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PRELIMINARY DISCUSSION OF 21-CM OBSERVATIONS OF THE SAGITTARIUS ARM AND THE SYSTEMATIC MOTION OF THE GAS NEAR ITS EDGE

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A total of 236 profiles of the twenty-one centimeter line of neutral hydrogen emission have been obtained between (new) longitudes $l = 43°$ and $l = 56°$ and latitudes $b = +4°.5$ and $b = -4°.5$, using the 25-metre radio telescope in Dwingeloo. Contour maps have been prepared of brightness temperature as a function of longitude and velocity and as a function of latitude and velocity. Optical-depth line profiles have been represented as the sum of a number of Gaussian components. Fragments of galactic spiral structure, including the Sagittarius spiral arm, have been identified from a preliminary analysis of all the available data. Located in the same region in which the Sagittarius arm is seen in cross-section, another stream of hydrogen is observed which has a systematically higher velocity than the arm itself. The presence of this stream, which has the highest velocities represented in the line profiles, will influence galactic rotation curves which are determined from the cut-offs of the profiles.

1. Introduction

A total of 236 line profiles have been obtained with the 25-metre radio telescope in Dwingeloo at intervals of one half degree in latitude and longitude in the region $l = 43°$ to $l = 56°$ and $b = +1°.5$ to $b = -1°.5$. These and subsequent positions refer to new galactic coordinates. At intervals of 1°.5 in longitude the survey extends between $b = +4°.5$ and $b = -4°.5$. The survey was also extended to include every quarter degree in the region of the radio source W51 (3C400), against which the hydrogen is seen in absorption in those profiles with positions in the neighbourhood of $l = 49°.2$ and $b = -0°.4$. The profiles represent brightness temperature as a function of velocities positive with respect to the local standard of rest. The observations are being used to study the distribution and differential motions of the neutral hydrogen in a region of the Milky Way in which a spiral arm is seen in cross-section.

Two sets of contour maps have been prepared from these measurements. One set of maps, each at a constant latitude, represents contours of equal brightness temperature drawn in longitude-velocity coordinates. The other set of maps, each at a constant longitude, gives the brightness temperature contours in latitude-velocity coordinates. The contour map in the galactic plane, $b = 0°.0$, is shown in figure 1. An example of the maps at constant longitude is given in figure 3. The contour interval is 2 °K for brightness temperatures $T_b \leqslant 10$ °K and 5 °K for higher temperatures. Contours at intervals of 20° appear as heavy lines. The cross in the upper right corner of figure 1 represents the half-power resolution of the telescope and receiver. It is evident from the large amount of detail on this map that this region is a complicated one.

The line profiles have also been converted to optical depth with the usual formula, assuming a gas temperature $T_g = 135$ °K. These profiles have been represented as the sum of a number of Gaussian components. Approximations to the profiles were made at first by hand, fitting Gaussian components under peaks and shoulders of the line profiles. These approximations were improved by finding by means of a computer the difference between the line profile and the sum of the Gaussian curves, and then, again by hand, changing the parameters of the previous Gaussian components in such a way as to make the computed residual curve smoother and closer to zero. After between five to ten attempts to improve the computed residual curve of each profile, the resulting approximation was further improved by the method of least squares using a computer program which was written by W. W. Shane. The preliminary approximations by hand were an attempt to assure that the least-squares program would reach a physically justifiable solution. The final Gaussian approximations represent the line profiles over

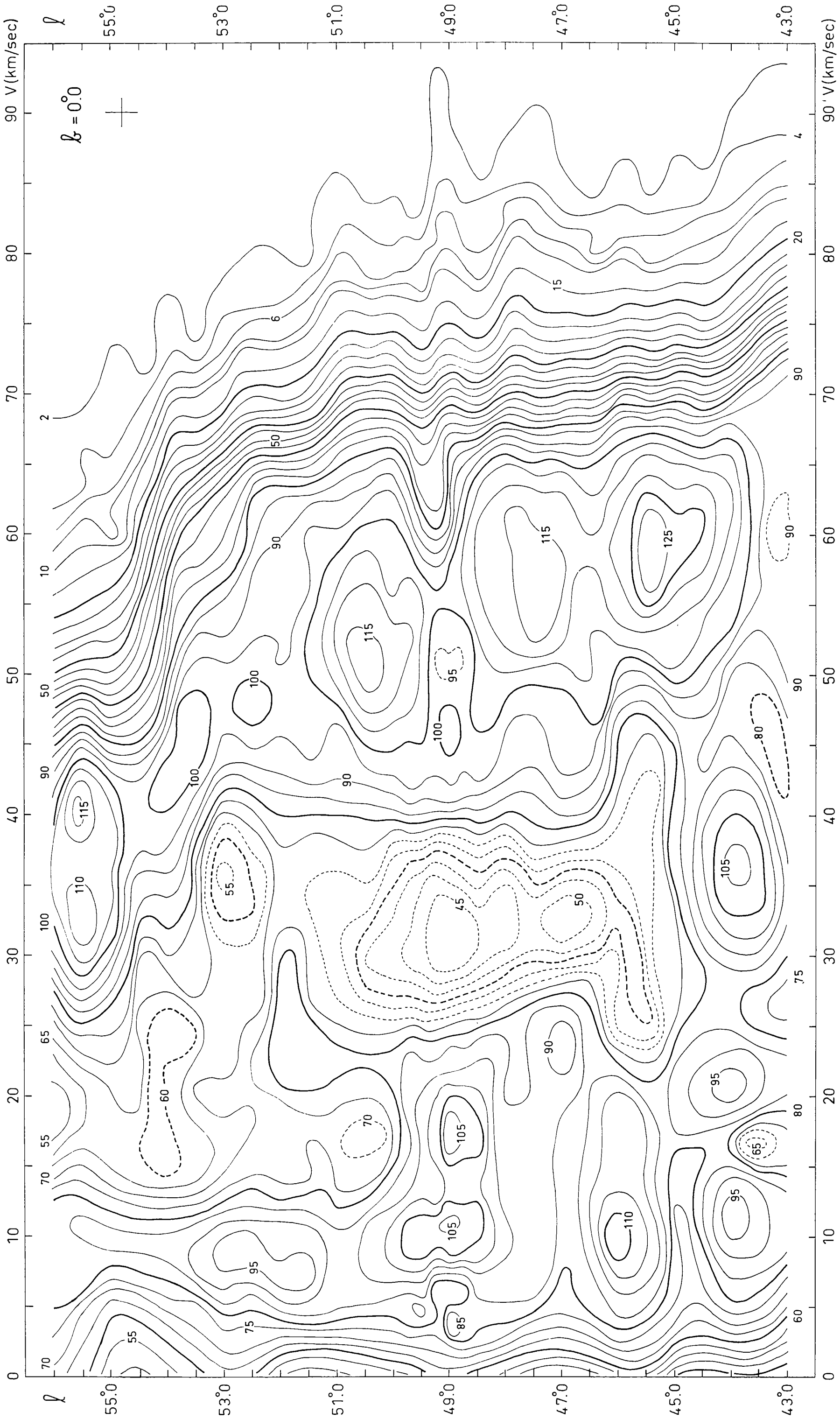

Figure 1. Contour map of brightness temperature in the galactic plane. The contour interval is 2 °K for $T_b \leqslant 10$ °K and 5 °K for higher values. Broken lines enclose regions of lower brightness temperature.

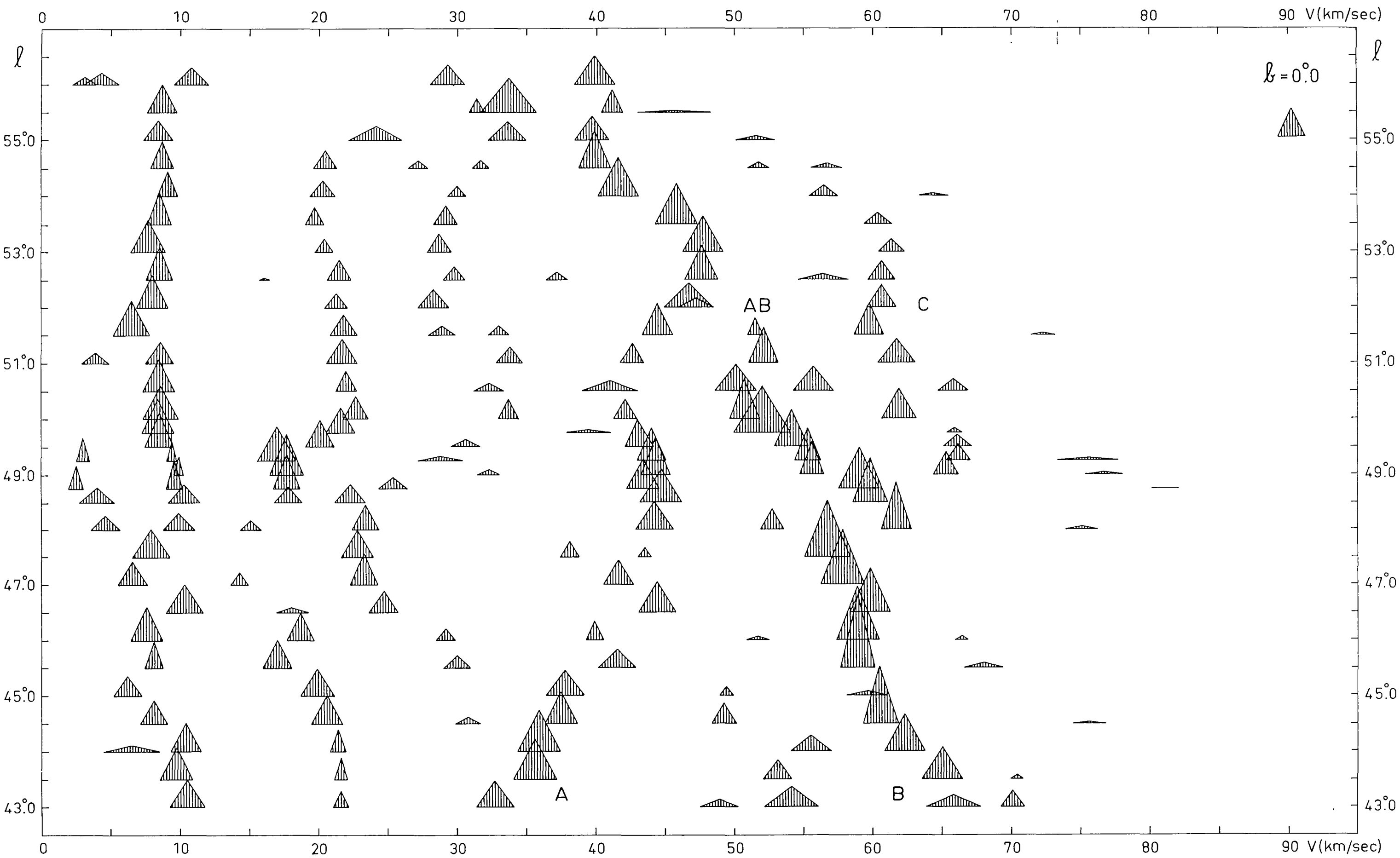

Figure 2. Representation of the analysis of optical-depth line profiles in the galactic plane into Gaussian components. Each triangle represents a Gaussian component, the altitude corresponding to the central optical depth τ and the base to the velocity dispersion σ. The triangle in the upper right corner corresponds to a standard component with $\tau = 1.00$ and $\sigma = 5.0$ km/sec.

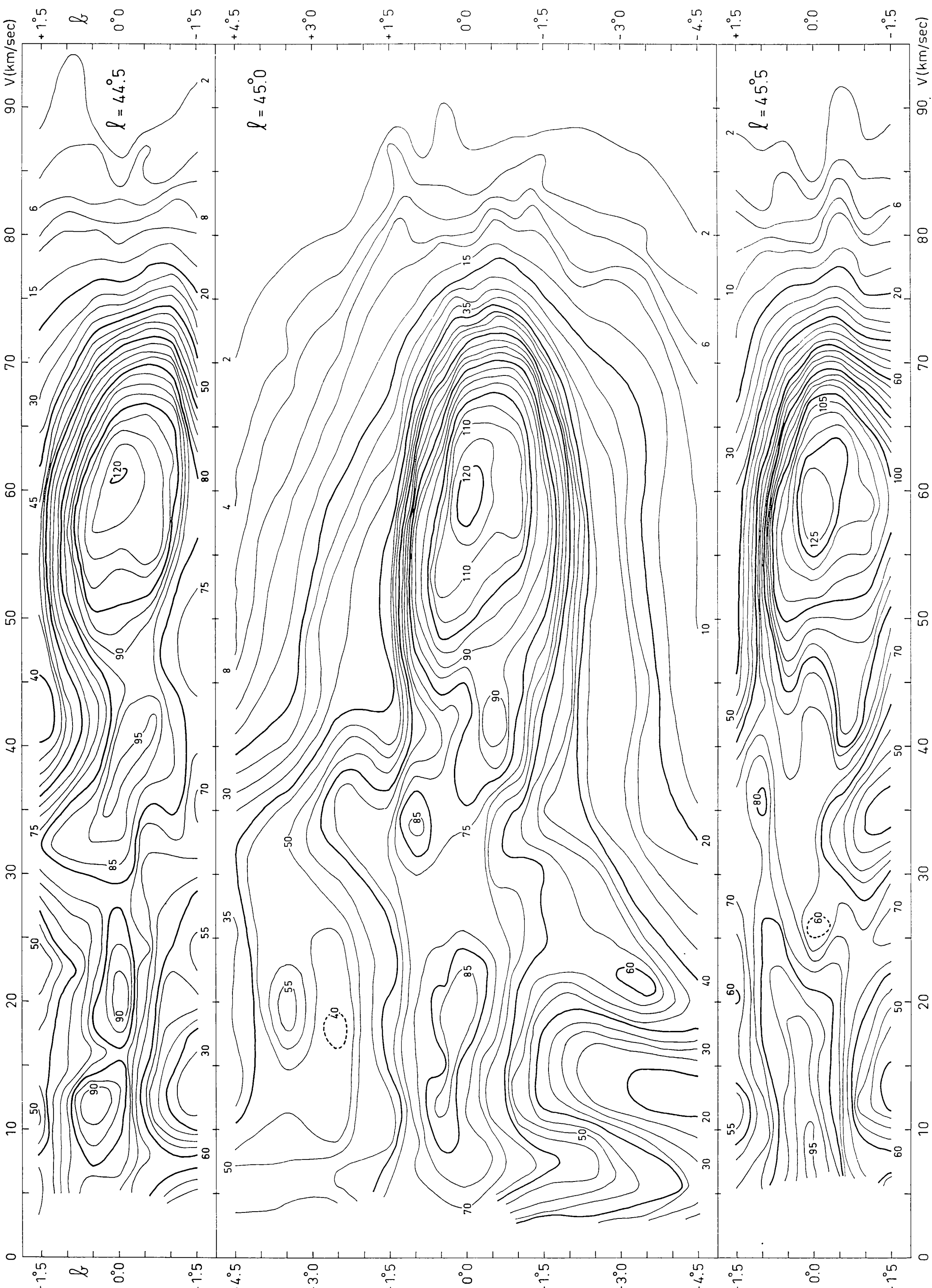

Figure 3. Example of contour maps of brightness temperature at constant galactic latitude. The contour interval is the same as in figure 1.

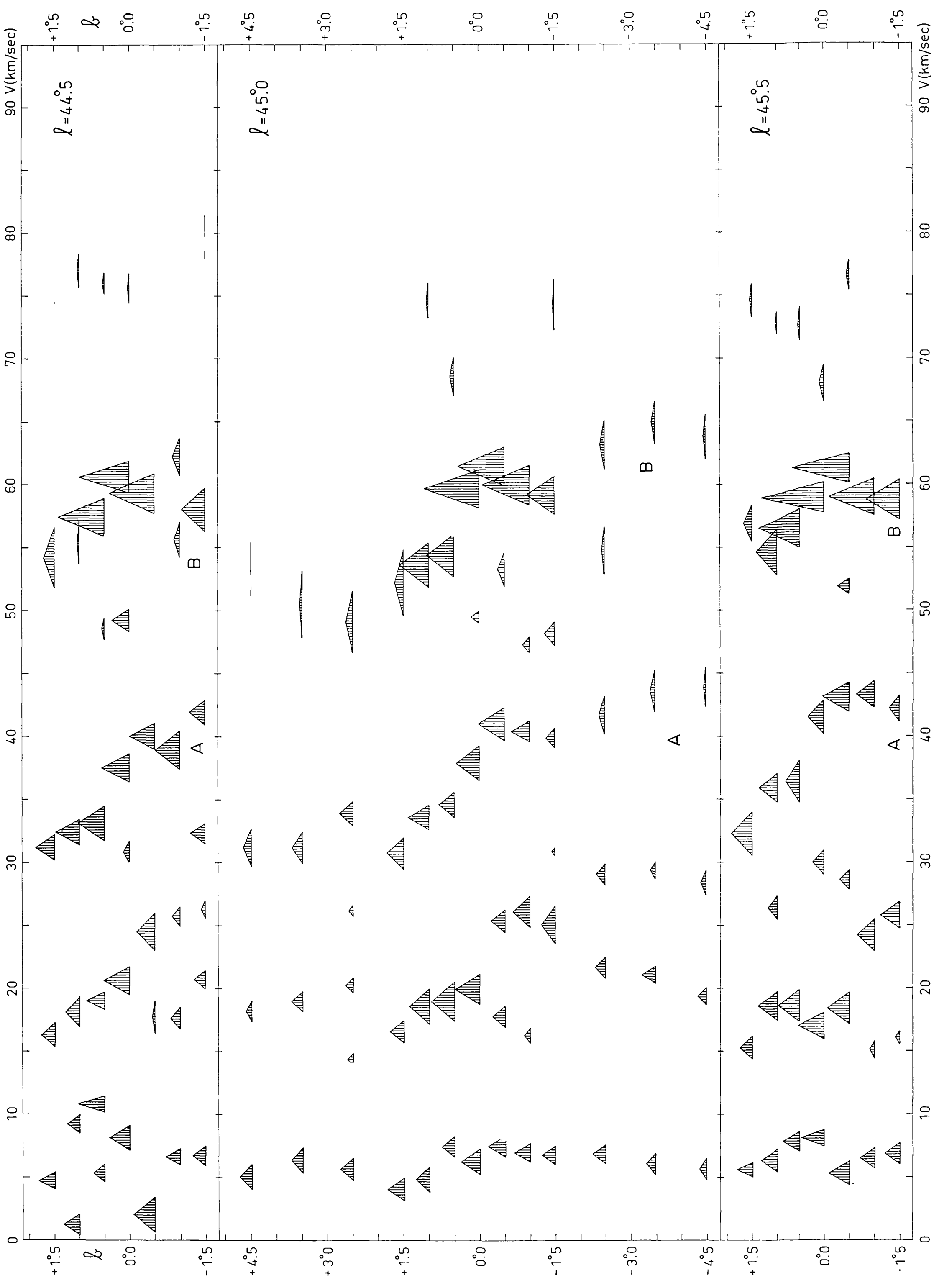

Figure 4. Representation of the analysis of optical-depth line profiles with constant longitude into Gaussian components. The scale of the triangles is the same as in figure 2.

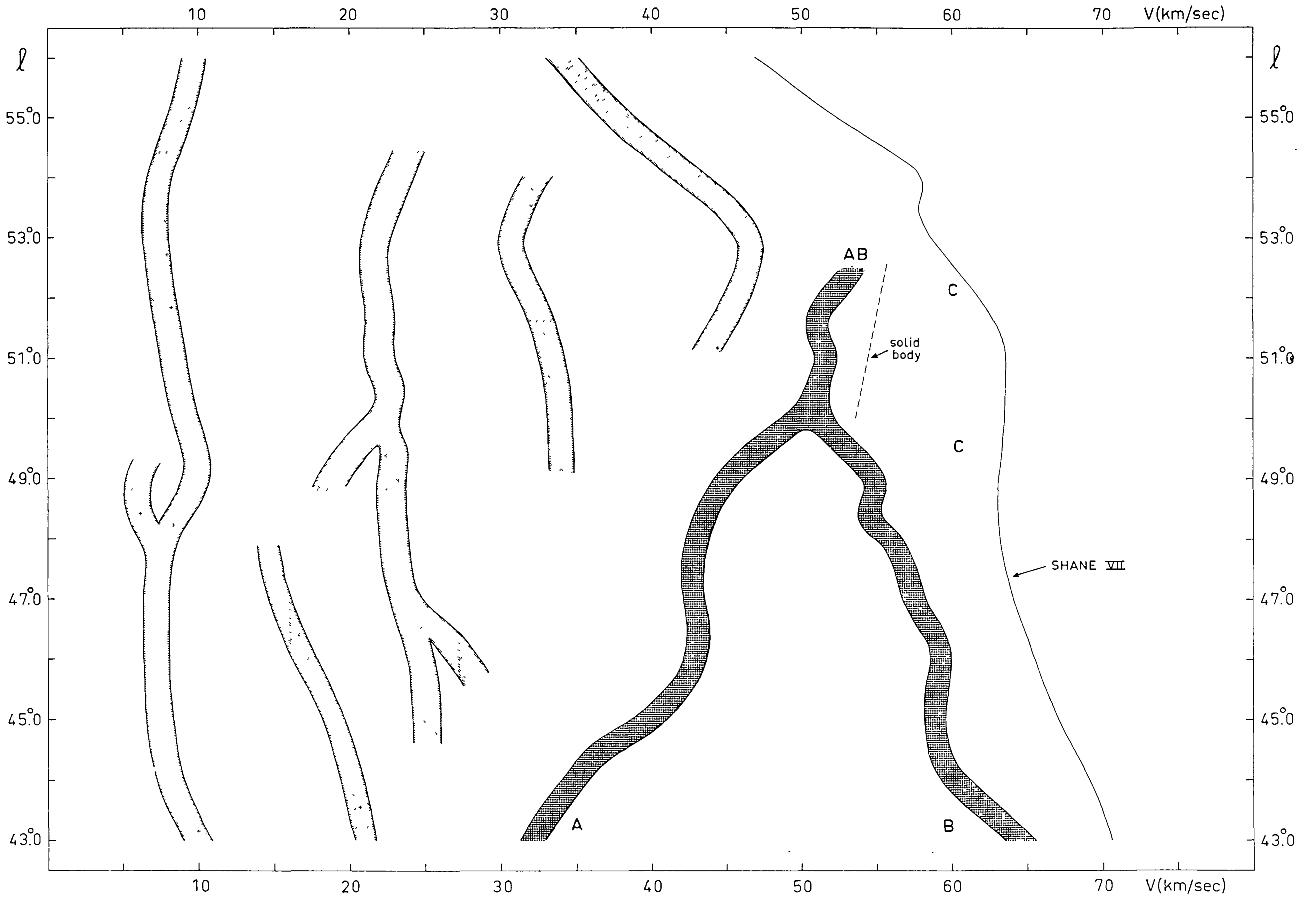

Figure 5. Identification of fragments of spiral structure from a preliminary analysis of all the available data. The shaded areas indicate patterns seen in the contour maps and especially resulting from the Gaussian analysis which are consistent in the various relevant parameters. The fragments marked A and B join to form the Sagittarius spiral arm. In the region AB the arm is seen in cross-section. Associated with the arm is a higher-velocity stream of gas in the vicinity of the region marked C.

their entire length to within an accuracy which is generally better than two or three times the noise level of the receiver. A high degree of objectivity was maintained since the profiles were individually treated, irrespective of approximations made on neighbouring profiles.

The results of the Gaussian analysis have been displayed in figures such as figures 2 and 4, in which each Gaussian component is represented by a triangle. The altitude of the triangle gives the optical depth τ of the component and the base gives the velocity dispersion σ. The triangle in the upper right corner of figure 2 indicates the scale, this triangle representing a Gaussian component of central optical depth $\tau = 1.00$ and dispersion $\sigma = 5.0$ km/sec.

2. Identification of features of spiral structure

The method of converting optical-depth line profiles into sums of Gaussian components and of displaying these components as shown in figures 2 and 4 is helpful in identifying features of the spiral structure. Consistent patterns in the triangle representation can be followed over a range of both longitude and latitude. Using the complete set of 46 maps of which figures 2 and 4 are examples several such consistent patterns have been identified. These patterns correspond to large-scale fragments of the galactic spiral structure.

A number of such consistent fragments are indicated in figure 5, which has been prepared from a preliminary analysis of all the data available. The fragments in this figure are also evident in figure 2 which, of course, represents only some of the data. There are differences in detail between various figures of the type shown in figure 2, but the fragments shown in figure 5 are generally evident. These fragments are not only consistent in velocity over a range of longitude and latitude (although the velocity may change with both l and b), but each fragment is also consistent in other characteristics. Separate spiral fragments may well have different heights with respect to the galactic plane, different velocity dispersion, different intensity, and different thickness, but within one fragment only gradual changes in these parameters are found. For example, the lowest velocity fragment in figure 5 is generally most intense at least one half degree above the galactic plane and has a uniformly large width in latitude between the points where the intensity of the feature reaches one half its maximum value.

Of these fragments of spiral structure, this preliminary report is concerned with those marked A and B in the figures. These two branches are the most consistent and intense in the region studied, and probably represent the Sagittarius spiral arm. At lower longitudes, the line of sight intersects the spiral arm twice, once a few kiloparsecs from the Sun and again on the far side of the Galaxy. The branch labelled B here is identified as being more distant than A primarily because it subtends a smaller angle between half-intensity points than A. As the line of sight sweeps to higher longitudes, A and B approach the same velocity and thus the same region in the Galaxy, and the branches meet at about longitude 50°, forming one continuous spiral arm. Between about longitude 50° and 52° the arm is seen in cross-section, and the observer looks along the axis of the arm. It is in this region, marked AB in figures 2 and 5, that the arm crosses the so-called tangent point circle, which is the locus of points at which the lines of sight pass closest to the centre of the Galaxy and are thus perpendicular to the galactic radii. The analysis of this region is complicated by the presence of the radio source W51, which may account for the gap in branch A seen in figure 2 at about $l = 49°$.

3. The high-velocity stream

The usual assumption that the gas moves in circular orbits about the galactic centre in such a way that the angular velocity, which is a function only of distance from the galactic centre, never increases outward leads to the prediction that the maximum velocity that will be observed will correspond to gas located on the tangent point circle, provided that there is enough gas there to be observed. In the region studied here this would correspond to hydrogen in the Sagittarius arm.

It is interesting to note that these present observations clearly show that there exists substantial neutral hydrogen at velocities about 5 to 10 km/sec higher than the velocities of the hydrogen in the spiral arm itself. This hydrogen appears as the highest-velocity Gaussian components located in the general region marked C in the figures. It is particularly strong in the region $l = 49°$ to $l = 53°$, which is just the region in which the arm is seen in cross-section and tangentially and is consequently the region where the line of sight would intersect most of the gas associated with the arm.

It should be pointed out that these highest-velocity components represent real hydrogen and do not just indicate a failure of the Gaussian form to fit the high-velocity wing of the line profile properly. If it were true that the failure of the Gaussian function necessitated another component to produce a good fit to the high-velocity part of the profile, then one would expect that the highest intensity peaks in the spiral arm feature B would require stronger highest-velocity components, but this is not observed to be the case. Furthermore, many of the profiles show this highest-velocity component as a distinct broad shoulder on the wing of the profile, and some show it even as a separate maximum of low intensity.

These observations indicate the existence of two streams of hydrogen located in the same region of the Galaxy but having fundamentally different kinematic properties. One stream is identified here as the Sagittarius spiral arm, and appears as the high-intensity branches A and B which join at about $l = 50°$ to form a continuous arm. In the vicinity of this spiral arm is another stream of hydrogen, of lower intensity but with a velocity 5 to 10 km/sec higher than the hydrogen in the spiral arm.

The fundamental difference between the properties of the gas confined to the main stream of the arm and the gas associated with it in the high-velocity stream

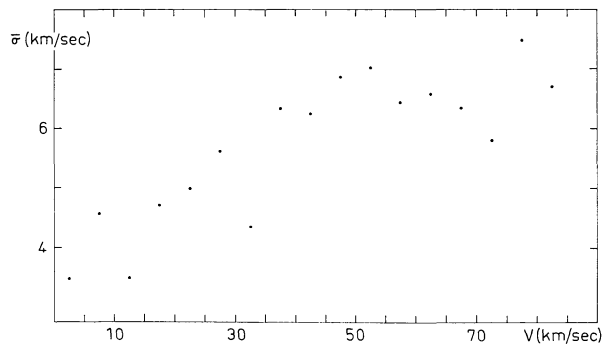

Figure 6. Velocity dispersion of all Gaussian components between $l = 49°$ and $l = 54°$ averaged in intervals of 5 km/sec. The different kinematic behaviour of the high-velocity stream is evident.

is further indicated in figure 6 by the average velocity dispersion of the related Gaussian components. The average dispersion was found in velocity intervals of 5 km/sec for all components which lie between $l = 49°$ and $l = 54°$. For the hydrogen which is contained in the fragments of spiral structure, the average dispersion increases monotonically with velocity. However, this monotonic increase clearly is not maintained by the gas in the high-velocity stream.

The observations are consistent with a situation in which the high-velocity stream is hydrogen flowing along the spiral arm, parallel to its axis. The differential flow would be in the direction of galactic rotation. The observations are also consistent with a situation in which the high-velocity gas is indicative of a motion away from or towards the arm, perpendicular to its axis. These two possibilities, a combination of which would also be possible, are indicated schematically in figure 7. In the case of either interpretation, the hydrogen associated with the Sagittarius arm at the tangent longitude occurs in at least two streams with different kinematic properties.

4. Effect of the high-velocity stream on the determination of the rotation curve

The existence of the high-velocity stream will have an important effect on the galactic rotation curve. Shane and Bieger-Smith (1966) obtained a rotation curve by comparing the positive velocity cut-offs of the profiles with profiles calculated on the basis of a model in which angular velocity is taken as a decreasing function of distance from the galactic centre. In the region in which the high-velocity stream is seen near the tangent point circle, it will be the gas in this stream which determines the cut-off of the profile, leading to a higher maximum velocity than should be observed in the case that the gas in the main body of the arm alone determined the termination of the line profile. If we assume that the high-velocity gas is associated with spiral arms, we may expect that the effect will be strongest in the neighbourhood of arms. This is indeed what was found in the Model VII rotation curve of Shane and Bieger-Smith, which shows a distinct maximum at about $R = 8$ kpc corresponding to the Sagittarius arm.

Using the value of the circular rotation velocity derived in Model VII of Shane and Bieger-Smith, the expected maximum velocity at each longitude has been

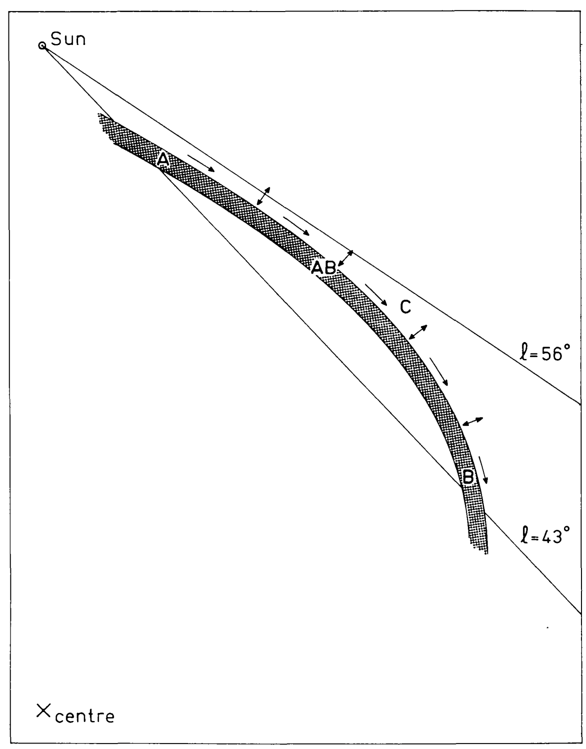

Figure 7. Schematic drawing of the Sagittarius arm and the associated high-velocity stream. Arrows indicate the possible direction of flow of the stream with respect to the arm. At any point about the arm, there could be gas flowing perpendicular to the arm, as indicated by the double-headed arrows. The gas could also flow away from the observer along the arm or along part of it, as indicated by the single-headed arrows. A flow which is a combination of the directions indicated would also be consistent with the observations.

computed using the equation $V_{max}(l) = \Theta_c(R) - \Theta_0 \sin l$, where Θ_0 is the circular velocity of the local standard of rest about the centre, which was taken equal to 250 km/sec. The resulting curve is shown in figure 5, and it is not surprising in the light of the present observations that it predicts a velocity higher than that which is actually observed for the spiral arm.

It is interesting that in the region in which the arm is seen in cross-section its differential motion approaches that of solid-body rotation. The broken line in figure 5 shows the slope of the rotation curve which would result from solid-body rotation.

Acknowledgements

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Reference

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