THE ANTICENTER HIGH-VELOCITY-CLOUD STREAMS AS A GALACTIC PHENOMENON

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The galactic anticenter region contains several streams of high-velocity clouds of HI. The principal stream is associated with a localized HI feature at forbidden negative velocities near ℓ, b = 197°, 2° (Weaver 1970, 1974). Here we show that the forbidden-velocity feature, in addition to being the culmination of three streams of high-velocity clouds, is correlated with a disturbance in the permitted-velocity gas. Evidence suggests that this disturbance is located within the Galaxy, implying by association that the anticenter high-velocity clouds and the culmination feature are at distances interior to the Galaxy.

The high-velocity cloud streams in the anticenter have been mapped (from data of Weaver and Williams 1973) by Weaver (1974), Simonson (1975), and Burton and Moore (1978). There are three streams of negative-velocity HI which converge to a focus near ℓ, b = 197°, 2°. The principal stream extends continuously from ℓ, b = 200°, 2° to 160°, 8°. Two less intense secondary streams also converge to the focus. These extend from the focus towards ℓ, b = 191°, -7° and towards 184°, -5°.

In addition to the positional convergence, it has been shown that these streams converge in velocity space to the negative-velocity feature (the focus). A latitude-velocity cut at ℓ = 197°.3 (Burton and Moore 1978) reveals a constant db/dv gradient of the primary stream from b, v = 8°, -80 km s^{-1} to join the focus near 2°, -50 km s^{-1}. Longitude-velocity maps of the primary stream show continuity of the stream from ℓ, v = 197°, -50 km s^{-1} to 160, -130 km s^{-1}. The gradient dℓ/dv is similar to that of differential galactic rotation; however, the pattern

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*Operated by Associated Universities, Inc., under contract with the National Science Foundation.

W. B. Burton (ed.), The Large-Scale Characteristics of the Galaxy, 535–540.

https://doi.org/10.1017/S0074180900015047 Published online by Cambridge University Press

is offset by -90 km s^{-1} from circular velocities. There is no significant emission at anomalous positive velocities throughout the region considered.

From the convergence in both velocity and spatial coordinates of three streams of high-velocity material towards the region near ℓ, b = 197°, 2°, it is apparent that this focus is the center of activity for the anomalous-velocity HI. To examine the small-scale structure of this feature, we have obtained high-sensitivity HI spectra on a densely-sampled grid of the focus region. These observations were made with the NRAO 140-foot telescope (HPBW = 20'), at a velocity resolution of Δv = 1.4 km s^{-1}. Antenna temperature spectra are mapped; the conversion to brightness temperature is $T_B = 1.44\ T_A$.

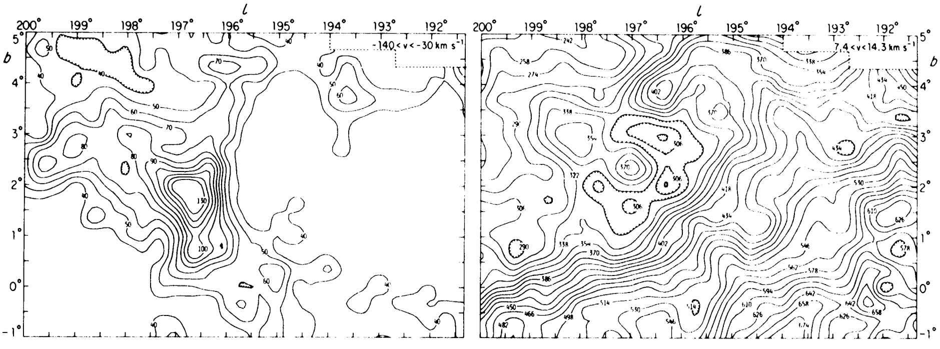

Fig. 1. Intensities integrated over the indicated velocity ranges. The left panel (a) shows the three streams converging to the focus. The right panel (b) shows the permitted-velocity minimum at the focus position.

Figure 1 shows the spatial arrangement of intensities integrated over two velocity ranges. The total extent of the anomalous negative velocities, $-140 < v < -30$ km s^{-1}, is represented in Figure 1a and shows the streams and focus as discussed above. Figure 1b shows the spatial behavior of emission integrated over the velocity range $7.4 < v < 14.3$ km s^{-1}. Perturbing the general pattern of emission in this velocity range is an isolated region of relatively low intensity.

It is crucial to the interpretation of the focus that it coincides in position with this disturbance in the permitted-velocity material. Figure 2 shows orthogonal position, velocity cuts through this region. Centered near ℓ, b, v = 197°, 2°, 10 km s^{-1} is a localized deep minimum in the permitted-velocity material. The rareness of such features in this area of the sky implies that the coincidence in position of the minimum with the stream-focus is not fortuitous. The possibility of hydrogen absorption can be ruled out because (1) the velocity width of the intensity minimum is larger than would be expected from cold-cloud absorption and (2) there is no extragalactic continuum source or concentration of the galactic continuum in the direction of the feature.

For the above reasons, we conclude that the permitted-velocity intensity minimum represents a true absence of material, and that this

https://doi.org/10.1017/S0074180900015047 Published online by Cambridge University Press

absence is associated with the forbidden-velocity focus of the high-velocity streams. These conclusions are supported by additional arguments. The total column density across the extent of the streams is approximately equal to the "missing" density in the minimum, suggesting that the focus region is the origin of the stream material. Comparing the spatial structure of the permitted-velocity depression (Fig. 1b) with that of the forbidden-velocity focus (Fig. 1a), we note the repetition of a characteristic "boomerang" shape in both features, suggesting association.

Three arguments support the conclusion that the intensity minimum is local. First, it occurs at a permitted velocity. Second, no plausible extragalactic phenomenon could cause such an intensity minimum. It does

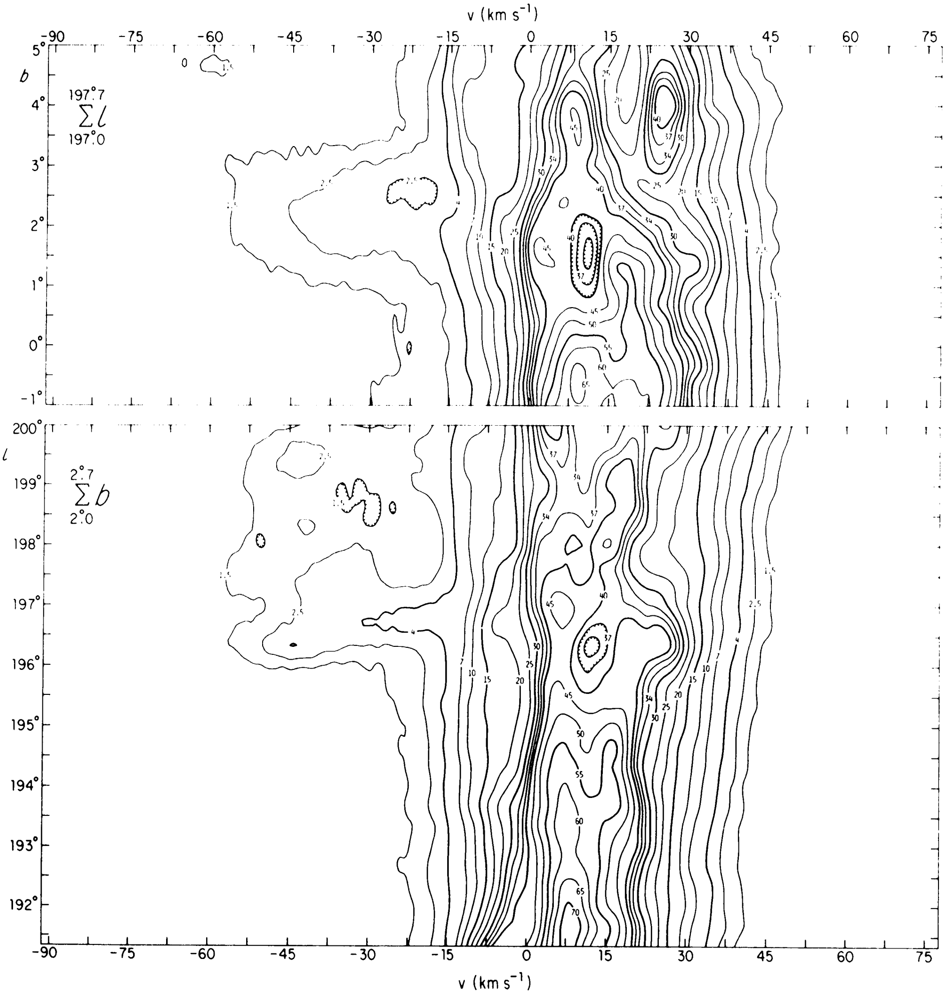

Fig. 2, Averaged position, velocity maps of HI intensities near the focus, showing the coincidence of the stream-focus with a disturbance in the permitted-velocity material.

https://doi.org/10.1017/S0074180900015047 Published online by Cambridge University Press

not coincide with an extragalactic source of continuum radiation and neither does it have the attributes of an absorption feature. Finally, the general galactic-layer emission near the intensity minimum has a disrupted appearance (see Fig. 2).

Because of the convergence of the high-velocity streams to a focus which coincides in position with a depression in the permitted-velocity gas, we consider these features to be different aspects of a single phenomenon. We believe that the intensity minimum is located within the Galaxy, and that because of their intimate association with this feature, the anticenter high-velocity streams and their focus are similarly of a galactic nature.

Several models have been proposed for this complex. Simonson (1975) proposed that the forbidden-velocity feature at the focus represents a dwarf galaxy at a distance of 17 $\pm$ 4 kpc. The primary stream is postulated to be debris from the dwarf galaxy tidally removed by the Milky Way. The observations discussed above, in particular the permitted-velocity minimum, argue against this interpretation. The culmination of the streams and their association with the localized disturbance within the Galaxy weigh against interpreting the high-velocity clouds as independent entities falling in towards the Galaxy, or as a spiral arm. While a supernova remnant model is attractive as a disruptive galactic phenomenon, it is difficult to explain the marked asymmetry of the complex with this type of model. Impingement on the galactic disk of a stream originating outside the Galaxy is, however, a situation compatible with a localized disturbance and with the observed kinematic structure.

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DISCUSSION

Verschuur: Why don't you see positive velocity features associated with the presumed removal of HI from the region of deficiency at permitted velocities.

Moore: The velocity asymmetry, as well as the spatial elongation of the streams, pose considerable difficulties for an explosive disruption such as would be given by a supernova. We have not constructed a specific model for the complex. A model in which a stream of gas impinges on the disk would provide agreement in a number of respects; most importantly, one can introduce a preferred direction of momentum.

Heiles: I believe that the weak emission you reported is part of a much larger loop, 10° to 30° in diameter, which is visible on my photos of the Weaver and Williams survey.

Moore: It is possible that these features are part of an even larger complex.

Burton: But why the association with the intensity minimum? We satisfied ourselves that such minima are extremely rare in the anticenter region, and that the association is therefore unlikely to be fortuitous.

Heiles: Your emission is, I believe, just a part of a huge loop...yet your hole is only 1° in diameter (?).

Simonson: The low-velocity gas has nothing to do with the small galaxy, but it may be correlated with the obscuration in front of it. Consequently, Moore and Burton's mass should be of some value to that optical astronomer who wants to establish the definitive value for the mass of the Milky Way. It may provide a guide to the nearest areas, where the 20 or so RR Lyraes we expect in the small galaxy may be observed.

Let us hope that Moore and Burton will also publish their line profiles, as Weaver and Williams did. This will allow somewhat greater accuracy than is now available in defining the central position, central velocity, and maximum velocity of the small galaxy. These quantities are used, together with the distance, in deriving the mass of the Milky Way. Moore and Burton have brought forth nothing of a quantitative nature to verify or support their contention. The model I computed is a simple dynamical model of the familiar kind of tidal interaction. It accounts for all the observed features in both space and velocity and leaves nothing unexplained.

Moore: We have approached the observations phenomenologically; our conclusions follow directly from the data, and require no modelling.

Giovanelli: What is an upper limit to the energy liberated in the event, for the upper limit of the distance that you quoted?

Moore: For a distance of 1 kpc, the mass present in the high-velocity streams is about 10^4 $M_\odot$, with a kinetic energy of 10^{50} - 10^{51} ergs.

Giovanelli: A feature similar (though of smaller angular extent) to Weaver's jet, which you have described, coincides with IC 443, a supernova remnant. In relation to your worry that an asymmetry in velocity is present in Weaver's jet, I would like to report that the feature IC 443 has been mapped at Arecibo by Haynes and myself and found to constitute an HI shell that closely matches the optical and radio continuum emission. It also shows mainly negative velocities; this may be explained by the presence of denser gas in the foreground ISM, which is being encountered by the blast wave.

Heiles: I want to point out that it is very rare to see both the approaching and receding halves of an expanding shell. This fact has two possible interpretations; one, that these structures are not, in fact, expanding shells; or two, that we shouldn't worry when our models of shells predict the existence of the "other half" of the shell which isn't there. Personally, I subscribe to the latter viewpoint.

Dickey: I should like to point out that the identification of the hole in the allowed-velocity gas on the basis of its line width is dangerous because even cold clouds may often show broad emission and absorption lines. The Arecibo data in particular show little correlation between line width and spin temperature. I find the spatial correlation very good evidence for your interpretation, but the line width is not.

Burton: Liszt and I searched the region of the permitted-velocity hole for CO emission, and found none. This also seems to rule out HI self-absorption because of the demonstrated general correlation of CO emission with HI self-absorption (Ap. J. 1978, 219, L67).

Baker: Dr. Burton and I have obtained high-resolution data from Arecibo for the putative galaxy. The maps confirm the features mentioned by Moore. We had hoped that if the object were a galaxy we might resolve some cloud structure recognizable by its small linewidths. The 3 arcmin resolution did indeed pick out small substructures but all showed broad, often asymmetric, profiles that are not typical of normal galactic gas. The gas looks like highly perturbed material within our system. The data will appear in A.&A. Suppl. (1978).