A TEST FOR GENERAL EXPANSION OR CONTRACTION
OF THE HYDROGEN IN THE GALACTIC DISK

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The paper describes an attempt to obtain evidence concerning possible systematic departures from circular motion in the region between 3 and 8 kpc from the galactic centre. Observations of the 21-cm line were made for this purpose with the Dwingeloo telescope in 10 longitudes within 5° of the centre. They consisted of cross-sections in latitude. Four hypotheses concerning the galactic velocity distribution (viz. circular motion, general contraction, outward motion of the solar neighbourhood and general expansion) were tested by means of a comparison between the observations and the calculated models.

Except for the existence of a certain amount of non-circular motion, probably in the central parts of the Galaxy, no indications of large systematic radial motions are found; so that the hypothesis of circular orbits does not seem to be far in error.

An outstanding feature of the contour maps derived from the observations is the occurrence of peak intensities at about +6 km/sec in the whole region (35° < l ≤ 5°, -5° < b < ±5°) covered by the measurements. This phenomenon might be ascribed to an outward motion of the adopted local standard of rest, such as has been proposed by Kerr. Equally well it may be caused by a nearby cloud of hydrogen receding from the Sun. Though in the present material there is no conclusive evidence for it, the latter interpretation seems to be the more likely.

1. Introduction

In order to find the distribution of neutral hydrogen in the Galactic System from 21-cm line observations, one must know the galactic velocity model. Conversion of 21-cm line profiles into graphs giving the density as a function of distance requires knowledge of the relation between radial velocity and distance, so that the appearance of the derived spiral structure diagram will depend on the velocity distribution which has been adopted.

The simplest kinematical concept assumes that the gas rotates in circular orbits around the galactic centre. On this assumption the radial velocity \( V_g \) of the gas at galactic longitude \( l \) is related to its distance \( R \) from the centre by the well-known formula

\[
V_g = R_0 \left[ \omega(R) - \omega_0 \right] \sin l,
\]

where \( \omega(R) \) and \( \omega_0 \) are the angular velocities of galactic rotation at the distance \( R \) and at the distance of the Sun from the centre, \( R_0 \), respectively. As no large-scale deviations from circular motion were observed, at least in the region farther than 4 kpc from the centre, it seemed reasonable to use the circular orbit hypothesis as a working basis. Therefore the maps of the galactic spiral arms (Westerhout, 1957; Schmidt, 1957; Kerr, Hindman and Carpenter, 1957; Oort, Kerr and Westerhout, 1958), derived from the extensive Leiden and Sydney 21-cm surveys (Muller and Westerhout, 1957; Kerr, Hindman and Gum, 1959), were based on relation (1).

A slight systematic difference appears, however, between the Leiden rotational velocity curve (circular velocity as a function of \( R \)) as derived by Kwee, Muller and Westerhout (1954) and that measured by Kerr and Hindman at Sydney. According to Kerr (1962), in his joint discussion of the Leiden and Sydney data, this difference could be due to an outward velocity component of the order of 7 km/sec for the region around the Sun. Assuming that this motion is a remnant of the high expansion velocities observed in the region within 3 kpc of the centre (Rougoor and Oort, 1960), he finally considered a velocity model involving both rotation and general expansion. By the use of this model the map of the Galaxy is transformed in such a sense that the actual arms become more circular. Direct evidence for a general expansion is still lacking.
Another possibility is that in addition to the rotational motion there is an inward flow of gas throughout the Galaxy. This would certainly not explain the difference between the measured rotational velocities, but the plausibility of such a general contraction follows from the fact that the amount of differential rotation in the Galactic System is such that it would efface the spiral arms in about one revolution if the motions were circular. In order to explain the general occurrence of spiral structure, one can imagine that the arms are kept in existence by systematic non-circular motions of the gas, its velocity having a radial component directed towards the centre in order to make it move along the arms in a suitable rotating frame of reference.

In the velocity model postulated by Genkin (1962), allowance is made for a negative K-effect proportional to the distance from the Sun, r. Relation (1) is then replaced by

\[ V_\theta = R_0 \left[ \omega(R) - \omega_0 \right] \sin \theta - 2 \pi r. \]  

(2)

Mapping the hydrogen distribution, making use of formula (2), Genkin obtained a pair of nearly logarithmic spirals.

The present investigation aims at obtaining evidence for the occurrence of radial motions in the region between 3 and 8.2 kpc from the centre, from cross-sections perpendicular to the galactic plane near the longitude of the galactic centre. Differential rotation effects are not yet serious at longitudes near the centre, and expansion or contraction effects, if present, will proportionally be more important. In case there is a systematic outward motion, gas with positive velocities must be beyond the central part of the Galaxy, and thus, if the hydrogen layer has roughly constant thickness, be thinner in latitude than the gas at the near side of the Galaxy which must be approaching the Sun. On the other hand, general contraction will make “far” clouds approach and “near” clouds recede, in which case the layer of gas with negative velocities would appear thinner than the positive-velocity gas. A comparison of these latitude distributions might thus provide a critical test of the expansion and contraction hypotheses.

The measurements and their conversion into contour maps are discussed in sections 2 and 3. Section 4 deals with model calculations, made to obtain a clearer insight into the effects to be observed when different velocity models are adopted. In section 5 the observational data are discussed and compared with the theoretical models.

2. The measurements

The observations were made with the 25-metre paraboloid and the eight-channel 21-cm line receiver at Dwingeloo, in June-September 1961. These instruments and the methods of observation and reduction will be discussed in a future Bulletin (Muller, Raimond, Westerhout and van Woerden). Calibrations of telescope and pilot have already been discussed by Westerhout (1958).

The measurements consisted of sweeps in latitude made successively at two sets of frequencies. While the telescope swept across the sky, from galactic latitude \( b^{11} = \pm 5^\circ \) along a line of constant galactic longitude \( l^{11} \) to about \( b^{11} = -5^\circ \), the receiver was kept tuned to a constant frequency. The spacing in \( b^{11} \), or the distance between two subsequent calibrated intensities, was 0\'.25. In this manner the region 355° ≤ \( l^{11} \) ≤ 5° was covered with sweeps 1° apart in \( l^{11} \). No sweep was obtained, however, at \( l^{11} = 0^\circ \).

A bandwidth of 20 kc/s and a channel separation of 50 kc/s were used, and as the measurements were made successively at two different frequencies, about 25 kc/s apart, we obtained for each longitude 16 cross-sections perpendicular to the galactic plane, with about 5 km/sec spacing in radial velocity. The approximate limits of the entire velocity interval covered, with respect to the local standard of rest, were -42 and +42 km/sec. By restricting ourselves to this velocity interval we may expect to be dealing only with the hydrogen gas outside the nuclear region, except at longitudes > 0° where the 3 kpc arm appears at velocities larger than -40 km/sec (Rougoor and Oort, 1960).

Although the frequency was constant during a sweep, the velocity with respect to the local standard of rest was different at the beginning and at the end of the measurement because of the difference in position. This difference in velocity ranged from 0.5 to 3 km/sec.

In order to make sweeps exactly perpendicular to the galactic equator, the sweep speed must be varied continuously during the measurements. As this was impracticable, a mean sweep speed was used. The measurements were then made in such a way that the
line $b^{11} = 0^\circ$ was intersected at the required longitude, but deviations increased with distance from the plane. At $|b^{11}| = 5^\circ$ they were of the order of $0'.15$.

The observations were recorded on punched tape, reduced on an electronic computer (Electrologica X1) and punched in IBM cards. The measurements were not corrected for the influence of the continuous background radiation on the receiver gain through the automatic gain control circuit (Muller and Westerhout, 1957).

Figure 1 shows an example of a measurement (brightness temperature versus latitude) and illustrates the variation of frequency shift $\Delta v$ and longitude $l^{11}$ with $b^{11}$, discussed above. The brightness temperature is measured in units defined in previous Bulletins (Volders and Högbo, 1961; van Woerden, Takakubo and Braes, 1962). A full discussion of the 21-cm intensity calibration will appear in a forthcoming Bulletin (Raimond and van Woerden).

3. Contour maps

We are primarily interested in the difference in width of the latitude distributions of the positive- and negative-velocity gas. The obvious means to derive this difference is to compute optical depths $\tau$ from the observed intensities, to plot $\tau$ against latitude $b^{11}$ and to compare the angular halfwidths of the respective latitude distributions. However, because of the asymmetry of the cross-sections (see figure 1), partly caused by the variation of $\Delta v$ with $b^{11}$ and partly by the occurrence of discrete clouds of hydrogen, angular halfwidths may be misleading. For that reason, instead of relying on figures representing these halfwidths, we decided to make use of contour maps to judge, in a subjective way, the latitude distributions.

For each longitude the cross-sections were converted into a contour map showing curves of equal brightness temperature (with intervals of 10 units) against $b^{11}$ as ordinate and radial velocity $V = -\Delta v/4.738$ (in km/sec) as abscissa. The maps are shown in figures 2 up to 11 inclusive.

It should be stressed here that some details shown on the maps must be considered with caution, because of the quite large spacing (5 km/sec) in $V$ of the cross-sections from which the maps were made. Thus bulges in the contours indicate regions of higher intensity without giving their exact outline. This is particularly true for the part of the maps between about $V = 0$ and $+10$ km/sec, where absorption features often occur, the depth and width of which are quite difficult to estimate. The contour maps are useful for our purpose, comparing latitude distributions and looking at symmetry properties, but they are not very suitable for instance for studying the distribution in space and velocity of the distinctive hydrogen complexes appearing on them. For an investigation of that type less spacing in $V$ and $l^{11}$ is a necessity.

Unfortunately the contour maps for $l^{11} = 358^\circ$ and $l^{11} = 3^\circ$ had to be derived from cross-sections unequally spaced in $V$, and therefore are less accurate.

Before we discuss the conclusions which may be drawn from a study of the maps, we shall give an account of the calculation of theoretical models in the following section.

4. Model calculations

The approach adopted in this section is to consider what the contour maps would look like under various hypotheses. With this intention, theoretical line profiles based on various assumed velocity distributions were calculated with the aid of an electronic computer (Electrologica X1). A comparison between the resulting theoretical contour maps and the observational ones provides a test of the plausibility of the postulated velocity models. However, the conclusive force of such a comparison must not be overestimated, because of the many parameters entering into the model calculations.
The following velocity distributions were explored:
Model 1: The hydrogen gas rotates in circular orbits around the galactic centre, the Leiden rotational velocity curve (KWEB, MULLER and WESTERHOUT, 1954) being adopted (see table 1).

Model 2: A general contraction model. In addition to the rotational motion of model 1, the gas whose distance from the centre is less than that of the Sun has an inward velocity component, making it stream along the spiral arms. The spiral pattern, which is permanent and rotates with an angular velocity \( \omega_0 = 26.4 \text{ km/sec} \cdot \text{kpc} \), is equiangular with an inclination \( i = 59.7^\circ \pm 0.1 \text{ radian} \).

Model 3: While the Sun and the local standard of rest move outwards with a velocity of 7 km/sec, the amount of rotation of the gas is given by a rotation curve midway the Leiden and Sydney curves (see table 1).

Model 4: KERR’S (1962) general expansion model. The gas has an outward velocity component of \( 470/R^2 \text{ km/sec} \) in addition to the circular motion as defined in model 3.

The rotation curves used are given numerically in table 1, the Leiden curve being designated as L and the mean of the Leiden and Sydney curves as LS.

### Table 1

Values of \( \omega(R) - \omega_0 \) used in the model calculations. \( \omega_0 = 26.4 \text{ km/sec} \cdot \text{kpc} \).

<table>
<thead>
<tr>
<th>R(kpc)</th>
<th>( \omega(R) - \omega_0 ) (km/sec \cdot kpc)</th>
<th>( \omega(R) - \omega_0 ) (km/sec \cdot kpc)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>L</td>
<td>LS</td>
</tr>
<tr>
<td>3.0</td>
<td>39.3</td>
<td>36.2</td>
</tr>
<tr>
<td>3.2</td>
<td>36.0</td>
<td>33.5</td>
</tr>
<tr>
<td>3.4</td>
<td>33.2</td>
<td>31.0</td>
</tr>
<tr>
<td>3.6</td>
<td>30.7</td>
<td>28.8</td>
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<td>28.4</td>
<td>26.7</td>
</tr>
<tr>
<td>4.0</td>
<td>26.1</td>
<td>24.6</td>
</tr>
<tr>
<td>4.2</td>
<td>24.2</td>
<td>22.9</td>
</tr>
<tr>
<td>4.4</td>
<td>22.3</td>
<td>21.1</td>
</tr>
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<td>4.6</td>
<td>20.6</td>
<td>19.4</td>
</tr>
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<td>4.8</td>
<td>19.0</td>
<td>17.8</td>
</tr>
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<td>5.0</td>
<td>17.3</td>
<td>16.3</td>
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</tr>
<tr>
<td>5.4</td>
<td>14.6</td>
<td>13.7</td>
</tr>
<tr>
<td>5.6</td>
<td>13.4</td>
<td>12.5</td>
</tr>
</tbody>
</table>

Other parameters involved in the computations are:
1. The dispersion \( \sigma \) of the random cloud velocities, assumed to be given by the relation

\[
\sigma(\text{km/sec}) = \sqrt{756/R - 56},
\]

2. The hydrogen density \( n_H \), for which a constant value of 0.7 atoms/cm\(^3\) was adopted for the region 3 kpc < \( R \) < 8.2 kpc. This is the mean value of the average densities at the near and far points derived by SCHMIDT (1957, table 8). Beyond this range \( n_H \) was taken equal to zero, so that the contribution of the gas in the nuclear region was neglected. The actual deviations from uniform density are not expected to seriously influence the results. For example, a computation based on the density distribution derived by WESTERHOUT (1957) hardly changed the appearance of the contour maps.

3. The kinetic temperature \( T \) of the neutral hydrogen. It is quite probable that in many local regions the temperatures differ considerably from 125 \(^\circ\text{K}\), the harmonic mean temperature found from 21-cm observations, but we cannot hope to do better than adopt this uniform temperature.

4. The thickness \( t \) of the hydrogen layer between the points where the density has dropped to half the maximum density, assumed to be 220 pc (SCHMIDT, 1957).

5. The distribution of hydrogen in the direction perpendicular to the galactic plane, for which SCHMIDT’S (1957) function \( a_q \) was adopted.

6. The intensity \( I_0 \) of the continuous radiation at the positions for which line profiles were obtained. The values of \( I_0 \) were read from WESTERHOUT’S (1958) figure 9.

Line profiles were derived for \( l^\Pi = 355^\circ, 359^\circ, 1^\circ \) and \( 5^\circ \); for \( b^\Pi \) ranging from 0\(^\circ\) to + 5\(^\circ\) with intervals of 0\(^\circ\).5 and for the frequency interval - 237 kc/s \( \leq \Delta v \leq + 237 \text{ kc/s} + 50 \text{ km/sec} > V > - 50 \text{ km/sec} \). In the following, distances are always expressed in kpc, velocities in km/sec and intensities in units.

For each model and each longitude the computation was carried out in the following way. As a first step, \( V_{r}(R) \), the radial velocity at a distance \( R \) from the centre or at distances \( r_i(R) \) (\( i = 1, 2, \ldots \)) from the Sun, was computed for \( R = 3.0 + 0.2 \text{ k} \) (\( k = 0, 1, \ldots, 26 \)), while \( r_i(R) \) and \( dV_{r}(R)/dr_i(R) \) were derived for \( R = 3.2 + 0.4 \text{ k} \) (\( k = 0, 1, \ldots, 12 \)). So far as the centre
region is concerned, \( r_1(R) \) may be approximated by the formulae \( r_1(R) = 8.2 - R \) and \( r_2(R) = 8.2 + R \) \( (R_0 = 8.2) \), and \( V_{\text{el}}(R) \) and \( dV_{\text{el}}(R)/dr_1(R) \) are related to \( R \) by the formulae assembled in table 2.

These relations may be proved by simple geometrical considerations. In deriving \( d\omega(R)/dR \), \( \omega(R) \) was assumed to vary linearly with \( R \) over intervals of 400 pc.

**Table 2**

Relations used in the model calculations.

When double signs occur the upper one corresponds to the quantity with index \( i = 1 \).

<table>
<thead>
<tr>
<th>Model</th>
<th>( V_{\text{el}}(R) = )</th>
<th>( \frac{dV_{\text{el}}(R)}{dr_1(R)} = )</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>8.2 ([\omega(R) - \omega_0] \sin \theta_1)</td>
<td>( \pm 8.2 \frac{d\omega(R)}{dR} \sin \theta_1 )</td>
</tr>
<tr>
<td>2</td>
<td>8.2 ([\omega(R) - \omega_0] \sin \theta_1 + R [\omega(R) - \omega_0] \tan 5^\circ.7)</td>
<td>( \pm 8.2 \frac{d\omega(R)}{dR} \sin \theta_1 - \left[ R \frac{d\omega(R)}{dR} + \omega(R) - \omega_0 \right] \tan 5^\circ.7 )</td>
</tr>
<tr>
<td>3</td>
<td>8.2 ([\omega(R) - \omega_0] \sin \theta_1 + 7)</td>
<td>( \pm 8.2 \frac{d\omega(R)}{dR} \sin \theta_1 )</td>
</tr>
<tr>
<td>4</td>
<td>8.2 ([\omega(R) - \omega_0] \sin \theta_1 + 7 \pm \frac{470}{R^2})</td>
<td>( \pm 8.2 \frac{d\omega(R)}{dR} \sin \theta_1 - \frac{940}{R^3})</td>
</tr>
</tbody>
</table>
Next, for $R = 3.2 + 0.4 k$ ($k = 0, 1, \ldots, 12$) and $b^\Pi = 0.0 + 0.5 k$ ($k = 0, 1, \ldots, 10$), optical depths $\tau'_i(R)$ were computed by means of the relation (Van de Hulst, Muller and Oort, 1954)

$$\tau'_i(R) = \frac{n_{HI} a(q_i)}{0.000595 T dV_{HI}(R)/d_r(R)}$$

where

$$q_i = \frac{2 r_i(R) \sin b^\Pi}{t}.$$

These optical depths $\tau'_i(R)$ were multiplied by $\Delta V_{HI}(R) = V_{HI}(R - 0.2) - V_{HI}(R + 0.2)$ and, to make allowance for the broadening of the line profiles by random cloud velocities, final optical depths $\tau_i(V)$ were computed for $V = -50 + 2 k$ ($k = 0, 1, \ldots, 50$) according to the relation

$$\tau_i(V) = \sum_{R=3.2, 3.6, \ldots, 8.0} \frac{\tau'_i(R) \Delta V_{HI}(R)}{\sigma(R) \sqrt{2\pi}} \cdot \exp \left\{ - \left[ \frac{V - V_{HI}(R)}{\sigma(R) \sqrt{2}} \right]^2 \right\}.$$

Finally, intensities $I(V)$ were derived by means of the formula

$$I(V) = T \left[ 1 - e^{-\tau_i(V)} \right] - I_e \left[ 1 - e^{-\tau_i(V)} \right].$$

The line profiles were converted into contour maps. These are given in figures 2a, 2b, 6a, 6b, 7a, 7b, 11a and 11b. As the maps will be symmetrical about $b^\Pi = 0^\circ$, only the southern halves are shown.

5. Discussion

5.1. The Observational Data

Despite the uncertainty of drawing some contours, as conceived in section 3, it is still clear that the maps reflect a quite complicated distribution and motion of hydrogen. It is apparent that the criterion for general expansion or contraction is difficult to test, because of the disturbance produced by the presence of discrete masses of hydrogen and absorbing features. Nevertheless, considering only the gross features of the contours, the following conclusions may be reached.

In the longitude range $1^\circ \leq \l^\Pi \leq 5^\circ$ there might be some indication of contraction, as the negative-ve-
locity gas is thinner in latitude distribution than that with positive velocities. However, the opposite effect, though less pronounced, appears at longitudes 355° to 359°; the latitude distribution of the gas moving away from the Sun being the thinner. From this it is clear that no large systematic outward or inward motions are present, otherwise the effects would be more striking and show up over the whole range of longitudes from $l = 355°$ to $l = 3°$ in the same way. Certainly radial motions must be smaller than assumed by Kerr (1962) in his general-expansion model. An expansion or contraction of such an amount will not be masked by local effects, unless there is no hydrogen in the relevant regions. Moreover, the effects mentioned above are most perceptible at $l = 355°$ and $l = 3°$, where they are least expected from the expansion or contraction hypothesis because differential galactic rotation tends to mask them at those longitudes.

As an alternative explanation of the appearance of the maps we may suppose the following:

1. The circular orbit hypothesis is not in error.
2. Towards longitude $l = 5°$ the difference in width of the respective latitude distributions is mainly due to the 3-kpc expanding arm, appearing in the negative-velocity part of the maps.
3. At lower longitudes, towards $l = 355°$, the extension of the contours towards “forbidden” velocities in the interval $-1° < l < +1°$ is caused by hydrogen moving with both negative and positive velocities and, judging from its small angular extent, probably situated in the central parts of the Galaxy. Perhaps it indicates expanding material on the near and far side of the nucleus, inside the 3-kpc arm and partly also within this arm.

One phenomenon remains to be explained, namely the occurrence of peak intensities at about $+6$ km/sec throughout the range of longitudes, indicating that the local standard of rest is moving away from the gas providing these high intensities. This could reflect an outward motion of the local standard of rest, in accordance with Kerr's (1962) first suggestion to explain the observed difference between the northern and southern rotation curves. From the contour maps this possibility cannot be excluded.
However, since the peak intensities at $V = +6$ km/sec extend to $|b^I| = 5^\circ$, and judging from other observations indicating that the phenomenon even seems to extend to higher latitudes, it may equally well be attributed to the motion of a hydrogen cloud in the neighbourhood of the Sun. McGee and Murray (1961) found that velocities averaging $+4.5$ km/sec occur in the centre region at all latitudes between $+30^\circ$ and $-30^\circ$. Part 1 of the Dwingeloo Atlas of 21-cm profiles (van Woerden, Takakubo and Braes, 1962) also shows that near $l^II = 0^\circ$, up to $b^II = +26^\circ.5$, the tops of the line profiles are displaced towards positive velocities. Finally, Heeschen (1955) already noted that in the same region the peak velocity decreases from about $+6$ km/sec at $b^I = +5^\circ$ to about $+1$ km/sec at $b^I = +50^\circ$. Whereas these measurements are not necessarily inconsistent with an expansion of the local standard of rest, observations made in the direction of the anticentre do not support this hypothesis. If the solar neighbourhood moved outwards, one would expect line profiles in the region of the anticentre to have their main top at negative velocities, but on the contrary they are rather symmetric about slightly positive ones (Mulder and Westerhout, 1957). According to McGee and Murray (1961), the mean velocity in the anticentre direction is approximately zero in the northern latitudes and $+6$ km/sec between $b^I = -4^\circ$ and $-30^\circ$. Therefore it is more likely that we are observing a nearby hydrogen cloud receding from us at the rate of about $6$ km/sec, possibly associated with the extensive Ophiuchus gas and dust complex (Heeschen and Lilley, 1954; McGee and Murray, 1961; Helfer, 1961).

It is possible that this same cloud causes the absorption features visible at about $+5$ km/sec especially at longitudes $>0^\circ$ and latitudes $>0^\circ$. These absorption features were first mentioned by Heeschen (1955), who stated that they result from selective absorption of the line radiation by a cold hydrogen cloud with a temperature of at most $55^\circ$K.

The absorption dips appearing at $+6$ km/sec and $b^{II} = 0^\circ$ for $l^{II} = 359^\circ$ and $1^\circ$ are unmistakably caused by absorption of the continuous background radiation from the galactic centre and prove that the hydrogen
gas with that velocity is situated in front of the centre.

Another interesting feature of the contours is that, apart from the absorption, the peak intensities generally occur at lower velocities for $b^{\Pi} > 0^\circ$ than for $b^{\Pi} < 0^\circ$. In view of the uncertainties inherent in the contour maps, no reliable conclusions can be drawn from such details. Nevertheless, their presence suggests the possible existence of a complex flow pattern, whose exact nature is not yet clear.

5.2. THE THEORETICAL CONTOUR MAPS

None of the four models considered in section 4 represents the observations well. In some cases either the negative- or the positive-velocity part of an observational map is quite well represented, but never the whole of it and certainly not the set of maps over the whole longitude range.

The extensions of the contours towards forbidden velocities in the narrow latitude range $-1^\circ < b^{\Pi} < +1^\circ$, already discussed before, are not explained by any of the models. Model 4 yields such a feature at positive velocities, but as could be expected from a model taking into account such a large amount of expansion, this feature persists over the whole longitude interval from $\pi = 355^\circ$ to $\pi = 5^\circ$. Thus the theoretical maps based on model 4 indicate that a large amount of expansion or contraction cannot be present without causing a considerable difference between the latitude distributions of the positive- and negative-velocity gas from $\pi = 355^\circ$ to $\pi = 5^\circ$. There is also no resemblance between the negative-velocity parts of the maps derived from model 4 and those derived from the observations, the latter showing much thinner distributions in $b^{\Pi}$. The principal advantage of model 3 is that the symmetry line of the contours based on that model runs at positive velocities, ranging from about $+4$ km/sec at $\pi = 355^\circ$ to about $+10$ km/sec at $\pi = 5^\circ$. Whether or not this same trend is to be found in the observed maps, model 3 seems to represent the observations fairly well. Since model 1 is based on a rotation curve only slightly different from that used for model 3, the two maps strongly resemble one another, except for the 7 km/sec shift towards positive velocities of model 3 with respect to model 1.

Model 2 fails seriously at $\pi = 5^\circ$, but at $\pi = 359^\circ$ and $\pi = 1^\circ$ the contours are very similar to the
observations, even the absorption features at $b = 0^\circ$ and $V > 0$ being present. A smaller amount of contraction would certainly improve the fit, because the present model gives too narrow a latitude distribution for the gas with negative velocities.

The conclusion reached from the consideration of the theoretical contour maps thus confirms the conclusion drawn in section 5.1, that rather large deviations from circular motion cannot be present. Models calculated on the basis of an outward motion of the local standard of rest are consistent with the observations.

It is a pleasure to express my thanks to Prof. Dr J. H. Oort for his helpful advice and discussions and to Prof. Dr G. Westerhout for suggesting this investigation.

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