comerón & Torra (1992) that assumes an oblique impact of a HVC on the galactic disk. The Complex H should be somewhere between the cavity and the Outer arm. We assumed a distance to the Sun of 14 kpc. At this distance the HI masses of the core and of Complex H are 1.2×10^5 and 4.0×10^6 $M_\odot$, respectively, and the kinetic energy of the core, with respect to the medium, 1.2×10^{52} erg.

It ought to be stressed that all these numbers are derived from a kinematical distance which has a large uncertainty. The important point, however, is that Complex H appears to be in the outskirts of the Galaxy.

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