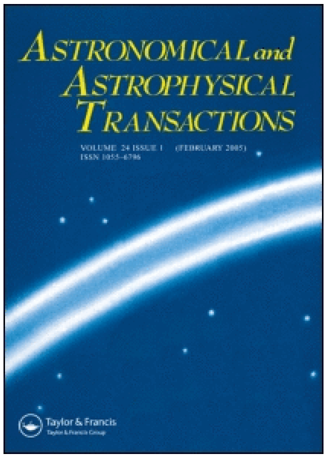


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# New arguments on nearness of the HVC stream of the kapteyn group

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# NEW ARGUMENTS ON NEARNESS OF THE HVC STREAM OF THE KAPTEYN GROUP

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More than in 2200 sky points H I have radial velocities, satisfying the condition: $|v_r + 289 \sin l \cos b| \leq 50$ km s$^{-1}$. This system of high-velocity clouds (HVC) consists of individual filaments. The arguments on their nearness to us are: (1) community with the nearby Eggen stellar group; (2) features of close interaction of filaments with the giant molecular clouds situated inside the radioloops, which belong to the Local System; (3) symmetrical disposition of HVC filaments relative to both the stellar group and radioloops.

KEY WORDS High-velocity clouds, Kapteyn stream

Ideas about the nature of high-velocity clouds H I (HVC) vary mainly in terms of the distances involved. In some hypotheses the HVC are very remote, even outside Galactic limits; in others — at distances of some kiloparsecs inside the Galaxy, but even then they are huge and massive objects. The hypothesis of near and small HVC has been furthered by the absence of reliably established absorption lines in spectra of stars situated behind them.

Is this argument strong enough? Detailed examinations (Schwarz and Oort, 1980) have discovered very thin structure of clouds which is small and grainy. The better the observational technique the smaller the grains. The probability of exact screening of a star by the grain of a HVC is not as great as by the continuous extent cloud. Also, the optical thickness of a grain must be enough to make the visible absorption line.

Apart from the discovery of these lines, it is desirable to obtain other evidence of nearness. This could be the correlation of HVC with nearby objects — the stars, or with radio- and X-loops.

It is doubtful whether one should consider all HVC together as they can be at different distances. Let us limit ourselves to the group of the Kapteyn stream (Shatsova, 1993a). Reasons exist to connect it with the nearby Eggen's stellar Kapteyn group, undoubtedly belonging to the halo subsystem. Taking into account the great age of its stars ($\sim 10^{10}$ yr), one can assume that during 10s of revolutions around the Galactic centre the stream has stretched along the whole orbit or circular ring. In any case it is considerably more stretched than the observed $\sim 2$ kpc.

The reason for connecting the HVC with stars was that about 50% of the group's stars have the neighbouring HVC with almost the same radial velocity $v_r$ (Shatsova, 1993a). For the whole stream it is not necessary to tie all clouds to the concrete stars. It is enough for them to move identically. This means that HVC and stars — the group members, must satisfy one and the same condition:

$$|v_r(l,b) - v_r^k(l,b)| \leq (1-2)\delta.$$

Here $v_r^k(l,b) = -289 \sin l \cos b$ is the stream radial velocity at the point with coordinates $(l,b)$, if the space velocity $v^k = 289$ km s$^{-1}$ is directed to $l^k = 270°$, $b^k = 0°$. The velocity dispersion of group stars is $\delta = 50$ km s$^{-1}$.

So far as $v_r = 80$–$100$ km s$^{-1}$ is attributed to the HVC then the clouds with large $b$ and $l$ near to 0 and 180° (±20°–30°) are excluded.

Recent arguments for Kapteyn stream nearness are determined from examination of all the HVC in the catalogues of Bajaja *et al.* (1985) and Hulsbosch and Wakker (1988). More than 2200 points occur on the HVC whose $v_r$ differ from $v_r^k$ by not more than for $\delta = 50$ km s$^{-1}$. They are shown by dots in Figure 1. As we see, the present HVC are dissipated over all the sky, and besides not uniformly. There is not a wide continuous front but a small number of filaments.

If the HVC picked out are really moving from $l = 90°$ to $l = 270°$, then the question of symmetry relative to this direction or the corresponding galactic meridian is interesting.

In Figure 1 in the left hemisphere we see some symmetry relative to $l \approx 90°$. This is an almost complete absence of points in the region $90 \pm 30°$ along $l$ at all $b$ more southern than $+30°$. In this region the symmetry is for places with a concentration of points. They form the arc in the northern hemisphere between $l \approx 15°$ and 170° (within the limits of HVC observations); the top of the arc is at $l \approx 90°$ from large latitudes upto $\leq 45°$. The filament of the eastern part of arc is, perhaps, observed also in quadrant (180°, 270°). The symmetry we see also at southern latitudes. An almost circular or oval rings with the central meridian are near $l = 90°$–$100°$. The diameters of the rings (or their projections) are between $l \approx 40°$ and 150°–170° and between $b = +10°$ and $-80°$. Near the poles the points are almost absent, obviously because of $\cos b \approx 0$.

It is natural that the symmetry at all $b$ is not exact and not complete. First of all, concerning the point density: at the side $l > 120°$ it is greater than at $l < 60°$.

Besides filaments, symmetrical relative to the symmetry plane, let us point out two filaments in the plane itself. The first one is at large positive latitudes at $l < 270°$, the second is southern, but at $l \geq 270°$. It looks as though the symmetry plane is somewhat turned relative to the meridian $l = 270°$.

In this case it passes through the filament, usually connecting with the Magellanic clouds. We call it a Magellanic Filament at $l \approx 90°$.

It is hard to imagine that such stretched HVC filaments are far from us and from each other. But they are moving identically in space and are symmetrical relative to the Solar orbit (directed to $l = 90°$). And one side of the arc in quadrant (180°, 270°), even partly went around the Sun from behind. There are no such difficulties in the case of the near Kapteyn stream.

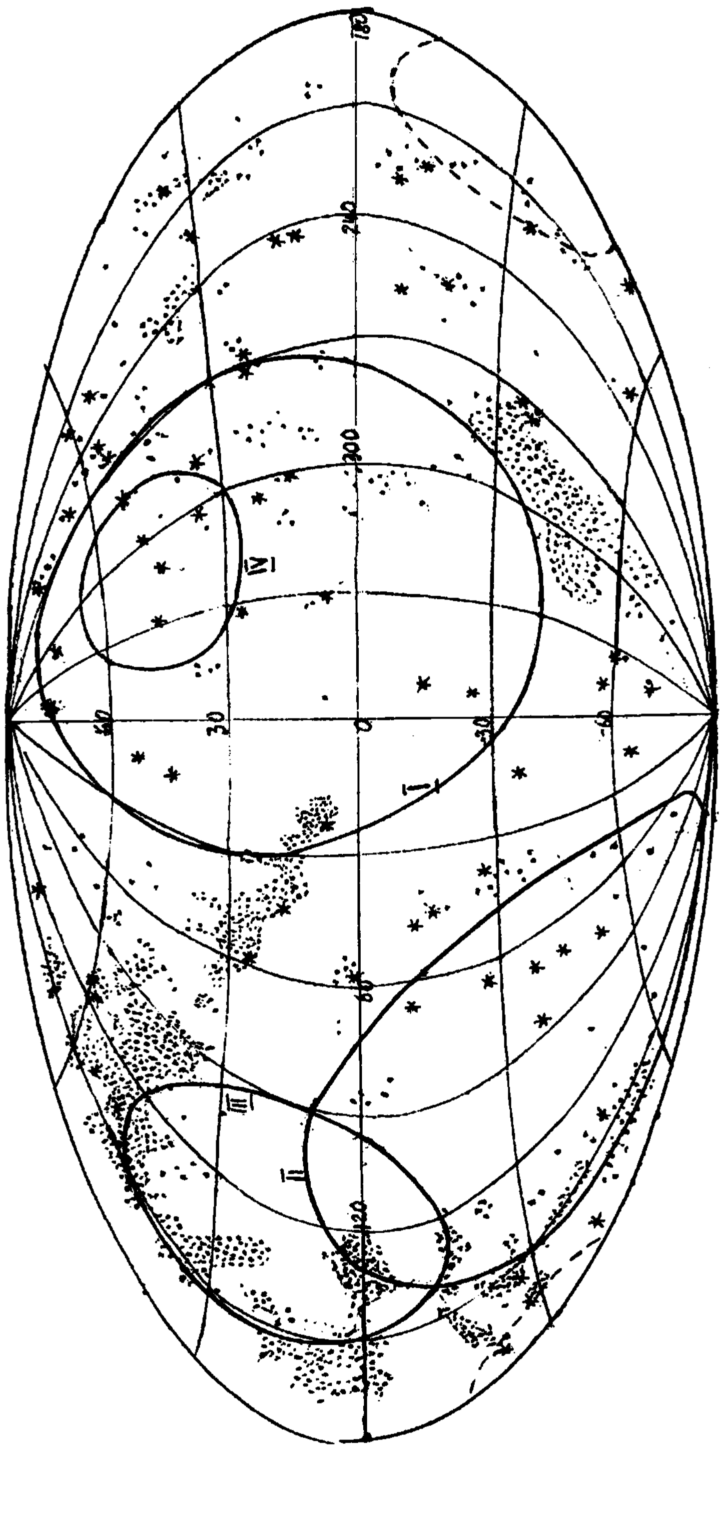


**Figure 1** HVC of Kapteyn group (·), radioloops I–IV, stars of the Kapteyn group (*).

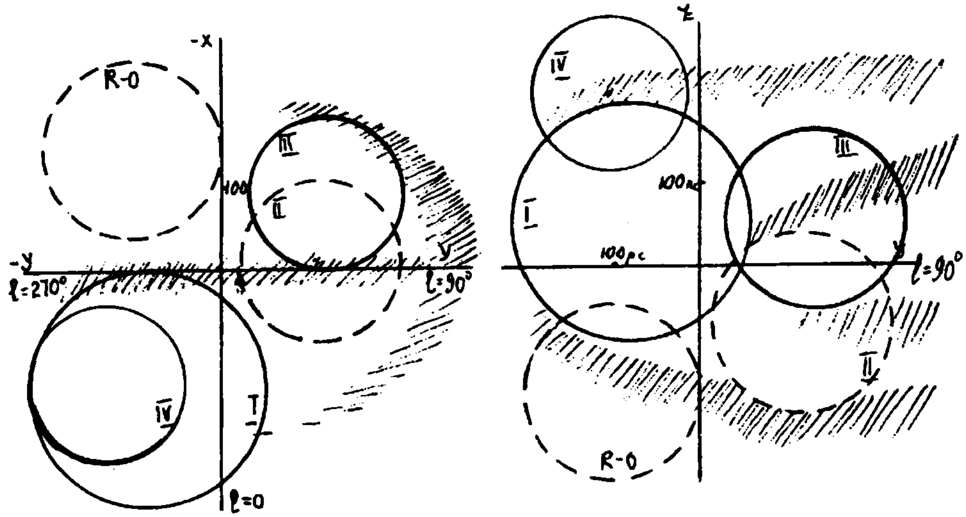


**Figure 2** $(x, y)$ and $(y, z)$ projections of HVC filaments (shaded) and radioloops (continuous lines at $b > 0$, dashed lines at $b < 0$).

On the other hand, it is doubtful, that all the major elements of HVC system — the arc, the ring and the Magellanic Filament initially had these forms. It is more probable, that originally the Kapteyn stream consisted of several narrow rays parallel to the line $l = 90°–270°$, $b = 0$. And only during interaction with the Local System and the rays develope the forms observed. More exactly, it is the interaction with Giant Molecular clouds (GMC) of $10^5$–$10^6 M_\odot$. The loops, observed as radioloops I–IV, serve as the spheres of tidal radius. Four radioloops are shown in Figure 1 over a Landecker and Wielebinski (1970) map. The dotted line shows the shell in Orion and Eridanus (R–0) over Reynolds and Ogden (1979). At distances of 100–250 pc the linear radii of shells are 100–150 pc (Berkhuijsen, 1973).

We have already dealt with the dynamic GMC action in the radii of their shells (Shatsova and Anisimova, 1990a, b) during the examination of the distribution of stellar clusters. They are absent in large shell volumes, but they are moving in the narrow corridors between them. Apparently, the clusters, which during their motion have crossed the shells, were destroyed by the GMC tidal forces. The released stars are filling in the rather thin shell. In the same situation there can also be other rather stretched, not very compact objects. They may be the gas or dust clouds. Perhaps, the extreme rarity of very hot gas ($T > 10^6$ K) inside the shells is connected with this fact. The gas is found here, mainly in the nucleus and along the bar.

These facts led us to a joint examination of the HVC Kapteyn stream and shell system. If the facts of their interaction could be discovered, then it would be an important argument for nearness of these HVC.

As one would expect, even excluding the sections with sin $l \approx 0$ in Figure 1, there are not many HVC in the great area of loops. Perhaps, they are completely absent in the shell volumes, as in the stellar clusters. But the Kapteyn group stars are present, at least, in loops I and II. This means that just these stars are deprived of neighbouring HVC. The group stars, situated between the loops (the majority, but not all) are combining with HVC. One can understand this fact, if while the pair crosses the shell the HVC is being destroyed and is dissipating. But the stars with high velocities are freely passing, perhaps being slightly deflected in direction. Outside the near HVC will be stars, which came from the shell. So the question of combination of stars and HVC is more one of regularity than chance.

The majority of HVC in Figure 1 are near the loop limits and between the loops. One can see on the map, that the loops are connected by the powerful HVC filaments. Loops III and I by the western arc part, III and R–0 by the eastern part, II and I by the Magellanic Filament.

The combination scheme of shells and HVC is given in two rectangular projections $(x, y)$ and $(y, z)$ in Figure 2. The shells I and III of the northern hemisphere are shown by continuous lines, the II and R–0 shells of the southern hemisphere by dashed lines. The HVC filaments are shaded. The II shell is cut in two by the symmetry plane $x = 0$. The I and IV shells are on one side of this plane, nearer to the Galactic Centre or $x > 0$. The III and R–0 shells are on the other side $(x < 0)$, but they are displaced on a quadrant, to meet the Kapteyn stream. The main HVC filaments are as if embracing the pairs of shells. The arc must be inclined to the Galactic Plane at the angle $\beta$, in order to embrace the loop III limits — the eastern (at $l \approx 150°$) and northern (at $b \approx 45°$) — and then to reach the fallen behind loop I (at $l \approx 30°$, $b \approx 15°$). Also the Magellanic Filament, passing from under loop II $(b \approx -80°)$ to $b \approx -25°$ under loop I, is inclined at $\beta$. The axes of both the arc and Magellanic Filament are situated in the same symmetry plane $(x \approx 0)$. The angles of inclination one can calculate using the formula:

$$\tan \beta = (z_1 - z_2)/(y_1 - y_2),$$

if attributing to the indexes a meaning, corresponding to both cases. Using the data of Figure 1 and Berkhuijsen (1973), we can obtain $\beta \approx 50°$ and $\beta' \approx -10°$ as approximate values. So, the angle between the axes is about 120°, but it is obtained with low accuracy as of yet.

The geometric picture of the combination of filaments and shells is completed by the kinematic picture (Figure 3). We divided the abovementioned HVC into three groups, according to the radial velocity value. In the first group — $\Delta v_r = v_r - v_r^k$ in limits $\pm\delta/2 = \pm 25$ km s$^{-1}$. In the second group — $\Delta v_r > 0$, and $\Delta v_r < 0$ in the third, in limits $|\delta/2, \delta|$. All three groups proved to be filaments, more narrow, than in Figure 1. The filaments of the second group are inside loop III, and those of the first and third are outside. The complex A is the exception. In the case of loop II one can see the general displacement of three groups, but the order is the same. At $l(30°, 110°)$ $\Delta v_r > 0$, at $l(150°, 270°)$ $\Delta v_r < 0$. From here follows that the dispersion in each filament is several times smaller than the whole velocity dispersion in the group.

Even such a dispersion is enough during the time $\sim 10^6$ years to mix the gas of neighbouring filaments, to dissipate the long narrow filaments, frequently straight.

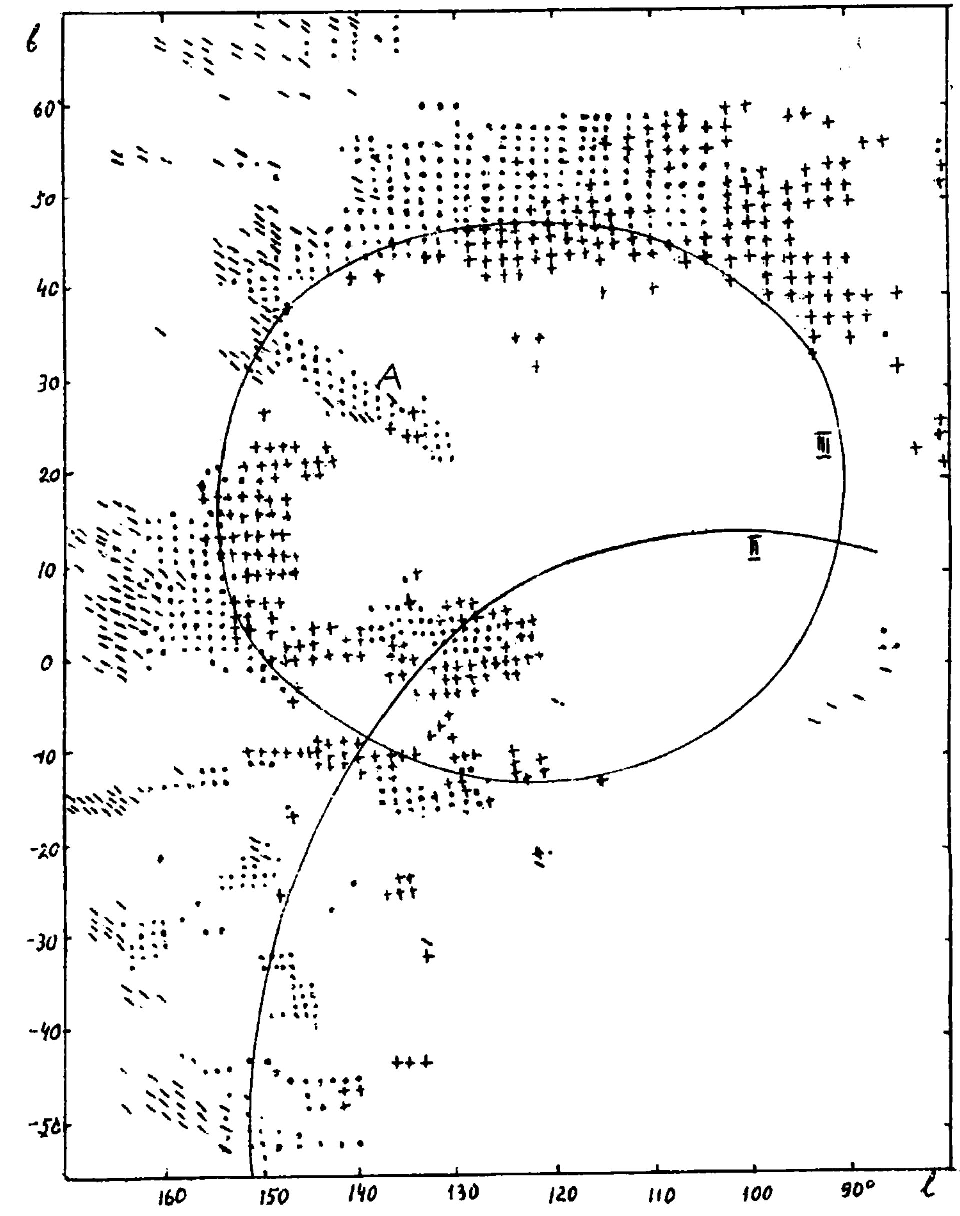


**Figure 3** The example of relative HVC distribution of loops II and III. Three groups according to $v_r$: $-25$, $+25$ km s$^{-1}$ ($\cdot$); 26, 50 km s$^{-1}$ (+); $-50$, $-26$ km s$^{-1}$ ($\backslash$).

The facts are consistent, if the collisions of the Kapteyn stream and Local System are still occurring. The observed filaments were formed recently. This question is a difficult one for numerous hypothesis of HVC origin, discussed in particular by Oort (1978).

The strict systematics in the filament disposition relative to the loop system, their differentiation, the absence of a gas neighbour for the stars, crossing the shells — are possible only if there is interaction between the filaments and GMC.

Let us examine qualitatively how this happens. The interactions of the GMC and four rays of the Kapteyn stream, from the side $l = 90°$, in twos in each hemisphere, can correspond to the scheme shown in Figure 2. When the ray is approaching the GMC at the distance of the tidal radius it begins to feel its strong influence.

The most northern ray passes near the pole at $Z \approx 200$ pc. Along the tangent plane $l \approx 270°$ it reaches loop I, only slightly displacing to its nucleus. The northern ray from latitudes $b > 45°$ is attracted simultaneously to two GMC (III and I), as it passes between them. Although it meets earlier with loop III, the greater mass is inside loop I. Both nuclei are at smaller latitudes (16° and 18°, respectively). As a result the initial ray divides in two and inclines, so the inclined arc is formed.

At average southern latitudes the central part of the arc meets shell II along the normal or at a small angle to it. These HVC can run through the GMC tidal radius and here they explode and dissipate. The lateral parts of the ray meet the gas shell almost along the tangent to it. The interaction of two mediums here does not destroy HVC, but provides differentiation on velocity magnitude. HVC surround shell II by a ring. The remaining parts of the ray continue their motion in the previous direction or with a small turn. They pass into the opposite hemisphere (relative to us). Here one part of the ray meets the new obstacle — the R–0 shell with similar effects, or passes at greater longitudes. The other part is in front of loop I at $l > 300°$.

The most southern ray passes under shell II. Parallel to the Galactic Plane in the begining, it diverges to the north at $Z \leq -150$ pc under the GMC II influence. Then at the Magellanic Filament section it falls under GMC I influence and meets its shell at $b \approx -25°$.

So GMC II and III cause gravitational focusing of the parallel rays stream, gathering them to loop I. The ray near the north pole comes here freely.

Let us also note two known details. The first is the branch of arc at $l \approx 150°$, directed to the loop III nucleus or along the shell. It is the known complex A (Oort, 1978). The second one is the branch near the basis of arc (at $l \lesssim 30°$) in loop I (north polar spur region). It belongs either to the shell, or the bar of this loop.

As we see, almost all point concentrations in Figure 1 can qualitatively be explained as the result on interaction of both the rays of the Kapteyn stream and GMC, surrounded by shells.

The mentioned scheme absolutely naturally and simply explains the $v_r$ signs of HVC: the negative ones in hemisphere $l(0°, 180°)$ with HVC approaching us, and positive ones in $l(180°, 360°)$ with HVC removing from us.

Here one should note that an earlier paper (Shatsova, 1993b) discussed the possibility of explanation of the majority of observations by the case of opposite direction of HVC movement: from loop I to loops II and III. This would take place if HVC arose in the nidus of strong X-radiation in loop I. No mention of the Kapteyn group was made. Perhaps, some other groups, among them the groups connected with the Eggen group have such an origin. However, this is not the case for the Kaptevn group. More than this, one may suppose, that the collisions of its rays with loop I could be a reason for the high activity with strong X-radiation of both the north polar spur and the opposite region, Vela.

Finally, let us note that the hypothesis of collision of HVC fallen from haloes with gas in the Galactic Plane has been suggested by Tenorio–Tagle (1986), and it has been supported by some other authors. The formation of the Local System and the molecular clouds in Orion and Monoceros (Franco *et al.*, 1988) and other objects were connected with this event. The model calculations were made.

Unlike these theoretical works, the present paper deal with the observed facts. The structures of the Local System belonging to the disk or flat subsystem of the Galaxy, have collided with the concrete HVC, really belonging halo. Instead of the $v_z$-component we are interested, on the whole, in the azimuthal $v_x$ and $v_y$-components. Aslo, this event is taking place now, rather than tens of millions of years ago. However, it is not unique, and is not an accidental event. If haloes are always present in the disk volume then they are constantly interacting between themselves, but also with the new objects.

The examination of some circumstances of collision in the context of this paper, had an additional importance. It served as an argument for coincidence of HVC distances with the nearby shells. However, at the same time it nighlighted some problems which require theoretical analysis.

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