RECENT EVIDENCE ON THE ROTATION CURVE OF OUR GALAXY FOR $R > R_o$

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Studies of the rotation curve of our Galaxy at galactocentric radii, R, greater than the solar distance, R_o , from the center require the use of conventional optical techniques since the distances to as well as the radial velocities of Population I objects are needed.

HII regions are the best objects to use for a study of the rotation curve over large distances because (i) they can be detected easily on, say, Palomar red prints, (ii) they have high intrinsic luminosity and (iii) they have low (~ 8 km/sec) dispersion from circular galactic rotation. Y. M. Georgelin's thesis (Georgelin 1975) provides us with H α radial velocities for HII regions which are sufficiently accurate that the measurement error is usually less than the actual velocity dispersion. However, she usually relied on MK spectral classification of presumed exciting stars in order to determine the distance to the regions. This procedure is subject to the relatively large errors in MK luminosity determination for a single star as well as possible misidentification of the exciting star. Nevertheless, Georgelin's work clearly showed a discrepancy between her spectrophotometric distances and kinematic distances based on the Schmidt (1965) mass model in the sense that the former were greater than the latter.

The present authors have undertaken extensive UBV observations (Moffat, FitzGerald, and Jackson 1978 - in preparation) in order to determine more accurate distances by ZAMS fitting to de-reddened color-magnitude diagrams for stars in the neighborhood of distant (mostly Sharpless) HII regions, in the longitude range ℓ = 150° to 260°. Many of the HII regions have such stellar 'aggregates' (clusters or associations) surrounding them. Image tube slit spectrograms for MK classification and (some) for radial velocity determinations were taken for many of the brighter member stars. The distances we determined by ZAMS fitting were not systematically different from spectrophotometric distances we determined for the same aggregates, nor were they systematically different from Georgelin's (1975) distances for stars studied in common. Our

W. B. Burton (ed.), The Large-Scale Characteristics of the Galaxy, 221–224.

https://doi.org/10.1017/S0074180900014509 Published online by Cambridge University Press

stellar radial velocities (Jackson, FitzGerald and Moffat 1978 - in preparation), while showing a larger scatter (σ = 14 km/sec) were not systematically different from Georgelin's H α velocities.

Table 1 gives a summary of our results for regions having both distances (given in kpc with estimated errors) and velocities available. The radial velocity, referred to the LSR, is the mean of stellar and H α velocities if both were available for a given region.

Table 1. Distances and velocities for HII regions

Name	ℓ	b	d	V_r	Name	ℓ	b	d	V_r
S206 = NGC 1491	150.°6	-0.°9	3.0 ± 0.7	-22	S284 = Dol 25	211.°9	-1.°3	5.2 ± 0.8	+27
S207 S208	151.2 151.3	+2.1 +2.0	7.6 0.8	-30	Bo 2 (cluster)	212.3	-0.4	4.8 0.7	+49
Wat 1	151.4	+1.9	4.4 0.4	-30	S285	213.9	-0.6	6.9 0.7	+38
S212 = NGC 1624	155.4	+2.5	6.0 0.6	-48	S287	218.1	-0.4	3.2 0.8	+21
S217	159.2	+3.3	5.2 0.8	-37	S289	218.8	-4.6	7.9 0.8	+47
S219	159.3	+2.6	4.2 0.6	-19	S299 S300	231.0 231.1	+1.5 +1.5	4.4 0.6	+37
S224	166.2	+4.4	2.4 0.6	-89:	S301	231.5	-4.4	5.8 0.9	+50
S225	168.1	+3.1	3.7 0.9	-22	S305	233.7	-0.3	5.2 1.3	+29
S241	180.9	+4.1	4.7 1.2	-4	S306 = RCW 10	234.3	-0.4	4.2 0.4	+47
S247	188.9	+0.8	3.5 0.9	+6	S307 = RCW 12	234.6	+0.7	2.2 0.5	+35
S253 = Bo 1	192.4	+3.2	4.4 0.4	+6	S309 = Bo 6	234.8	-0.2	5.5 0.8	+32
S254-8 = IC 2162	192.6	-0.1	2.5 0.4	-4	RCW 19 RCW 20 = NGC2579	253.8 254.4	-0.3 -0.1	3.0 0.7	+30
S269	196.4	-1.7	3.8 1.0	+6	Ru 44	245.7	+0.5	6.6 0.6	+20
S271 S272	197.8 197.8	-2.3 -2.3	4.8 0.5	+15					

Figure 1, from Moffat et al. (1978), shows the positions of HII regions plotted in the galactic plane, as well as the positions for O-B2 galactic clusters (see Vogt and Moffat 1975).

Figure 2 shows the galactic rotation curve in the form where $\omega - \omega_o$ is plotted against $R - R_o$ and where we have assumed circular galactic rotation for which $\omega - \omega_o = V_r / (R_o \sin \ell)$. We have also assumed the IAU values of 10 kpc for R_o and 250 km/sec for Θ_o , the circular velocity at the Sun, whence ω_o = 25 km/sec/kpc. Lines of constant circular velocity, Θ , equal to 250 km/sec (lower line) and 300 km/sec (upper line) are also shown on figure 2. We have used $\omega - \omega_o$ as ordinate in figure 2 instead of $\Theta = R\,\omega = (R/R_o)\,(\Theta_o + V_r / \sin \ell)$ because (i) errors in $\omega - \omega_o$ depend only on errors in V_r and (ii) it is easy to see the effect of assuming different values for Θ_o and R_o.

In figure 2, we see an initial drop in Θ from R = 10 kpc outwards to near R = 11.8 kpc where Θ is about 230 km/sec, but there is then a rise to about Θ = 275 km/sec near R = 14 kpc, followed by, perhaps, a drop back to near 250 km/sec at greater R. Thus, the rotation curve for our Galaxy seems flat overall at large galactocentric distances, but with large-scale regional deviations of about 15 km/sec.

Dr. Rubin, at this Symposium, showed evidence for overall flat rotation curves in the outer regions of most external spiral galaxies, but with clear rises across spiral arms. Note that the rise in Θ near R = 14 kpc shown in figure 2 corresponds to the distance of a general maximum in the HI density near R = 14 kpc as reported at this Symposium by Dr. Henderson.

The non-circular motions closer to the Sun shown in figure 2 have been discussed by Crampton and Georgelin (1975). Note that the value of dω / dR in the neighborhood of the Sun is steeper than average and thus values for the rotation constant, A, near 15 km/sec/kpc determined by many workers is not inconsistent with the value for A of 12.5 km/sec/kpc required for a completely flat rotation curve with no local variations.

The effect of different values for R_0 can be easily seen in figure 2, since reasonable changes in R_0 have negligible effects on R - R_0. A smaller value for R_0 , say R_0 = 8.5 kpc, causes a steepening in the lines of constant Θ (after rescaling the ordinate to keep the positions of the data points the same) which worsens the fit in the outer parts

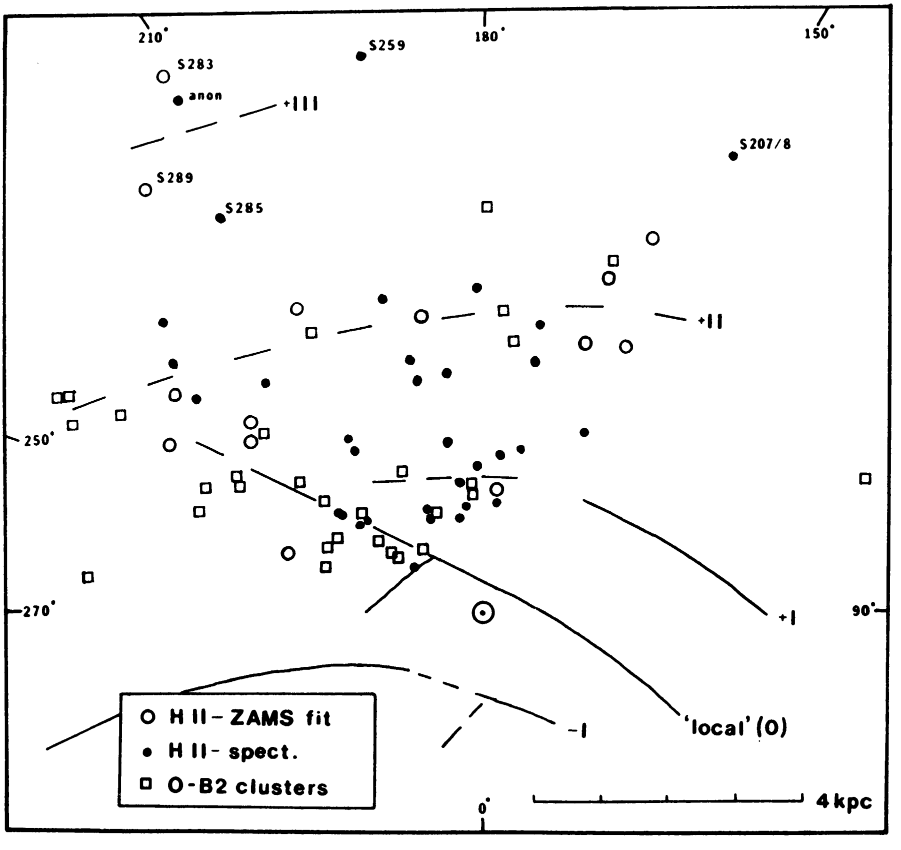

Figure 1. Positions of HII regions and O-B2 clusters plotted on the galactic plane in the longitude range 150° to 260°. Well determined spiral features are shown as solid lines while tentative features are shown as dashed lines.

https://doi.org/10.1017/S0074180900014509 Published online by Cambridge University Press

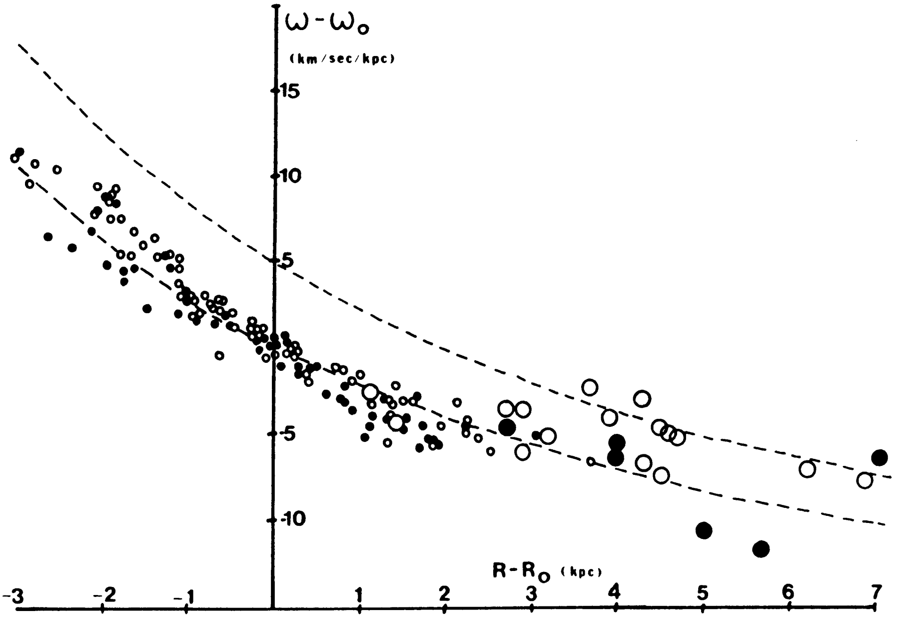

Figure 2. Plot of $\omega - \omega_0$ versus $R - R_0$ for HII regions whose distances have been determined by the present authors (large circles) and for HII regions for which data have been taken from Georgelin (1975; small circles). In both cases, filled circles represent the first and second quadrants of ℓ and open circles represent the third and fourth quadrants of ℓ . The dashed lines represent constant rotation speeds of 250 km/sec (lower line) and 300 km/sec (upper line), assuming R_0 = 10 kpc and ω_0 = 25 km/sec/kpc.

of the Galaxy.A smaller value for Θ_0 (say 220 km/sec, favored by Drs. Knapp and Einasto at this Symposium) flattens the lines of constant in figure 2, improving the fit in the outer parts of the Galaxy. A lower value for Θ_c would also be indicated in view of Dr. Rubin's results that no Sb or later galaxies examined have rotation curves which exceed 250 km/sec.

The authors wish to acknowledge the support of the National Research Council of Canada and PDJ wishes to acknowledge the support of U.S. National Science Foundation grant AST-77-26898, to Prof. F. J. Kerr.

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