IX. THE GALACTIC WARP

https://doi.org/10.1017/S0074180900014984 Published online by Cambridge University Press

OBSERVATIONAL DESCRIPTION OF THE WARP IN OUR GALAXY

A. P. Henderson
University of Maryland, College Park, MD.
and Manhattan College, New York City

In 1975 F. J. Kerr and P. F. Bowers of the University of Maryland made a full coverage survey of the neutral hydrogen in the southern hemisphere between $\pm 10°$ latitude from 240° to 350° in longitude. This survey taken with the CSIRO 18 meter telescope is still in the reduction stage but when completed it will provide an ideal complement to the full $\pm 10°$ coverage of the northern sky by H. Weaver and D. R. W. Williams (1973). The possibility of a unified analysis of the outer region of the Galaxy has inspired this present study. The plan here is to use the $\pm 10°$ Weaver-Williams survey in the region $10° < \ell < 130°$; the $\pm 30°$ extension to this survey (H. Weaver and D. R. W. Williams, 1974) in the region $115° < \ell < 245°$ and finally the Kerr-Bowers survey, $240° < \ell < 350°$. Since the latter survey is incompletely reduced at this time we have only used profiles at 5° intervals in longitude and thereby have produced a preliminary determination of the plane in the southern hemisphere. The northern hemisphere determination is complete.

REDUCTION PROCEDURE

Since this paper is only concerned with the large scale aspects of the outer part of the Galaxy, we assume overall circular symmetry considering "streaming" and "explosive" events as perturbations on this symmetry. We start with an assumed rotation curve and with this, transform the intensity contours at constant longitude which initially measures brightness temperature as a function of velocity and latitude into contours of density as a function of galactocentric radius and z position. By integrating in z, four quantities can be determined: a) the surface brightness σ, b) the half-thickness Δz which is measured as the distance from the $\sigma/4$ to the $3\sigma/4$ position, c) the median position of the plane, $\bar{z}$, which is the $\sigma/2$ position, and finally d) the position of the hydrogen layer as indicated by the z position where the density is maximum. In each case the latter three quantities are only carried out to the radius where $\sigma = 1.25 M_{\odot}/pc^2$.

W. B. Burton (ed.), The Large-Scale Characteristics of the Galaxy, 493–499.

https://doi.org/10.1017/S0074180900014984 Published online by Cambridge University Press

Two rotation curves were assumed in this study: a) the Schmidt curve and b) a flat, θ = 250 km sec^{-1}, curve. The results are similar since the angular velocity, Ω, is monotonic in each curve. The only difference is in the resultant size of the Galaxy such that the $\sigma = 1.25 M_{\odot}/pc^2$ contour is 30% larger using the flat curve. Using the Schmidt curve we could compare the position of the median z as found by the above reduction procedure with that determined by taking 5° intervals in longitude, integrating at constant velocity (Henderson, 1967). The results are quite compatible, justifying the use of this simple procedure for the preliminary analysis of the southern hemisphere data included in this paper. Optical thinness has been assumed in this outer part of the Galaxy. It will be shown later that this also seems justified.

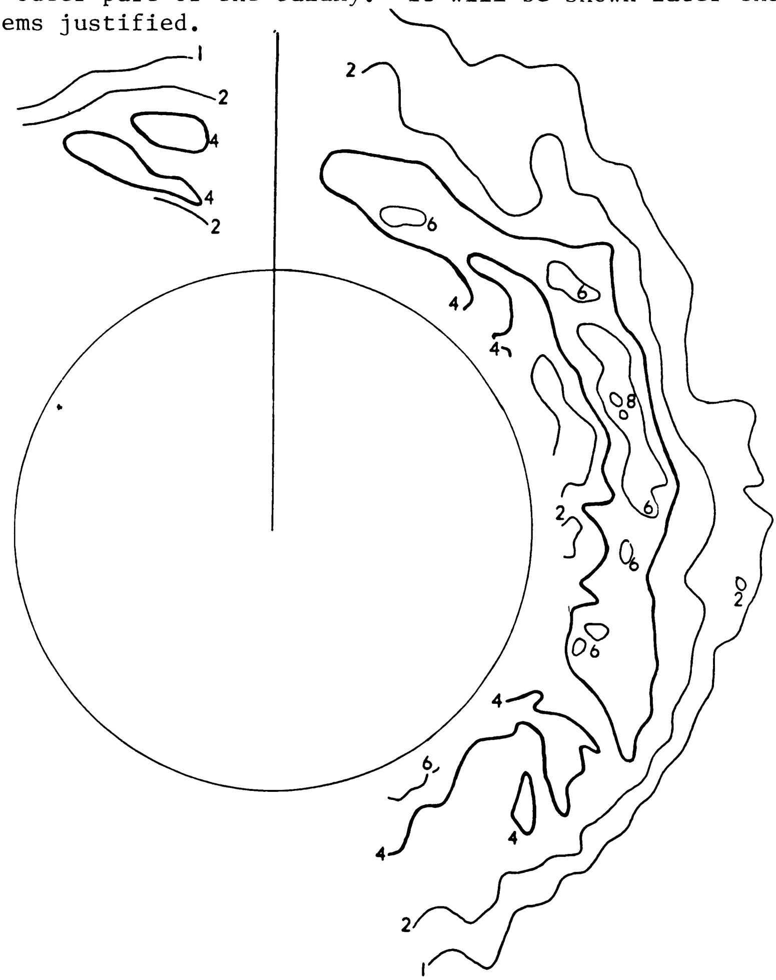

Figure 1. Surface brightness, σ, of the neutral hydrogen determined from the Weaver-Williams surveys using a flat rotation curve. Contours are in units of $1.25 M_{\odot}/pc^2$, the solar radius (10 kpc) is indicated by the circle and the line from the galactic center through the solar region is also indicated.

https://doi.org/10.1017/S0074180900014984 Published online by Cambridge University Press

RESULTS

As can be seen in figure 1, the increased spatial and velocity resolution of the Weaver-Williams surveys have changed little the over-all structure as represented by the original work of van de Hulst, Muller and Oort (1954). There is a hint of a spiral appearance but it is much weaker than the ring-like structure at 14 kpc. This appearance is not altered when optical depth effects are taken into account. Some of the strong surface brightness features are enhanced but the overall picture remains unchanged. Figure 2 shows the average surface brightness at constant galactic radii averaged between 20° and 160° galactic azimuth, the value calculated on the assumption of a 125° spin temperature is represented by the solid line and the value calculated on the assumption of optical thinness is represented by the dashed line.

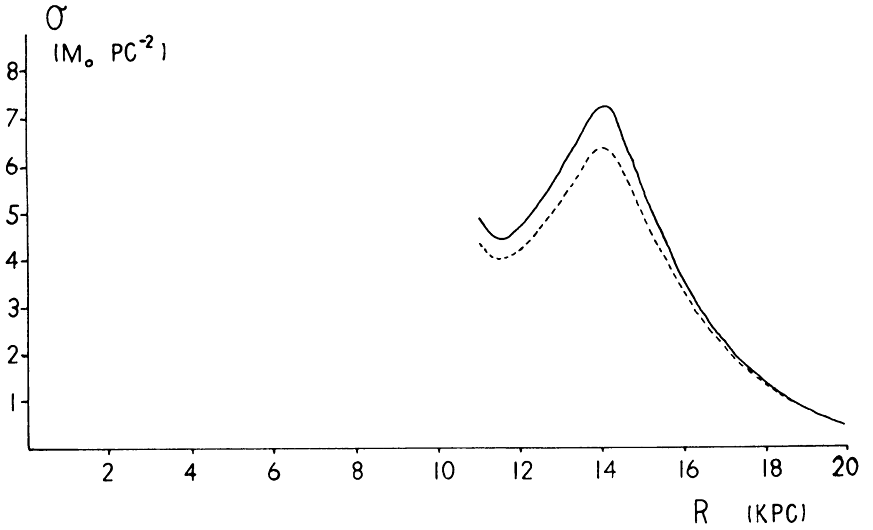

Figure 2. The average surface brightness in the northern hemisphere (dashed line). Optical depth effects were included in producing the solid line.

The half-thickness Δz is shown in figure 3. It does not uniformly increase with radius; in some regions it increases while it decreases in others. One must be careful because there seems to be a geocentric effect present as seen by the fact that Δz is smallest near the solar position. Nevertheless it seems that Δz has its greatest extent just on the outer edge of the regions where σ is maximum, but not coincident with the maximum. This result differs from the findings of Jackson and Kellman (1974) who report that in the region R = 4–10 kpc enhanced values of half-thickness are associated with regions occupied by major spiral features.

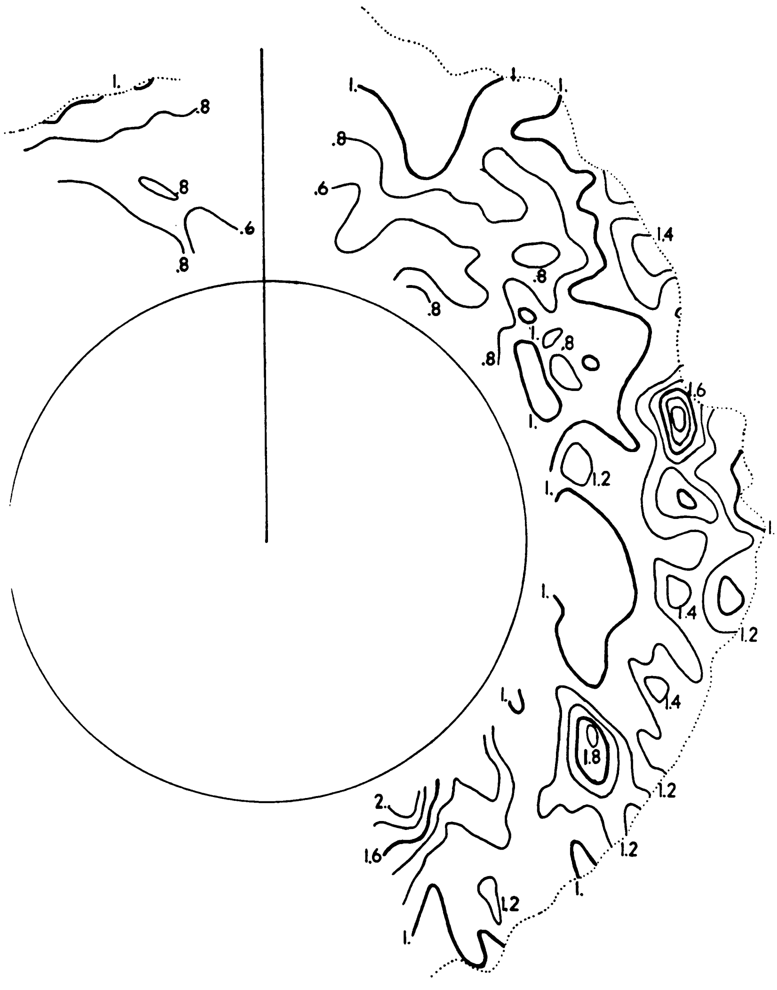

Figure 3. The half-thickness Δz of the galactic HI layer. Units represented are kiloparsecs.

The next property of the outer region of the Galaxy to be represented is the median z position of the HI. Here, the preliminary data from the Kerr-Bowers survey is added to the values of the median z determined from the Weaver-Williams surveys and shown in figure 4. It can be seen that the position of maximum warp is at 80° galactocentric azimuth in the north and approximately 260° in the south. However the extent of the warp is much greater in the north. Inside 14 kpc the deviations from the plane are roughly equal; beyond 14 kpc the distortion increases somewhat uniformly in the north making an angle of 18° but in the south the distortion rapidly levels off. In this way the north is apparently much more warped than the south.

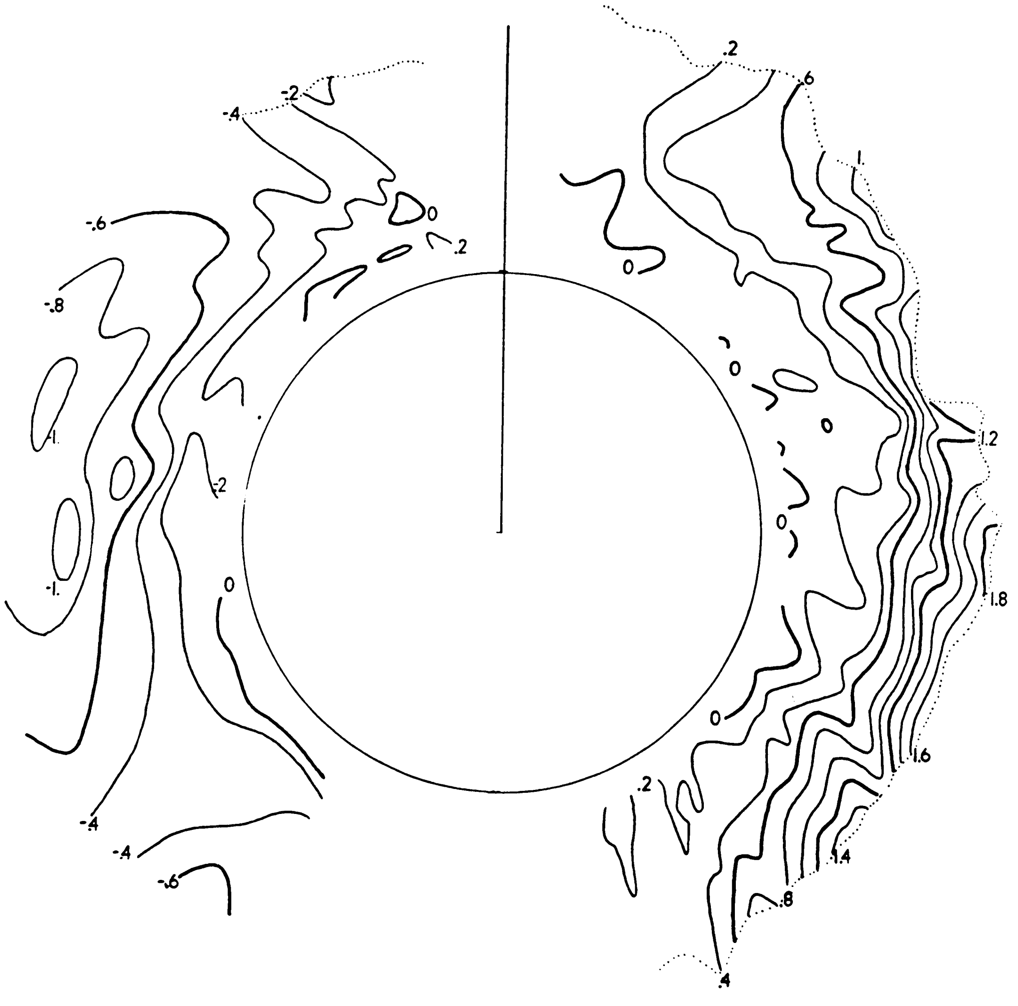

Figure 4. The median position of the HI layer. The results from the southern hemisphere are incompletely sampled.

When the position of the plane in the north is calculated by using the position of the density maximum rather than the median, there is little measurable difference in the contours. Peak density positions show more random fluctuations but the average is quite similar. This is consoling because both methods have been used in the past and this indicates that the results should be consistent. Probably the $\pm 10°$ cut-off in latitude as well as the fact that measurements were only carried out to the $\sigma=1$ contour level have eliminated any of the great latitude asymmetry in the contour diagrams found by Burton and Verschuur (1973).

It is possible to determine a mean plane for the northern hemisphere data by assuming the Galaxy to be in the form of concentric annuli and fitting this model to the data by the method of least squares, calculating the azimuth and extent of the distortion. These are listed in the table. Note that the slope of

Radius	11	12	13	14	15	16	17	18
Max z(kpc)	.04	.18	.28	.40	.58	.87	1.22	1.54
Position(deg)	51	62	64	73	80	80	79	79

the increase of z with radius is a rather constant 18° from R=18 kpc and the position is constant at 80° galactic azimuth. This mean value as determined from the set of rings can now be subtracted from the median z position and in this way large scale, consistent deviations from the plane can be found. At R=14 kpc these regions vary as much as 200 pc above or below the mean whereas in the inner part of the Galaxy (Henderson, 1967) similar regions of large scale deviation are found but usually no more than 50 pc from the plane. Nevertheless, regions which are above the plane in the outer part correlate approximately with regions above the plane in the inner part and vice-versa.

Full analysis awaits completion of the southern hemisphere data. At that time we can make more accurate comparison between the neutral hydrogen on the north and that on the south. As indicated we plan to calculate the surface brightness, the half-thickness, the position of the plane as well as possible large scale deviations from the mean position.

This work has been funded in part by grant AST-77-26898 from the National Science Foundation. The author acknowledges the help of Dr. P. D. Jackson in analyzing the southern hemisphere survey and in general discussions.

REFERENCES

Burton, W.B. and Verschuur, G.L., 1973, Astron. Astrophys. Suppl., 12, 145.
Henderson, A.P., 1967, Ph.D. thesis, Univ. of Maryland, College Park.
Jackson, P.D. and Kellman, S.A., 1974, Astrophys. J., 190, 53.
van de Hulst, H.C., Muller, C.A. and Oort, J.H., Bull. Astron. Inst. Neth., 12, 117.
Weaver, H. and Williams, D.R.W., 1973, Astron. Astrophys. Suppl., 8, 1.
Weaver, H. and Williams, D.R.W., 1974, Astron. Astrophys. Suppl., 17, 251.

DISCUSSION

Verschuur: Having done some work on the warping of the plane, I am keenly aware that the presence of cloudiness in the outer parts of the Galaxy severely confuses estimates of both the z thickness and the deviation from the plane. If you remove the clouds, you get a different picture of the warp and thickness. I believe that it is essential to consider the presence of cloudiness as a biasing factor. Are you taking this into account?

Henderson: There was no attempt to put any model into the reduction in addition to "circular symmetry". Many of the clouds seen by Burton and Verschuur are biased out of the reduction by the $\pm$ 10° cut-off that exists between ℓ = 10° and ℓ = 115° because they were at higher latitudes. Clouds at more extended radii are biased out by the fact that z and $\Delta\bar{z}$ are only carried out to the radius where $\sigma = 1.25\ M_\odot/pc^2$.

van Woerden: Could you give a number for the (maximum) inclination in the warped region?

Henderson: Using the model whereby rings at constant R were fit to the data by the method of least squares, the slope in the outer region from R = 16 to R = 18 is rather constant at 0.32 kpc per kpc.

Pişmiş: In your earlier work you had found indications that adjacent spiral arms were alternately up and down with respect to the average galactic plane. Do your recent results support such an arrangement of the spiral forms?

Henderson: The data show that there are consistent regions below the plane and also consistent regions above the plane. These regions follow an approximate spiral pattern. It is not clear that the center of these regions corresponds to the central region of the spiral arm.

Toomre: How far out do you detect gas unambiguously?

Henderson: Using a flat rotation curve, and to the sensitivity of the Weaver-Williams survey, the extent of surface brightness is approximately 22 kpc.