PAPER 5

# A 21-CM. LINE SURVEY OF THE OUTER PARTS OF THE GALAXY

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In a strip 20° wide around the galactic equator, extending from $l=340°$ to $l=220°$, line profiles were measured at 620 points. The interval in latitude was 2°5, the longitude interval was 2°5 from $l=340°$ to 110°, and 5° from $l=115°$ to 215°. At some longitudes the latitude range was extended to ±15°.

A one-dimensional correction was made for the finite width of the antenna pattern. As the intensity changes slowly along the galactic equator, relative to the half-width of the antenna pattern, only a correction perpendicular to the equator was applied.

The results appeared to be influenced by the fairly large band-width used. Therefore a correction for the blurring effect of the band-width was also made.

The profiles were reduced to optical depth at zero random cloud velocity, following the procedure described in *B.A.N.* no. 452. In the correction for random cloud velocities a dispersion of 6 km./sec. was used throughout, although it was realized that this dispersion may change from point to point. An investigation by Mr Pottasch showed that the dispersion might range from 5·5–9 km./sec., whilst the velocity distribution function, especially in the regions near the sun, resembles a Gauss curve instead of the exponential function found by Blaauw.

Many of the unpermitted wings show extensions of very low intensity, reaching as far as 25–40 km./sec. from the zero frequency. These may be due to systematic velocities, but may also be part of the velocity distribution function. A form which might better represent the observed distribution is for example $ae^{-v^2/2\sigma^2}+be^{-v/\eta}$ where $b \ll a$ and $\sigma \ll \eta$. It was not found necessary in this stage to investigate this possibility much closer.

An investigation by A. Ollongren and H. C. van de Hulst showed that for a programme of this size the Eddington approximation for removing the blurring effect of the cloud velocities, although not applicable at first sight, is, when slightly modified, a satisfactory and not too laborious reduction method. A Fourier analysis of this correction procedure shows that a velocity dispersion of 6 km./sec. fits the observations best. If the profiles are Gaussian in shape, negative intensities arise inevitably with

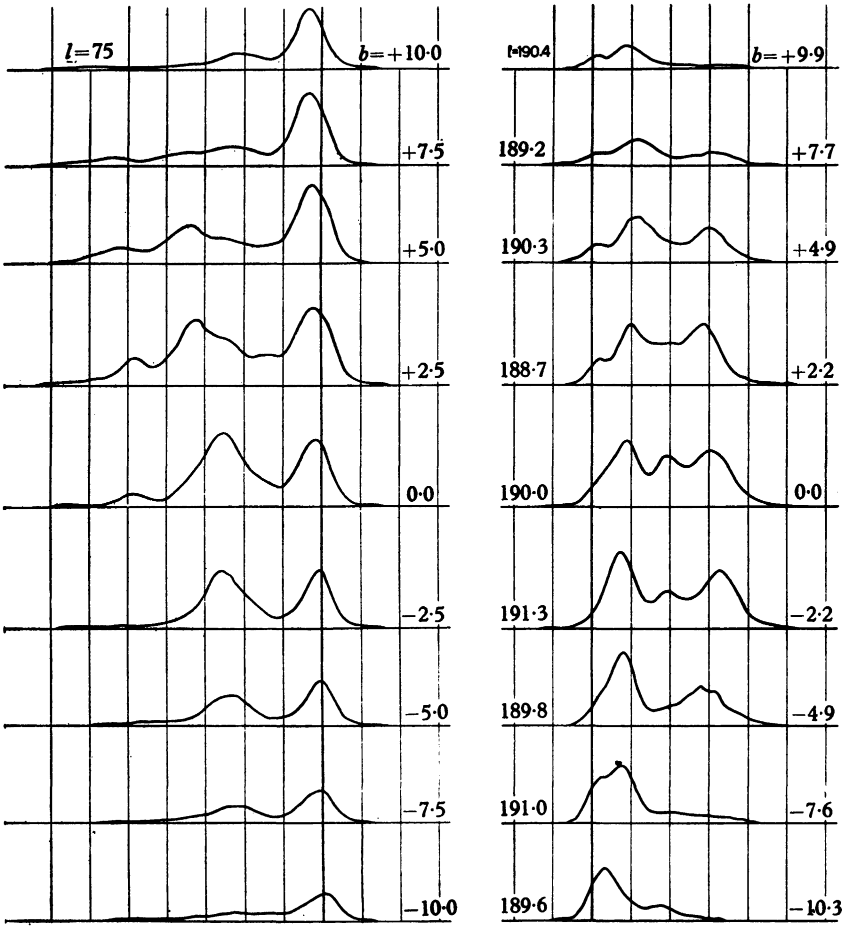


Fig. 1. Sets of line profiles at various galactic latitudes, at longitudes 75° and 190°. The vertical lines have intervals of 20 km./sec.

the present correction method. However, they occur mainly at the forbidden side of the profiles, and have been corrected for by keeping the sum of the ordinates constant. It was found from the reduction of artificial profiles that this should be done by distributing the sum of the negative ordinates evenly over the neighbouring steep slope.



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On the basis of a new model of the galactic system, recently prepared by M. Schmidt and based on the latest dynamical data available, the frequency scale was transformed into a distance scale and the hydrogen densities were determined as a function of distance from the sun. The velocity–distance relation at latitudes $\neq 0°$ starts to deviate from the one at $b = 0°$ towards higher latitudes. For the region between $l = 135°$ and $160°$, a velocity-distance relation cannot be established.

The hydrogen densities were plotted in planes perpendicular to the galactic plane, at all longitudes for which this was possible. Some examples of the final isodensity contours are given in Figs. 1 and 2.

The instrumental constants may be expressed in terms of distance. In the Perseus arm, for example at $l = 75°$, $r = 3500$ parsecs, the receiver band-width represents a distance of 570 parsecs, while the resolving power of the aerial corresponds to distances of 115 and 165 parsecs, perpendicular to each other and to the line of sight. Details much smaller than 500 parsecs in the line of sight and 130 parsecs in a direction perpendicular to it cannot be detected. This is clearly illustrated by Figs. 1 and 2.

A smaller band-width would show up smaller details in the direction of the line of sight, but the position of the hydrogen clouds causing these details would be indeterminate for three reasons. (*a*) The random velocity would give it an uncertainty of at least 450 parsecs (corresponding to 6 km./sec.). (*b*) Systematic velocity deviations give an uncertainty which may be even greater. (*c*) The aerial resolving power would still set the limits mentioned above.

For a large-scale survey of regions far from the sun, the band-width of 7·5 km./sec. is therefore quite suitable, with the aerial used.

In the present survey, systematic velocity deviations from a purely circular velocity may well distort the shape of the equidensity lines. Nothing definite can be said about this problem so far. It may be that, for example, at $l = 75°$, $r = 3{\cdot}2$ kiloparsecs, $z = +0{\cdot}5$ kiloparsec, the trunk sticking out of the main body of the Perseus arm is due to large scale motion of the part of this arm at $r = 3{\cdot}6$ kiloparsecs, $z = 0{\cdot}4$ kiloparsec. The same applies to an extension at $l = 80°$, $r = 1{\cdot}4$ kiloparsecs, $z = 0{\cdot}2$ kiloparsec.

The hydrogen densities were projected on the galactic plane to give a picture consistent with M. Schmidt's representation. These projected densities are given in Fig. 4.

At several places, it is clear that a systematic distortion of the density contours in the line of sight influences the picture. This is particularly noticeable in the region close to the anti-centre. In this region the velocity–distance relation is very steep, and small deviations from circular motion

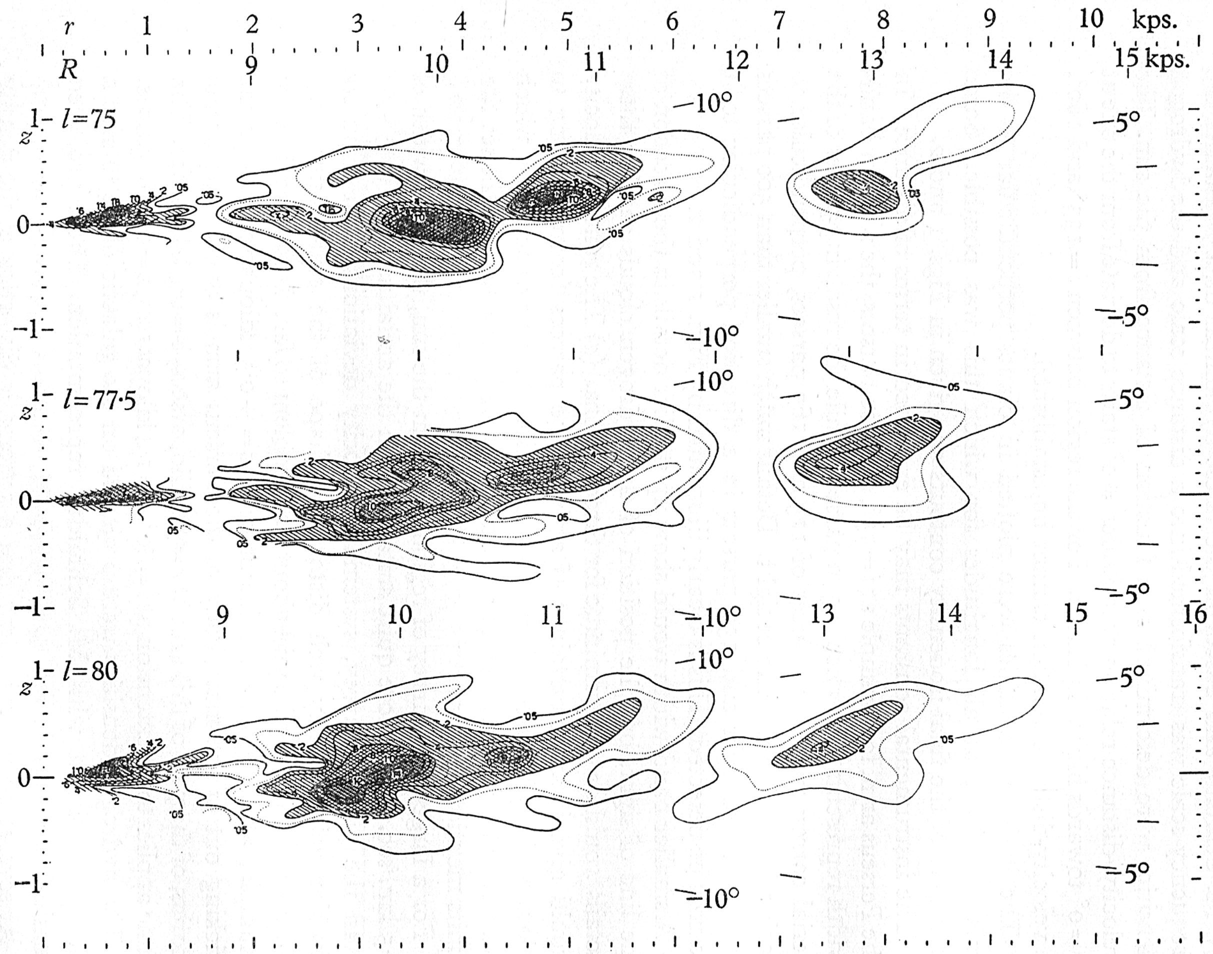


Fig. 2. Cross-sections perpendicular to the galactic plane, at longitudes $l = 75°$, $77°.5$ and $80°$. The co-ordinates are in kiloparsecs from the sun and above or below Ohlsson's galactic plane. The distance to the centre, $R$, is also indicated. Four shadings of density are given, the limits of which are $n_H = 1{\cdot}6$, $1{\cdot}0$, $0{\cdot}6$ and $0{\cdot}2$ atoms/cm.$^3$

correspond to large distance variations. Also a slightly larger random velocity than assumed tends to widen the spiral arms considerably. This explanation may also be correct for the directions around $l = 82^\circ\!.5$.

In the future it may be possible to make an estimate of the variation in random cloud velocities, and to find some indication of systematic motions,

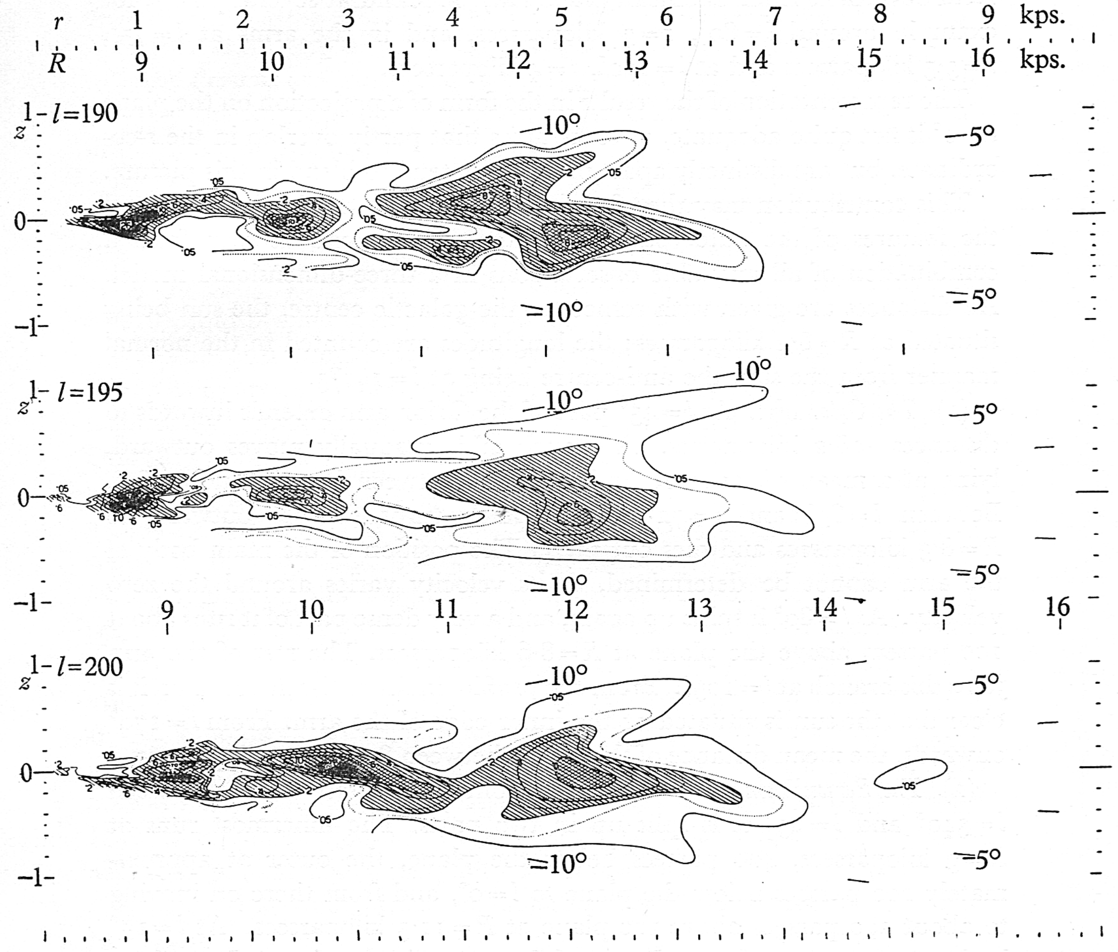


Fig. 3. Cross-sections perpendicular to the galactic plane, at longitudes $l = 190^\circ$, $195^\circ$ and $200^\circ$. For explanation see Fig. 2.

from detailed comparisons of different regions in the galactic system. It should be realized, however, that these deviations usually show up only in investigations like the present one, where large regions may be intercompared.



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A striking feature of most cross-sections is the tilt of the arms. This tilt averages approximately $+1^\circ.5$ and is opposite to the tilt found in the central parts. It is due to the wrong position of Ohlsson's plane. From the present measurements, supplemented with measures of the southern hemisphere, a very accurate determination of a new plane may be made. Real deviations from the mean plane may be found at several places, for example around $l=80^\circ$, $r=3$ kiloparsecs, and in the arms at $l=75^\circ$, $r=3.5$ kiloparsecs and at $l=190^\circ$, $r=4$ kiloparsecs.

The representation of the results in the form of a projection on the plane $b=0^\circ$ is not quite adequate, as some arms that partly overlap in the $r$-coordinate, but are distinctly apart in latitude, tend to blend in this picture.

This contribution may therefore be concluded by a brief description of the features of the outer parts of the galactic system, as seen from a combination of all available observations in a three-dimensional model. All distances are given with respect to the galactic centre, the sun being situated at $R=8.2$ kiloparsecs; the longitudes are counted in the normal manner from the sun, the anti-centre being at $l=147^\circ.5$.

(1) *The Orion arm.* At $l=45^\circ$ part of the Orion arm extends inwards to distances $<8.2$ kiloparsecs. A branch of it gradually moves outward, lying at a mean distance of 8·5 kiloparsecs between $l=52^\circ.5$ and $l=65^\circ$. Between $l=65^\circ$ and $l=72^\circ.5$ this branch turns sharply outward to $R=8.9$ kiloparsecs and dies out there. The position of the main body of the arm cannot be determined, as its velocity varies around the zero velocity. A $l=80^\circ$ it splits up again, and a very dense part of it runs about 100 parsecs above the plane at $R=8.6$ kiloparsecs. The rest of the arm joins this branch at $l=105^\circ$. From the profiles in the anti-centre region it is clear that the sun is situated at the inner edge of the arm. From $l=170^\circ$ onwards, the mean distance of the arm is between 8·7 and 9 kiloparsecs.

(2) *The Perseus arm* may be followed from $l=340^\circ$ to $l=220^\circ$. Between $l=340^\circ$ and $l=15^\circ$ it is split up in two parts. The innermost runs at $R=9$ kiloparsecs, 400 parsecs below the plane, the outer at approximately 200 parsecs below the plane to $l=0^\circ$, and from there on moving to about 200 parsecs above the plane at $R=11.5$ kiloparsecs. At $l=15^\circ$ both parts come together at $R=10.5$ kiloparsecs, in the plane. From there onward it lies on the average in the galactic plane. The region between $l=15^\circ$ and $l=50^\circ$ is very complicated. At $l=45^\circ$ the distance is 11 kiloparsecs, to decrease continuously to 10 kiloparsecs at $l=80^\circ$. Between $l=75^\circ$ and $l=82^\circ.5$ the arm splits up and a fairly dense part goes out to 10·8 kiloparsecs again. From $l=85^\circ$ onwards, the mean distance of the arm is 10·5 kiloparsecs. The mean height in the entire region is between



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100 and 250 parsecs above the plane. At $l = 170°$ the arm may be traced again and is seen to move outward from 11 to 12·8 kiloparsecs at $l = 215°$. It lies in the plane here and tends to a negative height from $l = 210°$ onwards.

(3) *Between the Perseus arm and the Orion arm*, at two places strong intermediate arms spring up. One is at $R = 9{\cdot}5$ kiloparsecs, running from $l = 45°$ to $l = 70°$. It is a very dense arm in places and does not have any connexion with the Perseus or Orion arms in the region investigated. The connexion at $l = 65°$ on the projection map is spurious. Contrary to the Perseus arm, this arm lies approximately in the plane.

At $l = 175°$ an arm originates at $R = 9{\cdot}7$ kiloparsecs, of which it is not clear whether it branches off from the Orion arm or from the Perseus arm. It is an arm of the same size as the Orion and Perseus arms and has still to be named. It runs gradually outward to $R = 10{\cdot}5$ kiloparsecs at $l = 220°$, and lies between 0 and 150 parsecs above the plane.

(4) The arm previously called *outer arm* begins to show at $l = 55°$, $R = 12$ kiloparsecs. It has a considerably smaller density than the other main arms, but is definitely an arm by itself. Partly due to the tilt of Ohlsson's plane, it runs at a mean height of 400 parsecs up to $l = 65°$, the height then gradually decreasing to about 200 parsecs. It can be traced as a separate arm to $l = 107{\overset{\circ}{.}}5$, where the distance is 14 kiloparsecs. A branch splits off at $l = 85°$ and moves outward to more than 15 kiloparsecs at $l = 105°$. Beyond this longitude the densities become too small to give reliable equidensity curves, but hydrogen can be traced farther than 20 kiloparsecs from the centre at $l = 130°$. It is very striking that at the other side of the anti-centre, up to $l = 180°$, no hydrogen is detected beyond $R = 14$ kiloparsecs. A second outer arm originates from the Perseus arm at $l = 12{\overset{\circ}{.}}5$, $R = 12{\cdot}5$ kiloparsecs, 600 parsecs above the plane, and runs outward to about $R = 14$ kiloparsecs at $l = 35°$. It bends sharply inward again to rejoin the Perseus arm at $l = 45°$. Its mean height, between 500 and 1000 parsecs above the plane, is very peculiar.

A detailed account of this investigation has been published in *B.A.N.* no. 475[1].

## REFERENCES

[1] Westerhout, G. *B.A.N.* **13**, 201, no. 475, 1957.

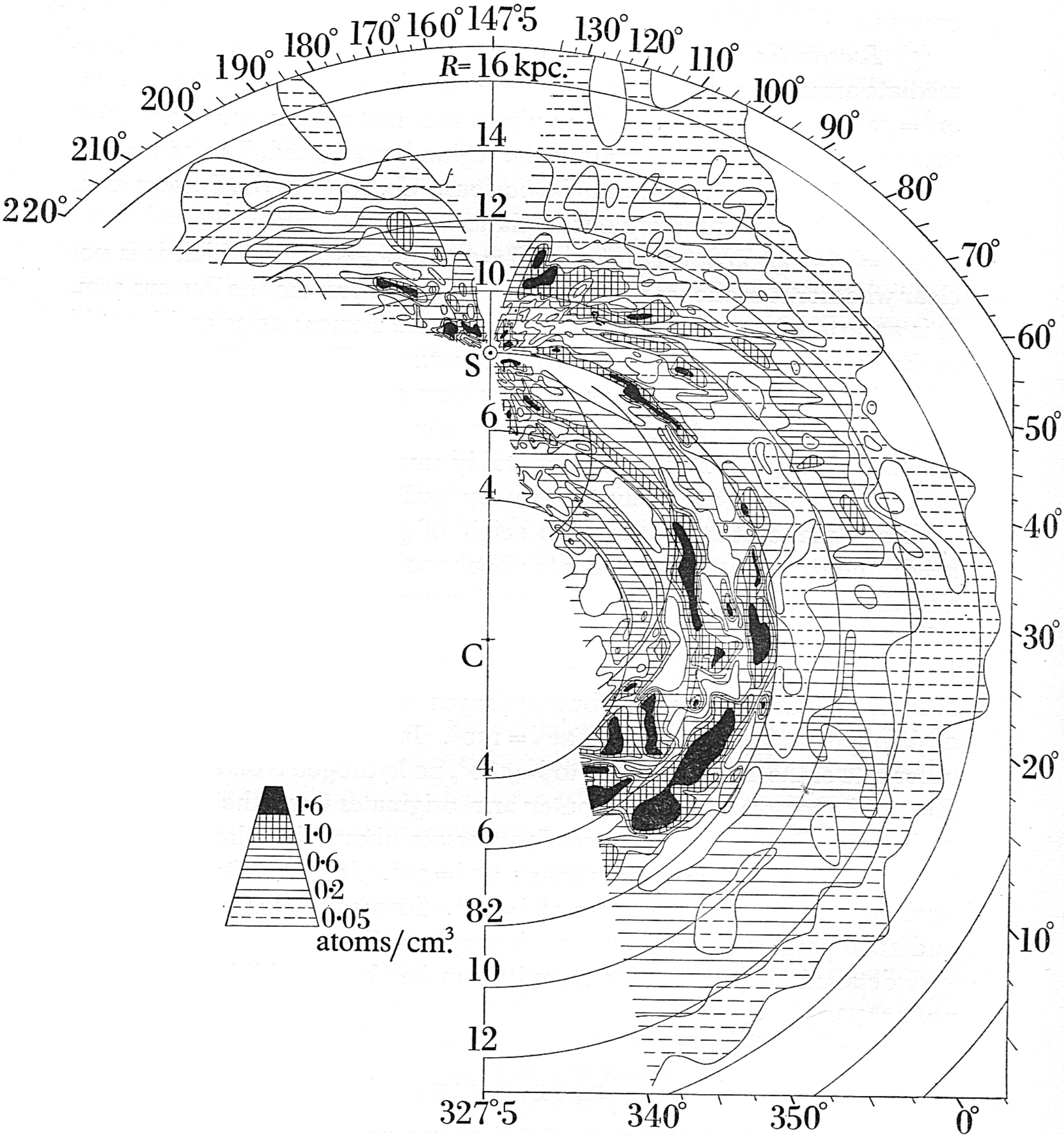


**Fig. 4.** Maximum hydrogen densities projected on the galactic plane.
This Figure represents the combined results described in papers 5 and 6.