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NEUTRAL HYDROGEN BETWEEN GALACTIC LONGITUDES 200° AND 265°

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Neutral Hydrogen Between Galactic Longitudes 200° and 265°

By R. J. Davis [1]

This paper presents the results of an observational program conducted with the George R. Agassiz radio telescope of Harvard College Observatory. The purpose of the program was to determine which OB associations between galactic longitudes 200° and 265° might contain sufficient neutral hydrogen gas to be effectively studied with 21-centimeter techniques. The present survey covers this entire strip of galactic longitude obtained by taking frequency scans on rather widely spaced centers between galactic latitudes +15° and −15°, with additional closely spaced centers covering five OB associations and the extremely young cluster NGC 2362. Table 1 lists these centers. Table 2 lists the characteristics of these and similar optical features in this region.

This paper uses throughout the new galactic coordinate system as defined by Blaauw, Gum, Pawsey, and Westerhout (1959). In addition, it employs the nomenclature for OB associations as defined by Alter *et al.* (1958, 1959, 1960), the most extensive list of associations yet published and continually kept up to date. Unfortunately, no list of designations for these associations is as yet either entirely authoritative or complete. Other authors, as indicated in table 2, have used different designations for the associations within this region.

In this region of the sky the primary features of the spiral structure as seen in the 21-cm radiation are the Orion Arm, in which the sun and all features of table 2 (except Puppis II) are located; and the Perseus Arm, in which Puppis II lies. The Outer Arm, beyond the Perseus Arm, is also evident on many of the scans.

This region of the Milky Way was included in two extensive 21-centimeter surveys of the galactic plane: the Leiden survey (Muller and Westerhout, 1957), and the Commonwealth Scientific and Industrial Research Organization (CSIRO) survey (Kerr, Hindman, and Gum, 1959). Both of these were conducted with less beamwidth and bandwidth resolution than that provided by Harvard's radio telescope. Certain of the OB associations within this region have already been studied elsewhere: Orion I, Monoceros I and Monoceros II by Menon (1955, 1958); and Lambda Orionis by Wade (1957a). In addition, van Woerden, at Groningen, using the higher beamwidth and bandwidth resolution of the Dwingeloo 25-meter radio telescope, is now making a much more detailed investigation of Orion I.

For the Orion associations the present evidence favors a strong correlation between the neutral hydrogen distribution and the optical features; the detailed features, however, do not appear to correlate well with one another. The evidence for such a strong correlation was less conclusive for Monoceros I and II. Since throughout this entire region the continuous radiation near 21 cm is extremely weak, its effects can be neglected for each of the centers of this study.

Table 1 lists the positions of the 90 centers observed. Each observation consisted of two frequency scans taken with the antenna track-

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Table 1.—*Coordinates of centers observed at 21 centimeters; epoch, 1958.0*

Center	Coordinate							
	α		δ		l^{II}	b^{II}	l^{I}	b^{I}
	h	m	°	′	°	°	°	°
S0	20	38. 96	+42	45. 8	82. 30	+ 0. 69	50	0
S1	5	16. 00	+16	28. 8	187. 13	−11. 96	154. 9	−10. 5
S2	7	19. 10	+15	32. 3	202. 32	+13. 51	170	+15
S3	7	01. 00	+13	22. 1	202. 32	+ 8. 51	170	+10
S4=A4	6	42. 22	+11	06. 5	202. 31	+ 3. 51	170	+ 5
S5=A6	6	24. 21	+ 8	47. 3	202. 31	− 1. 49	170	0
S6	6	06. 48	+ 6	24. 6	202. 30	− 6. 49	170	− 5
S7	5	48. 88	+ 4	00. 0	202. 29	−11. 49	170	−10
S8	5	31. 40	+ 1	34. 2	202. 29	−16. 49	170	−15
S9	6	33. 64	+ 4	22. 2	207. 31	− 1. 48	175	0
S10	7	36. 36	+ 6	51. 0	212. 21	+13. 52	180	+15
S11	7	18. 47	+ 4	34. 2	212. 24	+ 8. 52	180	+10
S12	7	00. 64	+ 2	15. 4	212. 26	+ 3. 52	180	+ 5
S13	6	42. 96	− 0	03. 6	212. 29	− 1. 48	180	0
S14	6	25. 24	− 2	22. 8	212. 32	− 6. 48	180	− 5
S15	6	07. 47	− 4	40. 8	212. 34	−11. 48	180	−10
S16	5	49. 56	− 6	57. 6	212. 37	−16. 48	180	−15
S17	7	54. 56	− 1	40. 8	222. 13	+13. 61	190	+15
S18	7	37. 04	− 4	06. 6	222. 19	+ 8. 61	190	+10
S19	7	19. 48	− 6	31. 8	222. 25	+ 3. 61	190	+ 5
S20=B1	7	01. 72	− 8	54. 0	222. 30	− 1. 38	190	0
S21	6	43. 72	−11	13. 2	222. 34	− 6. 39	190	− 5
S22	6	25. 44	−13	28. 8	222. 39	−11. 39	190	−10
S23	6	06. 80	−15	39. 0	222. 44	−16. 39	190	−15
S24	8	14. 44	− 9	58. 2	232. 09	+13. 74	200	+15
S25	7	57. 12	−12	37. 2	232. 17	+ 8. 74	200	+10
S26	7	39. 44	−15	12. 0	232. 23	+ 3. 74	200	+ 5
S27	7	21. 36	−17	41. 4	232. 30	− 1. 26	200	0
S28	7	02. 80	−20	04. 2	232. 37	− 6. 26	200	− 5
S29	6	43. 64	−22	19. 2	232. 44	−11. 26	200	−10
S30	6	23. 88	−24	26. 4	232. 52	−16. 26	200	−15
S31	8	36. 88	−17	57. 6	242. 04	+13. 89	210	+15
S32	8	19. 64	−20	52. 2	242. 13	+ 8. 89	210	+10
S33	8	01. 72	−23	40. 2	242. 22	+ 3. 89	210	+ 5
S34	7	43. 04	−26	20. 4	242. 31	− 1. 11	210	0
S35	7	23. 52	−28	50. 4	242. 40	− 6. 11	210	− 5
S36	7	03. 08	−31	10. 2	242. 49	−11. 11	210	−10
S37	6	41. 61	−33	16. 8	242. 57	−16. 11	210	−15
S38	9	02. 92	−25	29. 4	251. 99	+14. 08	220	+15
S39	8	45. 80	−28	43. 8	252. 10	+ 9. 09	220	+10
S40	8	27. 63	−31	49. 2	252. 20	+ 4. 09	220	+ 5
S41	8	08. 20	−34	45. 0	252. 30	− 0. 91	220	0
S42	7	47. 43	−37	28. 2	252. 40	− 5. 91	220	− 5
S43	7	25. 17	−39	56. 4	252. 51	−10. 91	220	−10
S44	7	01. 28	−42	07. 8	252. 61	−15. 91	220	−15
S45	9	33. 88	−32	23. 4	261. 96	+14. 29	230	+15
S46	9	17. 23	−36	01. 2	262. 07	+ 9. 30	230	+10
S47	8	59. 00	−39	29. 4	262. 18	+ 4. 30	230	+ 5
S48	8	38. 97	−42	46. 2	262. 30	− 0. 70	230	0
S49	8	16. 72	−45	48. 0	262. 41	− 5. 69	230	− 5
S50	10	15. 03	−38	23. 4	272. 57	+14. 99	240. 67	+15. 41
S51	9	55. 77	−42	26. 4	272. 03	+ 8. 56	240	+10
S52	9	38. 40	−46	22. 8	272. 16	+ 4. 54	240	+ 5

TABLE 1.—*Coordinates of centers observed at 21 centimeters; epoch, 1958.0*—Continued

Center	Coordinate							
	α		δ		l^{II}	b^{II}	l^{I}	b^{I}
	h	m	°	′	°	°	°	°
S53	10	55. 52	−43	09. 0	282. 73	+14. 79	250	+15
A0	6	36. 80	+10	25. 2	202. 31	+ 2. 04	170	+ 3. 5
A1	6	29. 24	+13	57. 6	198. 30	+ 2. 01	166	+ 3. 5
A2	6	33. 04	+12	11. 4	200. 31	+ 2. 04	168	+ 3. 5
A3	6	49. 47	+12	01. 2	202. 28	+ 5. 50	170	+ 7
A4=S4	6	42. 22	+11	06. 5	202. 31	+ 3. 51	170	+ 5
A5	6	31. 40	+ 9	43. 2	202. 31	+ 0. 54	170	+ 2
A6=S5	6	24. 21	+ 8	47. 3	202. 31	− 1. 49	170	0
A7	6	40. 52	+ 8	39. 0	204. 30	+ 2. 04	172	+ 3. 5
A8	6	44. 24	+ 6	52. 8	206. 30	+ 2. 04	174	+ 3. 5
B0	7	06. 24	−10	34. 2	224. 31	− 1. 13	192	+ 0. 2
B1=S20	7	01. 72	− 8	54. 0	222. 30	− 1. 38	190	0
B2	7	12. 68	− 9	43. 2	224. 30	+ 0. 66	192	+ 2
B3	7	09. 12	−10	11. 4	224. 30	− 0. 33	192	+ 1
B4	7	01. 92	−11	08. 4	224. 32	− 2. 34	192	− 1
B5	6	58. 32	−11	36. 6	224. 34	− 3. 34	192	− 2
B6	7	10. 12	−12	19. 8	226. 31	− 1. 08	194	+ 0. 2
C0	7	17. 03	−24	52. 5	238. 20	− 5. 50	205. 81	− 4. 36
C1	7	06. 96	−24	03. 6	236. 41	− 7. 18	204	− 6
C2	7	14. 92	−23	59. 4	237. 18	− 5. 54	204. 81	− 4. 36
C3	7	18. 84	−24	51. 6	238. 38	− 5. 14	206	− 4
C4	7	14. 96	−25	21. 0	238. 40	− 6. 15	206	− 5
C5	7	11. 04	−25	49. 2	238. 42	− 7. 15	206	− 6
C6	7	07. 08	−26	16. 8	238. 42	− 8. 15	206	− 7
C7	7	03. 12	−26	44. 4	238. 45	− 9. 15	206	− 8
C8	7	19. 17	−25	44. 4	239. 20	− 5. 42	206. 81	− 4. 36
C9	7	15. 24	−27	34. 2	240. 42	− 7. 11	208	− 6
D0	7	47. 00	−28	43. 5	244. 82	− 1. 54	212. 5	− 0. 5
D1	7	38. 84	−25	44. 4	241. 33	− 1. 60	209	− 0. 5
D2	7	49. 29	−26	39. 6	243. 30	− 0. 06	211	+ 1
D3	7	43. 48	−27	27. 0	243. 27	− 1. 56	211	− 0. 5
D4	7	37. 64	−28	13. 2	243. 35	− 3. 06	211	− 2
D5	8	00. 38	−26	51. 0	244. 76	+ 1. 97	212. 5	+ 3
D6	7	52. 80	−27	56. 0	244. 80	− 0. 03	212. 5	+ 1
D7	7	41. 14	−29	30. 6	244. 85	− 3. 04	212. 5	− 2
D8	7	33. 20	−30	31. 2	244. 89	− 5. 03	212. 5	− 4
D9	7	56. 48	−29	12. 0	246. 30	− 0. 01	214	+ 1
D10	7	50. 64	−30	00. 0	246. 32	− 1. 51	214	− 0. 5
D11	7	44. 72	−30	47. 4	246. 34	− 3. 05	214	− 2
D12	7	55. 64	−31	41. 4	248. 32	− 1. 47	216	− 0. 5

ing the center, the receiver being scanned both ways across the frequency of the hydrogen-line signal. The resulting profile was the mean of these two scans. Many of the observations were repeated on a second day. Centers S0, S1, and S8 were used as standards; each day's observations were referred to S8; then S8 was compared carefully with the other standards. Center S0 has been used as a standard at Leiden, and Center S1 by Wade.

Centers A0 through A8 are in the vicinity of Monoceros I and Monoceros II; B0 through B6 in that of Canis Major I; C0 through C9 in that of NGC 2362; and D0 through D12 in that of Puppis I and Puppis II. Table 1 gives right ascension and declination for 1958.0, as well as

TABLE 2.—*OB associations and similar*

Feature Nomenclature						
Alter *et al.* (1958, 1959, 1960)	Dieter (1960)	Drake (1958)	Howard (1958)	Kassim (1958)	Matthews (1956)	Menon (1958b)
Cyg III	I Cyg			I Cyg		
Cyg I	II & III Cyg			II & III Cyg		II Cyg
Cyg IV	VI Cyg			VI Cyg		VI Cyg
Cyg II				IV Cyg		
Lac I	I Lac		I Lac		I Lac	I Lac
Per I		h & χ Per				h & χ Per
Per II					II Per	II Per
Ori II	II Ori (S)					
	II Ori (M)					Ori II
Mon I	II Mon					NGC 2264
Ori I	I Ori				I Ori	Ori I
Mon II	I Mon					NGC 2244
CMa I	III Mon					
NGC 2362	I CMa?					
Pup II						
Pup I						
Vel I						
Car I						

galactic longitude and latitude in both the old and new coordinate systems. Between December 19, 1956, and June 4, 1959, I obtained 197 satisfactory observations on these 90 centers; 64 were on the secondary standard, Center S8.

Equipment and calibration

Wade (1957b) and Drake (1958) have described the 60-foot antenna of the George R. Agassiz radio telescope used for these observations. This antenna has an efficiency of 55 percent.

Lilley (1955) has described the older radiometer used for all but the last 37 observations. This instrument was a double-conversion superheterodyne receiver with automatic gain control.

In the autumn of 1958 the radiometer was entirely modernized. The local oscillator now uses a 2C39B lighthouse tube. It is tuned to oscillate 38.5 mc/sec above the signal frequency. The first IF amplifier now accepts a pass band between 34 and 39 mc/sec; the second uses a pass band between 7 and 12 mc/sec. A 46-mc/sec crystal-oscillator produces the necessary mixing signal. A new set of filters enables the operator to select the signal and comparison filters independently of one another. There is a new DC amplifier and comparator, as well as a new 2-channel Sanborn hot-wire recorder.

stellar groups discussed in this paper

Feature Nomenclature—Continued						
Morgan *et al.* (1953)	K. H. Schmidt (1958)	*l*	*b*	Distance	21-cm study by	Optical features
I Cyg	I Cyg	71° to 75°	+2° to +4°	2260 pc	Kassim	NGC 6871
II & III Cyg	II Cyg	74 to 77	0 to +4	1930	Kassim	P Cyg; M29
	VI Cyg	80	+2	1850	Kassim	
IV Cyg	IV Cyg	81 to 84	−7 to −5	1000	Kassim	σ Cyg
I Lac	I Lac	96 to 98	−17 to −14	460	Matthews, Howard	10 Lac
I Per	I Per	132 to 136	−4 to −2	2300	Drake	h & χ Per
II Per	II Per	157 to 163	−20 to −12	390	Matthews	ζ Per, IC 348 (Cluster).
	II Ori	187 to 189	−4 to +1	3240		
		196	−12	600	Wade	λ Ori, H II region
	II Mon	196 to 210	−2 to +2	550	Davis, Dieter	NGC 2264 (Cluster), IC 2169? (Cluster).
I Ori	I Ori	198 to 214	−25 to −13	500	Menon, Westerhout, van Woerden	Orion Nebula (M42), and many others.
I Mon	I Mon	205 to 209	−3 to +1	1550	Menon, Davis, Dieter	NGC 2244 (Cluster), NGC 2237, 2238, 2239 (Nebulae)
	I CMa	222 to 226	−3 to +1	950	Davis, Dieter	Stromlo 2 (H II region).
		238	−6	1450	Davis, Dieter	τ C Ma, Stromlo 8 (H II region).
	I Pup	242 to 245	−4 to +2	4200	Davis	AQ Pup? (Cepheid variable).
	II Pup	242 to 246	−1 to +2	2500	Davis	
	I Vel	262 to 268	−2 to +2	1450	(Davis)	
	I Car	283 to 292	−2 to +2	1100		η Car

Each observation consisted of a frequency scan obtained with the antenna tracking on a center; the radiometer was scanned by varying the frequency of the first local oscillator. With the old radiometer an AFC frequency of 5.3444 mc/sec corresponded to hydrogen at rest relative to the observer. With the modernized instrument, used for the last 37 observations, 8.9056 mc/sec corresponds to this rest frequency.

I calibrated the intensity scale by comparing, for 18 centers, my profiles with published profiles taken at Leiden and at CSIRO. Using a temperature scale higher by a factor of 1.28 than the Leiden scale, the CSIRO group obtained its intensity calibration from a fluorescent gas-discharge tube. Since both scales represent an uncertainty of 20 percent, this difference is not considered significant, even though in making comparisons it must be taken into account. Kerr, Hindman, and Gum (1959) ascribe the difference to the reduction from antenna temperature to brightness temperature.

As a further check on the calibration, I compared, for Center S1, my profiles with Wade's (1957b, 1959). He tied in the Harvard temperature scale with that of Leiden by observing the continuous radiation from Taurus A.

The advantage of calibration by the comparison method lies in the probable uniformity of available results obtained at different institutions and in the greater ease of comparison with subsequent observations. Until the absolute calibration of 21-cm intensities is more feasible, if all results are derived from a basis as nearly uniform as possible the necessary corrections will be easier to make.

The principal difficulties involved in such a comparison stem from the differences in the equipment used. The Leiden radiometer had a bandwidth of 33 kc/sec between half-power points, whereas at Harvard the bandwidth was 15 kc/sec. The Leiden profiles thus had lower peaks and higher troughs. The integrated intensity of the line, however, is not affected by receiver bandwidth.

The Leiden 7.5-meter antenna at Kootwijk had a beamwidth of 1°7 as compared with 0°8 for the Harvard 60-foot antenna. Complete correction for antenna patterns requires more information than is available from my observations. At any point in the galactic plane, however, the entire profile will in general be higher for the larger antenna. The lobe pattern of the antenna and the shape of the pass band can greatly affect the shape of the profile.

Raimond and van Woerden (1959) compare various Leiden observations of the center at $l=82°30$, $b=+0°69$ (table 3). These measurements indicate the effects of bandwidth and beamwidth on peak intensities.

The CSIRO data, obtained from drift curves with the 36-foot antenna near Sydney, are presented in the form of velocity versus galactic latitude curves of constant intensity. These data also indicate that variations of intensity with position will probably not cause difficulty in the region between galactic longitudes 200° and 260°. Additional evidence of this fact is provided by the agreement of my profiles with those of Leiden even for centers differing somewhat in position.

TABLE 3.—*Leiden standard center intensity comparisons*

Antenna	Bandwidth (kc/sec)	Peak intensity (units, by definition)
Kootwijk 7.5-meter dish	33	100
Dwingeloo 25-meter dish	33	107.7
" " "	16	113.8
" " "	7	115.2
" " "	3.5	116.4

The Harvard temperature scale is, therefore, approximately equivalent to that used by the Leiden group. However, primarily because of the smaller side-lobe contribution of the 60-foot antenna and the narrower bandwidth of the Harvard radiometers, the Harvard profiles are more nearly representative of the true intensity profiles. The observational estimates of T_K, the representative mean kinetic temperature of the hydrogen atoms responsible for the 21-cm radiation, as given by M. Schmidt (1957) and the Harvard observers, and as used by Oort, Kerr, and Westerhout (1958), are all based upon the Leiden temperature scale.[2]

Evidence of possible errors in that scale is not yet quite ready for evaluation. The scale was chosen for the present paper to permit easier comparison with the results of other investigators in the field. Muller and Westerhout (1957) believe the maximum error in the scale to be ±20 percent.

All scans used a 15-kc/sec signal bandwidth, a 2-mc/sec comparison bandwidth, and an integrating time of 10 to 20 seconds. This study used Center S8 ($l=202°29$, $b=-16°49$) as a secondary standard for observation with a single scan once each day. Except for the last 37 observations, when no such circuit was available, I used automatic gain control.

Muller and Westerhout (1957) discuss the scale nonlinearities introduced by a radiometer, such as the Harvard radiometer prior to late 1958, with a linear detector and automatic gain-control. For such an instrument, the recorder deflection h is given by

$$h=K\Delta T\left(1-\frac{\Delta T}{4T}\right)^2. \quad (1)$$

For a linear detector without automatic gain control, used for the last 37 observations, h is given by

$$h=K\Delta T\left(1-\frac{\Delta T}{4T}\right). \quad (2)$$

In equations (1) and (2), K is a constant determined by the sensitivity of the receiver; ΔT is the intensity of the signal arriving at the radi-

[2] A further discussion of the parameter T_K is given on pp. 216–222.

ometer; and T is the effective noise temperature of the radiometer,

$$T=2(N'-1)T_0. \quad (3)$$

Here, N' is the noise figure of the radiometer, and T_0 is very nearly the ambient temperature of the crystal mixer. For the Harvard radiometer, $T=900°$ K, corresponding (for $T_0=280°$ K) to a noise figure of 4.2 db. Both h and ΔT are, of course, functions of frequency.

Muller and Westerhout (1957) also discuss the effects of atmospheric absorption and radiation upon the incoming 21-cm radiation. They conclude on both theoretical and observational grounds, that

$$\Delta T=T_i p^{F(z)}\left\{1-\frac{2T_0}{T}[1-p^{F(z)}]\right\}, \quad (4)$$

where T_i is the intensity of the 21-cm signal beyond the earth's atmosphere; $p=0.9915$; and $F(z)$ is the air mass.

For observations taken within 5° of the horizon, the effects of ground radiation upon the AGC circuit become comparable to the direct atmospheric effects, even in the case of Harvard's 60-foot antenna. When this effect is included, equation (4) becomes

$$\Delta T=T_i p^{F(z)}\left\{1-\frac{2T_0}{T}[1-p^{F(z)}]\right\}\left\{1-\frac{2T_0}{T}\eta\right\}. \quad (5)$$

Here, η is the efficiency at which the antenna collects ground radiation when it is pointed at the center under observation; this efficiency is 0.5 when the antenna is pointed exactly at the apparent horizon, and 1.0 when depressed 5° or more below.

For a linear detector without AGC, equations (4) and (5) become

$$\Delta T=T_i p^{F(z)}. \quad (6)$$

Westerhout (1957) discusses the effects of bandwidth and beamwidth upon the observed profiles. Using Eddington's approximation, he derives the equation for bandwidth correction as equivalent to

$$T_i'(\nu)=T_i(\nu)-\frac{(0.425W_\nu)^2}{2(\Delta\nu)^2}\Delta^2T(\nu); \quad (7)$$

and his beamwidth correction is equivalent to

$$T_i''(b)=T_i'(b)-\frac{(0.425W_A)^2}{2(\Delta b)^2}\Delta^2T_i'(b). \quad (8)$$

Here, W_ν is the bandwidth of the receiver (assumed to have a Gaussian bandpass) between half-power points; ν is the frequency; W_A is the beamwidth of the main lobe of the antenna (also assumed Gaussian in shape) between half-power points; b is galactic latitude; and Δ and Δ^2 represent first and second differences, respectively.

Figure 1 shows the results of correcting the profiles on three centers for the instrumental effects listed above. These three centers are S27 at $l=232\overset{\circ}{.}30$, $b=-1\overset{\circ}{.}26$; S48 at $l=262\overset{\circ}{.}30$, $b=-0\overset{\circ}{.}70$; and the center at $l=282\overset{\circ}{.}30$, $b=-0\overset{\circ}{.}30$, which was observed by the CSIRO group.

From figure 1 it is evident that in the case of the Harvard radio telescope these corrections can safely be neglected for those centers where atmospheric extinction and ground effects are unimportant, i.e., for all centers observed more than 10° above the horizon. For Center S48, however, the correction for atmospheric extinction alone amounts to 14 percent, and the total correction for nonlinearity amounts to 20 percent. Center S52 at $l=272\overset{\circ}{.}16$, $b=+4\overset{\circ}{.}54$ ($\alpha=9^h\ 36\overset{m}{.}40$, $\delta=-46°\ 22\overset{'}{.}8$ (1958.0)) is probably too near the horizon for reliable observation.

For the CSIRO observers Center S48 passes nearly through the zenith. My profile, corrected by means of equations (1) through (8), has very nearly the same integrated intensity as theirs if one bears in mind the difference by the factor of 1.28 between the CSIRO and the Leiden temperature scales; my uncorrected profile has an integrated intensity 18 percent smaller. The beamwidth correction is important here. Table 4 lists these integrated intensities. Center S27 is included for comparison. In the last case the corrections amount to less than the errors and can be neglected.

Observational results and analysis

Through use of the Leiden intensity scales, there is plotted in figure 2 the mean intensity profile for each center. Note that l^{I} and b^{I} rather than l^{II} and b^{II} are indicated in the figure.

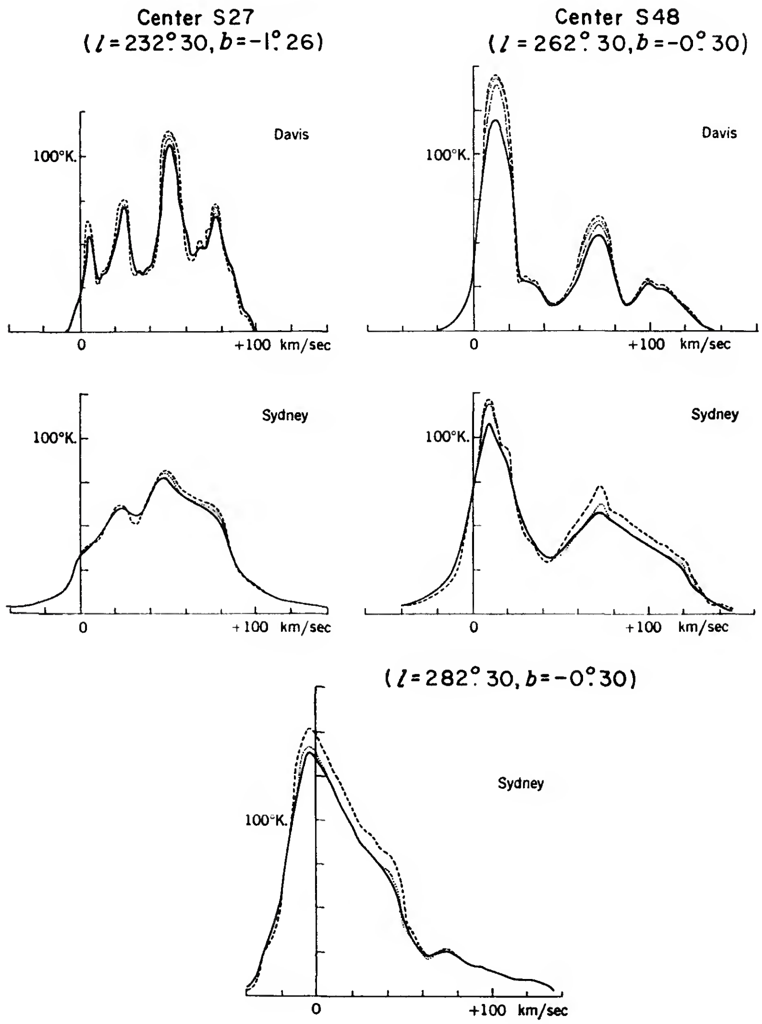


FIGURE 1.—Corrections to profiles on Centers S27; S48; and l=282.°30, b=±0.°30. Solid line, uncorrected profile; dash-dot line, profile corrected for intensity-scale nonlinearities (equations 1 and 5); dotted line, profile also corrected for receiver bandwidth (equations 1, 5, and 7); broken line, profile also corrected for antenna beamwidth (equations 1, 5, 7, and 8).

The profiles of Centers S47 through S53 have been corrected for the effects of intensity scale nonlinearity, bandwidth, beamwidth, atmospheric extinction, and horizon effects. These effects are unimportant for this survey except for Centers S48 through S53.

The observational results end with the derivation of the intensity profiles. In order to derive the hydrogen densities from these profiles, we must compute the optical depths. Heeschen (1955) gives the reduction formulas

$$\Delta T(\nu)=(T_K-T_C)(1-e^{-\tau_\nu}) \qquad (9)$$

for the case where a source of continuous radiation lies behind the source of line radiation; and

$$\Delta T(\nu)=T_K e^{-\tau_C}(1-e^{-\tau_\nu}) \qquad (10)$$

where a source of continuous radiation lies in front of the source of line radiation. In both cases, $\Delta T(\nu)$ is the measured intensity (in temperature units) at frequency v; T_K is the kinetic temperature of the interstellar hydrogen (assumed to be constant); T_C is the intensity of the continuous radiation in temperature units; τ_C is the optical depth in the continuum; and τ_ν is the optical depth in the line at frequency ν. The conversion from intensity units to temperature units is given by the Rayleigh-Jeans law,

$$I=\frac{2\nu^2}{c^2}\,k\Delta T, \qquad (11)$$

where c is the velocity of light and k is the Boltzmann constant.

Westerhout (1958) shows that in this region T_C and, therefore, τ_C are essentially zero, except in the vicinity of discrete sources. The measurements of Denisse, Lequeux, and Le Roux (1957) at 900 mc/sec substantiate this finding. No discrete source lies within 1° of any of my centers.

Since both T_C and τ_C can be neglected for each center, inversion of either equation (9) or equation (10) gives the reduction formula for converting intensity profiles to optical depth:

$$\tau_\nu=-\ln\left(1-\frac{\Delta T}{T_K}\right). \qquad (12)$$

Purcell and Field (1956) have shown that for the conditions obtaining in the interstellar medium it is correct to use T_K in equations (9) and (10), although these equations hold rigorously only when T_K is replaced by T_S, a spin temperature defined by the relation

$$\frac{n_1}{n_0}=3\exp\left(-\frac{h\omega}{kT_s}\right), \qquad (13)$$

where n_1 is the population of the upper ($F=1$) level, and n_0 is that of the lower ($F=0$); and $h\omega$ is the energy difference between the two.

Van de Hulst, Muller, and Oort (1954) show that optical depth is connected with $N_H(V)$, the number of hydrogen atoms per square centimeter in the line of sight with radial velocity V, by the equation

$$\tau_\nu=\frac{N_H(V)}{(1.835\times10^{13})T_K}. \qquad (14)$$

The most difficult part of the analysis lies in assigning the correct value to T_K. The usual method is to assume that T_K is constant, and that in the case of the strongest peak intensities the line is saturated. M. Schmidt (1957) discusses various refinements by which one can obtain T_K from the observed peak intensities. He agrees with van de Hulst, Muller, and Oort (1954) in assigning the kinetic temperature of the interstellar hydrogen, $T_K=125°$ K. We must remember, of course, that this value is based upon the Leiden temperature scale.

The greatest peak temperature (146° K) found in this study occurs for Center S48 at $l=262°.30$, $b=-0°.70$. This line is evidently not yet saturated, although it may be approaching that state. This area may possibly be characterized by hydrogen at a higher kinetic temperature than is normal for the part of the galaxy near the sun.

I agree with M. Schmidt (1957) in choosing a value of $T_K=125°$ K on the Leiden scale as probably the most representative kinetic temperature for this region as a whole. In the Orion Arm, the kinetic temperature may perhaps vary from $T_K=120°$ K at $l=202°$ to $T_K=130°$ K or 140° K at $l=262°$. Such variations, however, will not appreciably affect the reductions of centers other than S27, S41, B4, B5, and B6, where the peak intensity exceeds 100° K. Localized fluctuations of the type probably responsible for the high peak at $l=262°$ will introduce greater errors. The best indication of the kinetic temperature in the Perseus Arm comes from the Center S27 at $l=232°.30$, $b=1°.26$. This profile is definitely not saturated. The CSIRO observations near this center indi-

TABLE 4.—*Integrated intensities of selected profiles*

Profile	Integrated intensity (deg km sec⁻¹) S46	S25
Davis uncorrected profile	5104	4965
Davis corrected profile	6024	5200
Sydney corrected profile	6200×1.28	4850×1.28
Sydney uncorrected profile	5720×1.28	4700×1.28

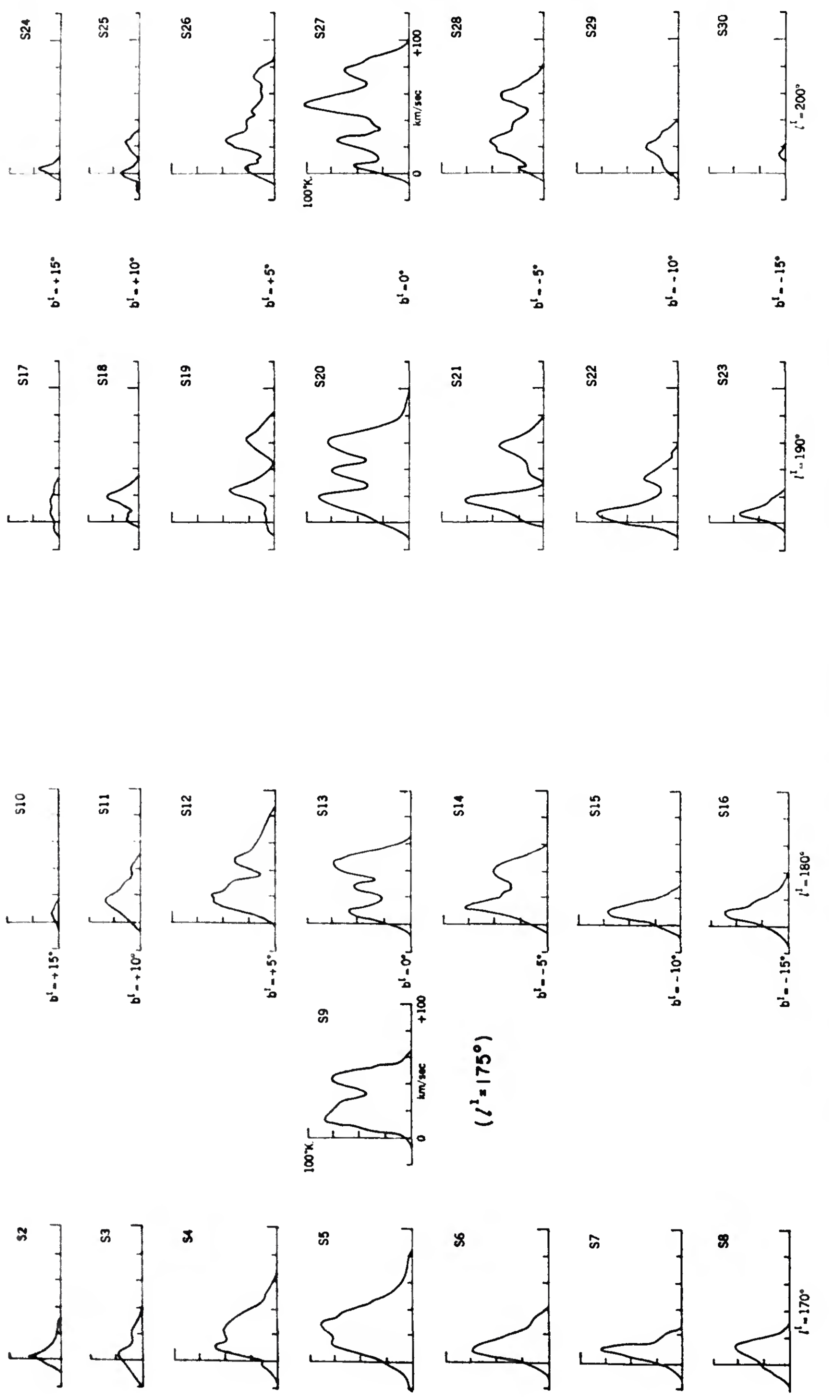


FIGURE 2.—Observed mean-intensity profiles. Solid line, profiles corrected for the effects of intensity-scale nonlinearity, bandwidth, beamwidth, atmospheric extinction, and horizon effects; dotted line, unreduced profiles.

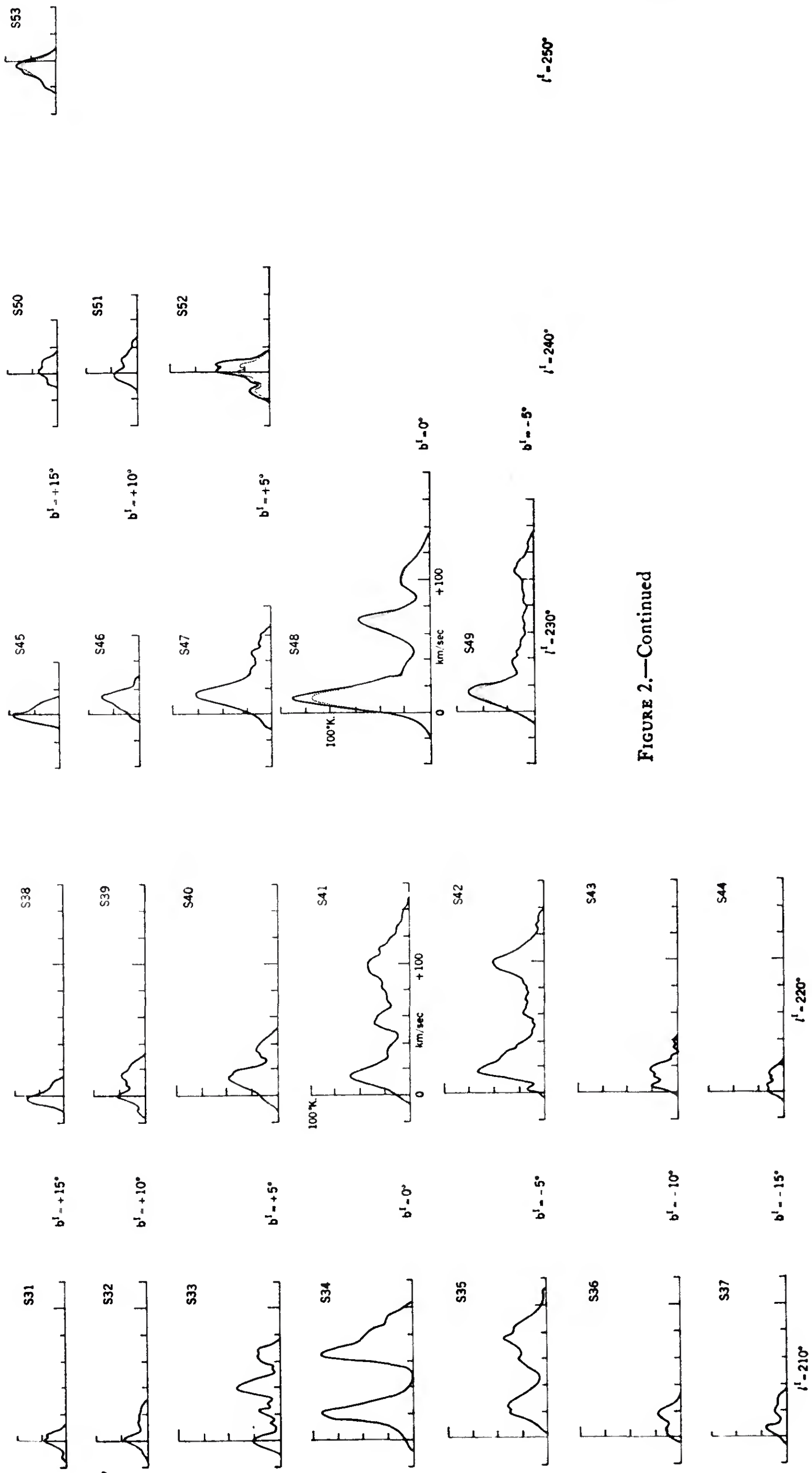


FIGURE 2.—Continued

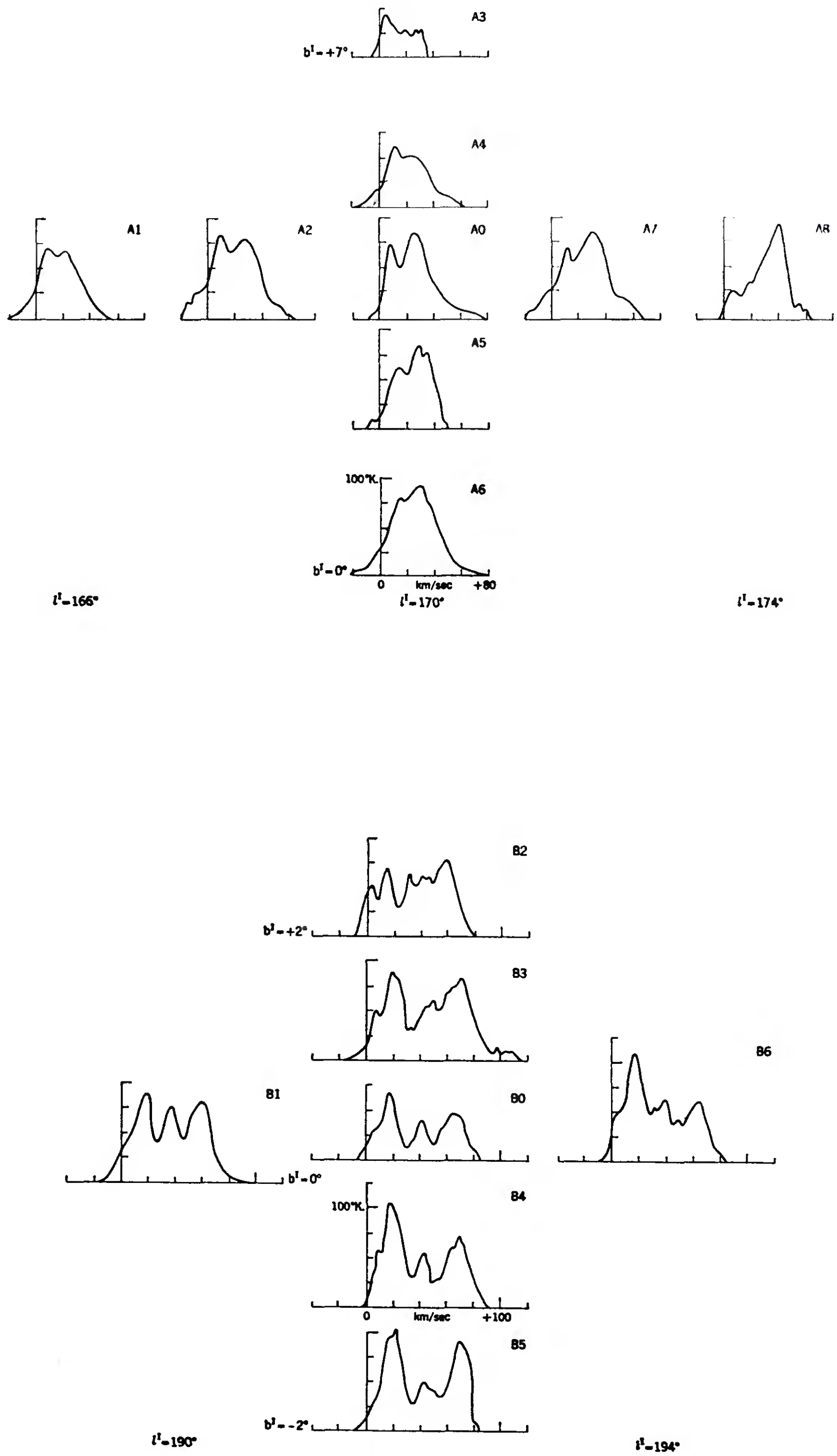


FIGURE 2.—Continued.

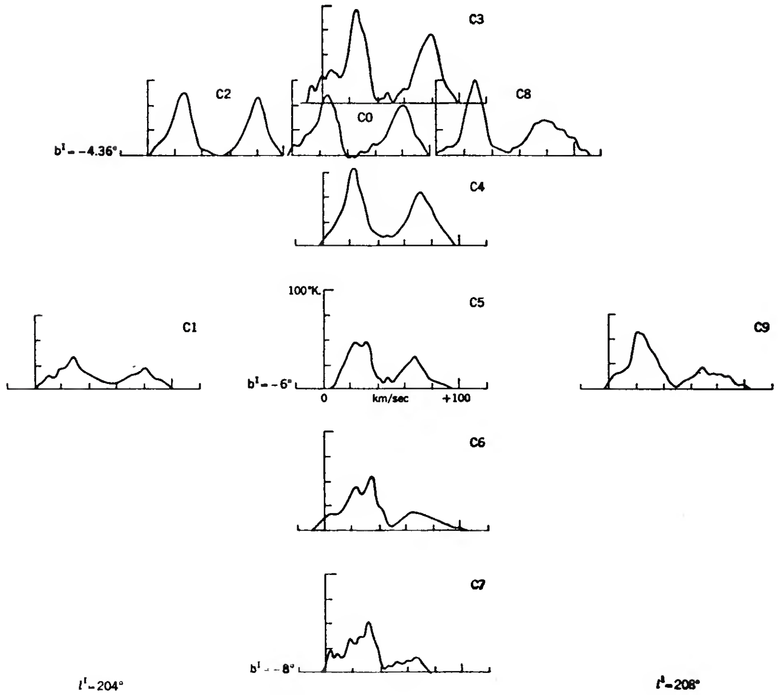
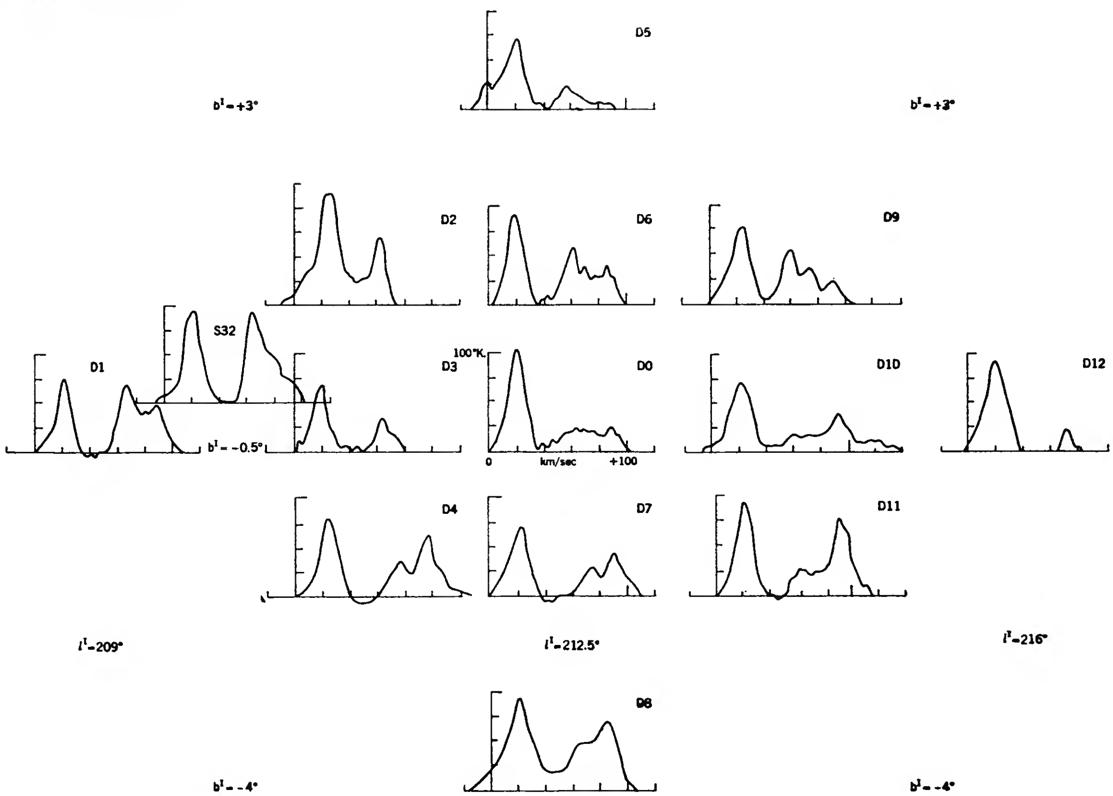


FIGURE 2.—Continued.



cate that in the region the beamwidth correction for Harvard's 60-foot antenna amounts to about 1° K. Corrected for bandwidth and beamwidth, the peak corresponding to the Perseus Arm is 114° K and occurs at a radial velocity of +51 km/sec.

Although 125° K is a fair estimate of the kinetic temperature of the neutral hydrogen throughout the region in both the Orion and Perseus Arms, serious errors came from the assumption that T_K is constant. Davies (1956, 1958), discussing the observed departures from this condition, finds indications that T_K may vary from perhaps 60° K to 250° K. Unfortunately, 21-cm data do not yet warrant for my region an assumption more refined than $T_K=$ 125° K. On that assumption, therefore, all corrected profiles have been reduced to optical depth. These results appear in figure 5, showing monochromatic optical depths, $\tau(V)$, as functions of position, and giving $\tau(V)$ at 5 km/sec intervals of radial velocity.

As Westerhout (1957) points out, the radial component of random cloud velocities tends to widen the 21-cm line. The root-mean-square value of this component lies between 5 and 10 km/sec (Spitzer, 1954). Blaauw (1952) suggests a velocity distribution of the form exp $(-|V|\eta)$, basing this suggestion on observations of interstellar absorption lines. For the 21-cm observations, Westerhout (1957) and Davis (1957) favor a Gaussian form, exp $(-V^2/2\sigma^2)$. The optical depths can be corrected for random cloud velocities by Eddington's second-order approximation,

$$\tau'(V)=\tau(V)-\epsilon\Delta^2\tau(V), \quad (15)$$

where $\Delta^2\tau(V)$ is the second difference of the optical depth as a function of radial velocity, and $\epsilon=c/\Delta V^2$. If we take $\Delta V=4$ km/sec and $\epsilon=2$, we fairly well represent the exact resolving function for a Gaussian distribution with $\sigma=6$ km/sec, or for a Blaauw distribution with $\eta=5.5$ km/sec, provided that the peak-to-valley distances of the profiles are approximately 10 to 15 km/sec. This procedure corresponds almost exactly to that used by Westerhout (1957). However, when we set $\Delta V=2$ km/sec and $\epsilon=8$, this method causes considerable overcorrection. The Harvard radiometer, with its 15-kc/sec bandwidth, is capable of detecting details much narrower than the assumed velocity distribution. As Westerhout points out, we should use $\epsilon=\sigma^2/2\Delta V^2=4$ when $\Delta V=2$ km/sec.

This survey does not include correction for the effects of random cloud velocities. In the first place, the correction appears to be unstable; small errors in either the assumptions or the observational data lead to large errors in the results. Secondly, we can see just as clearly the over-all galactic structure by plotting the positions of the peaks of the major features. We can obtain approximate hydrogen densities for major features by integrating under the observed curve between limiting velocities.

Since the quantitative derivation of space densities for neutral hydrogen depends upon the correction for random cloud velocities (which are here omitted) and upon the rather dangerous assumption that this hydrogen moves at the circular velocity in accordance with a prescribed model of galactic rotation, no attempt is made to determine quantitative values for this space density. Westerhout (1957) describes the procedures by which one may derive these data.

Differential galactic rotation must be based upon observational data. In the region of the galactic system the relationship between rotational velocity and the distance from the galactic center has been determined primarily from 21-cm observations. Kwee, Muller, and Westerhout (1954) tabulate this relationship for the galactic plane ($z=0$).

Optical data are useful mainly for examining the region near the galactic plane within two kiloparsecs of the sun. Away from the plane, where interstellar absorption is not so strong, this limit does not apply. The commonly accepted value of the distance from the sun to the galactic center is $R_0=8.2$ kpc. Baade (1955) determined this value from the magnitude distribution of RR Lyrae variable stars in a field near the galactic center. Baade (1951) had earlier described in detail the method he used. Allen (1955, p. 237) lists the same value for R_0; it is the mean of five values published in various journals between 1939 and 1952. It has a greater mean error. However, the value of R_0 should not be considered as really well established; it may easily be in error by as much as 10 percent. Weaver (1954), for example, found from observations made on Cepheid variables that $R_0=8.8$ kpc.

The outer part of the galactic system is best examined by means of galactic models. M. Schmidt (1956) constructed a series of such models, the final one of which was made both to agree as far as possible with observational data and to meet certain criteria of continuity and equilibrium. Although his is the best yet constructed, it should still be considered only preliminary.

Figure 3 shows two relationships between the angular velocity of rotation and the distance from the galactic center R. The solid curve

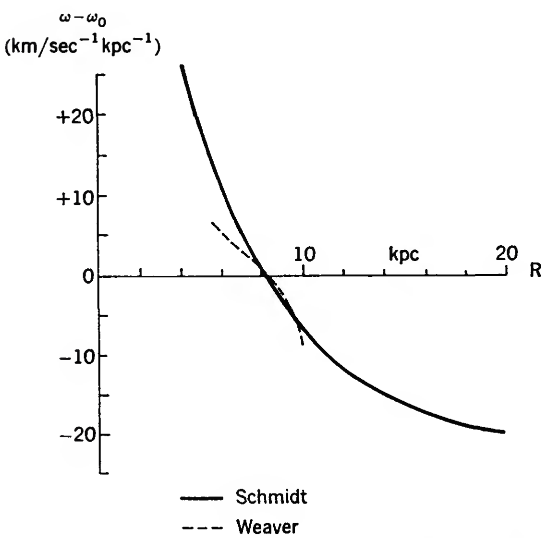


FIGURE 3.—Relationships between the angular velocity of rotation ω and distance from the galactic center R. Solid curve, M. Schmidt (1956); broken curve, Weaver (1955).

is from Schmidt (1956); for $R<R_0$, this curve was made to agree with that derived empirically by Kwee, Muller, and Westerhout (1954). The dashed curve shows the empirical relationship between these two quantities as derived by Weaver (1955) from observations of Cepheid variables.

Once this relationship between ω and R is assumed, the relationship between the radial velocity V and the distance from the sun D follows from the usual equations

$$V=R_0 \sin l(\omega-\omega_0) \qquad (16)$$

and

$$R^2=R_0^2+D^2-2R_0D \cos l, \qquad (17)$$

where l is the galactic longitude in the new coordinate system, and the subscript 0 refers to the sun's position in the galaxy.

Discussing some observational problems of galactic structure, Weaver (1956) emphasizes that none of the basic parameters is as yet really well determined. Better data are necessary for a really good determination of R_0, ω_0, the Oort A and B constants, etc.

Figure 4 plots the average positions of the 21-cm intensity peaks at 10° intervals of galactic longitude. It is based upon Schmidt's (1956) model. Note that this figure shows l^{I}, rather than l^{II}. Features A and B belong to the Orion Arm, feature D to the Perseus Arm, and feature E to the Outer Arm. Feature C is probably on the outer edge of the Orion Arm but could represent an interarm feature. These observations indicate that in the galactic system the spiral structure is trailing. This conclusion is not dependent upon the detailed structure of the distance-scale assumptions; it holds under any galactic rotation model in which the three following requirements are met.

First, ω must be decreasing with increasing R for all $R>R_0$; second, ω must not be a function of direction from the galactic center (Θ); and third, large interstellar neutral hydrogen complexes must have no systematic motions other than the circular velocity of rotation. The first condition is certainly met. There is as yet no adequate method of evaluating the degree to which the second condition is met. The third condition is very definitely not met. Such absence of ideal requirements represents the most serious limitations on establishing an adequate distance scale for neutral hydrogen.

For observations away from the galactic equator, there is a fourth consideration: ω must decrease with increasing distance from the galactic plane (z). Although this last condition is actually much more restrictive than is mathematically necessary, it is certainly met to the required degree of accuracy.

The strongest 21-cm feature in the region from $l=190°$ to $290°$ (Bok's [1959] Carina-Cygnus Arm, or the Orion Arm) may be distorted in figure 4 by departures of the hydrogen velocity from the circular velocity of galactic rotation. As plotted in figure 4, ten kilometers per second near $l=270°$ would make a significant difference in the appearance of this arm, which everywhere appears to be farther from the galactic center than the sun is. Because of departures of the hydrogen motion from the assumed model, however, the profiles near $l=285°$ show the peak from this arm blended with that from the inner arm.

As Baade (1958) points out, the structure of spiral galaxies is not simple. Arms branch, branches are lost, and even entire arms sometimes disappear, only to reappear farther on. His description of the Andromeda Galaxy is very similar in many respects to that of our own galaxy, as shown in figure 4.

These profiles show that Bok's (1959) Orion Spur is a 3-dimensional phenomenon, coming out from the Carina-Cygnus Arm at an angle to and lying considerably below the galactic plane. The Vela Spur, however, lies in the plane and seems to be a link between the Carina-Cygnus Arm and an outer arm that is probably a continuation of the Perseus Arm, but that cannot definitely be followed through the anticenter.

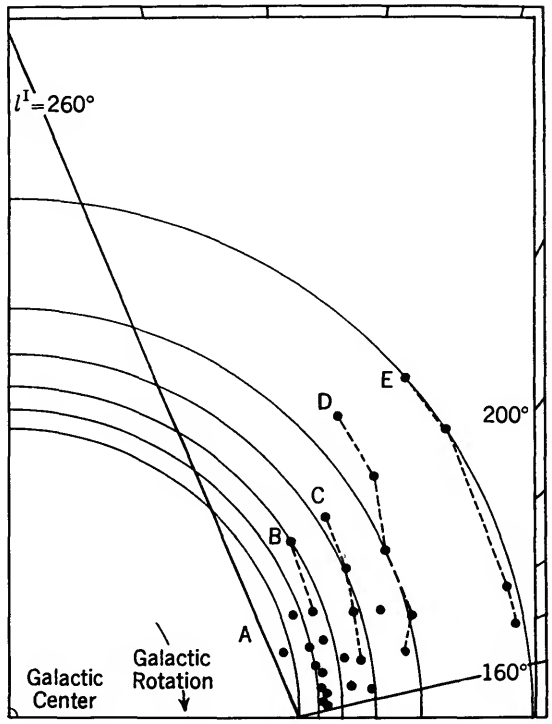


FIGURE 4.—Average positions of 21-cm intensity peaks at 10° intervals of galactic longitude.

Discussion

Several investigators have observed a definite concentration of neutral hydrogen near OB associations, e.g., Matthews (1956) for Lacerta I and Perseus II. Studying Lacerta I in more detail, Howard (1957) found it to be surrounded by an expanding H I region. Kassim (1958) obtained a definite correlation between the distribution of OB stars and that of neutral hydrogen in the Cygnus region, specifically mentioning an expanding H I shell surrounding Cygnus II, a branching of the Orion Arm at Cygnus IV, and a concentration of hydrogen in the vicinity of Cygnus I and III.

Menon (1955) studied associations Monoceros I and II. He found a branching of the Orion Arm to occur at Monoceros II. At Monoceros I, he observed a decrease in the 21-cm radiation, which he interpreted as due to the combination of the atomic hydrogen into molecules. Menon (1958) also found an expanding H I shell about Orion I. Wade (1957a) found a similar expanding shell about the grouping of extremely early-type stars associated with Lambda Orionis. As pointed out in table 2, Kassim's and Menon's nomenclatures differ from those used here.

Drake's (1958) study of the 21-cm radiation in the vicinity of a number of galactic clusters showed a very strong relationship between the age for a cluster and the ratio of hydrogen mass to stellar mass. The youngest clusters he dealt with—h and χ Persei (3×10^6 years) and the Pleiades (150 and 10^6 years)—contained the highest preponderance of interstellar neutral hydrogen. He found somewhat more mass in the interstellar hydrogen than in the stars. He specifically mentions the need for studying NGC 2362 as a further check on his conclusions.

Dieter (1960) used the Leiden results (Muller and Westerhout, 1957) to study 40 OB associations. Her method was to plot intensity contours at discrete radial velocities in the vicinities of each of these associations. She found neutral hydrogen to be connected with 31 of them.

Dieter's method has been used in this study for examining associations Monoceros I, Canis Major I, Puppis I and II, and the extremely young cluster NGC 2362. Figure 5 plots, at 5 km/sec intervals of radial velocity, contours of equal $\tau(V)$. It also gives the approximate outlines of each of these optical features (K. H. Schmidt, 1958). As pointed out in table 2, both Dieter's and Schmidt's nomenclatures differ from mine.

The total amount of hydrogen in the line of sight does not depend upon the corrections for random and systematic cloud velocities, but only upon the integral of optical depth over radial velocity (still on the assumption, however, that kinetic temperature is constant). Figure 6 shows the contours of equal N_H, the total number of hydrogen atoms per square centimeter in the line of sight. This information was obtained from the relationship (see Westerhout, 1957; Heeschen, 1955)

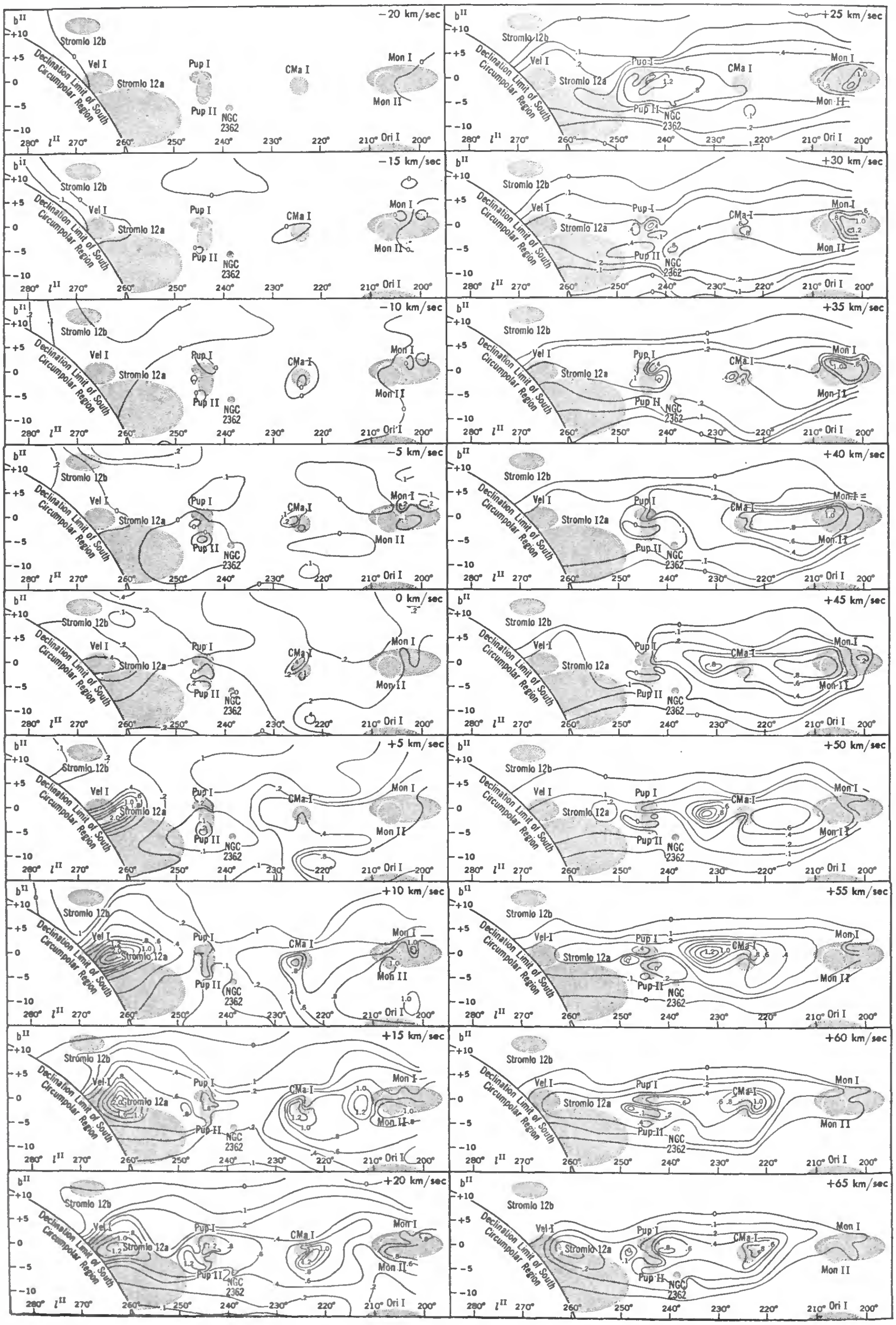
$$N_H=(1.835\times10^{13}\ \text{deg}^{-1}\ \text{sec cm}^{-3})\,T_K \int_{-\infty}^{\infty}\tau(V)dV. \quad (18)$$

Table 5, constructed from figure 5, gives for each of the indicated H I features the names of the associated optical feature (if any), and the radial velocity of its stars (V_*); the radial velocity of the neutral hydrogen (V_H); the distance to the feature (d); the approximate size of the feature in velocity (ΔV), and angular extent (r); the approximate mass of the excess hydrogen (M_H'); and the average excess hydrogen density ρ within the feature. The mass M_H' is, of course, only a very rough approximation, being in error even for the strongest concentrations by perhaps as much as a factor of three.

At this point one might look for possible differences between the H I regions connected with known OB associations in position and velocity, and those not so connected. It turns out that the four densest H I regions are those tentatively connected with Vela I, Canis Major I, Puppis I, and Monoceros I. In addition, the H I region tentatively connected with Puppis II is considerably denser than other H I regions of similar distance. As expected, the more distant H I regions tend to be less dense

TABLE 5.—*H I regions and OB associations*

Feature	l	b	V^* km/sec	V_H km/sec	ΔV km/sec	D (kiloparsecs)		I_{max} atoms cm^{-2} (km/sec)$^{-1}$	r		Excess hydrogen	
						optical	gal. rot.		deg.	pc	solar masses	atoms cm^{-3}
	221°	−12°		+5	5		0.2	0.9×10^{20}	3.5	12	286	7.9
Vel I	262	−1		+10	10	1.45	0.9	∞	3	47	∞	∞
	212	−1		+15	5		1.0	0.9	2.5	44	−3600	−2.02
CMa I	225	0		+17	17.5	0.95	0.8	2.3	2	33	18500	24.6
	248	−4		+20	7.5		1.3	1.4	2	45	9050	4.74
NGC2362	239	−5	+21	+25	5	1.45	1.5	1.2	0.7	18	790	6.48
Pup I	245	0		+25	12.5	2.5	1.3	3.0	0.8	35	19100	21.3
Mon I	203	−1	+21	+32	12.5	0.55	2.75	1.8	2.5	24	5420	18.7
	226	−1		+35	2.5		0.9	0.9	0.25	4	14	10.5
Mon II	207	0	+23			1.4						
	207	+2		+40	2.5		4.5	0.9	0.5	27	710	1.72
	241	−1		+45	17.5		2.7	−0.5	1.1	52	−9850	−3.36
	232	−1		+50	10		2.8	2.7	1.2	59	38900	9.05
	222	−1		+60	12.5		5	1.4	2.5	218	349000	1.61
Pup II	242	−1	+60	+65	10	4.2	4.2	0.9	0.8	59	13000	3.03
	261	−1		+70	7.5		5.3	1.8	3.5	324	593000	0.83
	235	−2		+80	7.5		5.7	0.9	3	298	252000	0.45
	244	−1		+85	5		6	−0.5	1	104	−11500	−0.49
	245	−5		+90	10		6.3	1.4	1.2	132	102000	2.12
	224	0		+95	22.5		8.8	0.2	0.5	77	11100	1.16


−20 km/sec
−15 km/sec
−10 km/sec
−5 km/sec
0 km/sec
+5 km/sec
+10 km/sec
+15 km/sec
+20 km/sec
+25 km/sec
+30 km/sec
+35 km/sec
+40 km/sec
+45 km/sec
+50 km/sec
+55 km/sec
+60 km/sec
+65 km/sec
Declination Limit of South Circumpolar Region
Stromlo 12b
Stromlo 12a
Vel I
Pup I
Pup II
NGC 2362
CMa I
Mon I
Mon II
Ori I

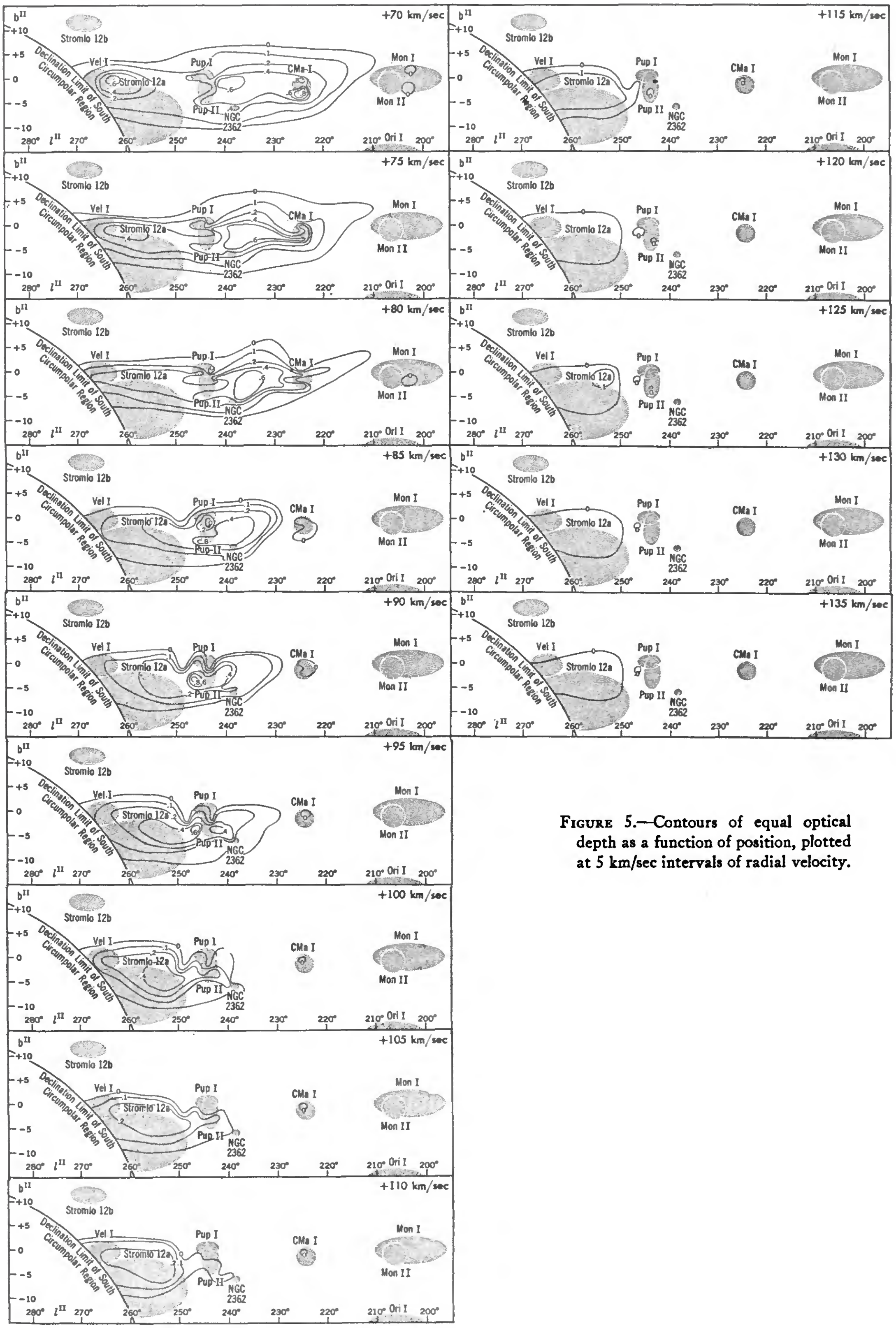


FIGURE 5.—Contours of equal optical depth as a function of position, plotted at 5 km/sec intervals of radial velocity.

because of the larger linear size required to make them stand out against the background.

A further difference between the associated and the other H I regions is the velocity spread of the feature ΔV. Those connected show a considerably greater ΔV.

Note also that the H I region suggested as associated with NGC 2362 is in all respects more nearly similar to the unconnected than to the H I regions with OB associations.

Table 5 also shows that the denser H I regions are considerably larger than the associations with which they seem to be connected. Thus, although there appears to be a statistical correlation between H I regions and stellar associations, most of the gas is contained outside the boundaries of the associations themselves. The H I region connected with NGC 2362 appears in this respect to be more closely related to the optical feature.

The H I region tentatively associated with Monoceros I may in reality belong to the Perseus Arm. Although at this galactic longitude radial velocity is a poor indicator of distance, there is a slight indication that the +32 km/sec feature at $l=200°$ to $210°$, which Dieter (1960) lists as connected with Monoceros II, separates from the Orion Arm feature at $l=215°$, becoming the main Perseus Arm feature at +40 km/sec. At the latter velocity, Dieter lists this feature as connected with Monoceros II.

These conclusions are based upon data derived from rather widely spaced centers. Without more intensive investigation we should not suggest a really strong connection between the optical features and the neutral hydrogen regions. The hydrogen complexes are considerably larger than the associations; the agreement in position and velocity may arise from the fact that both types of objects are found primarily in spiral arms.

In addition to these correlations (and lacks of correlation) between hydrogen distribution and optical features, certain details of the hydrogen distribution in this region are of special interest. Figure 5 shows two large areas where very little or no hydrogen is found near $V=0$. Unless local hydrogen is moving significantly relative to the local standard of rest, it must be absent. And in one of these same areas (from $l=237°$, $b=-6°$ to $l=262°$,

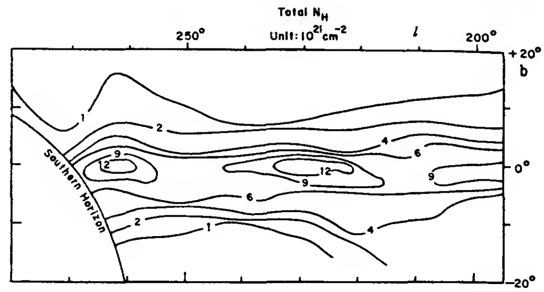


FIGURE 6.—Contours of equal N_H, the total number of hydrogen atoms per square centimeter in the line of sight, as a function of position.

$b=+4°$) the intensity minimum (which, on the Schmidt model, corresponds to a distance of about 10 kpc from the galactic center or 3 kpc from the sun) is very pronounced, approaching zero.

Peaks at $l=242°$ and $252°$, $b=+14°$ (Centers S31 and S38) are somewhat higher than those at the same longitudes, $b=+9°$. This

TABLE 6.—*Recommendations for further study of hydrogen in association with optical features*

Feature	Excess Hydrogen?	Recommendations
Mon I	Possibly	More study needed, using drift curves with 60-foot or larger antenna.
Mon II	No	Studied by Menon. Being studied at Leiden.
Ori I	Yes	Studied in detail by Menon. Being studied at Leiden.
λ Ori	Yes	Studied in detail by Wade.
C Ma I	Probably	More study needed, using drift curves with 60-foot or larger antenna.
NGC 2362	Possibly	More study needed, using drift curves with 90-foot or larger antenna.
{Pup I, Pup II}	{Possibly}	{More study needed, using drift curves with antenna preferably larger than 60 feet.}
Vela I	Possibly	
Stromlo 12a and 12b	No	

excess may be associated with a new hydrogen cloud discovered by Murray and McGee (1958) in the Pyxis-Hydra region.

No evidence has appeared for association of neutral hydrogen with Gum's (1955) H II regions Stromlo 12a and 12b. He gives their distance as 250 parsecs. Stromlo 12a lies in one of my areas of very low local hydrogen, whereas Stromlo 12b lies in an area of relatively high local hydrogen.

These conclusions are summarized in table 6. The amounts of hydrogen involved are probably about an order of magnitude greater than the mass of the average OB association.

References

ALLEN, C. W.
1955. Astrophysical quantities. Athlone Press, London.

ALTER, G.; HOGG, H. S.; RUPRECHT, J.; AND VANÝSEK, V.
1959. Catalogue of star clusters and associations. Supplement 1. Appendix, Bull. Astron. Inst. Czechoslovakia, vol. 10, no. 3, 16 pp.

ALTER, G.; RUPRECHT, J.; AND VANÝSEK, V.
1958. Catalogue of star clusters and associations. Publishing House of the Czechoslovak Academy of Sciences, Prague.
1960. Catalogue of star clusters and associations. Supplement 2. Appendix, Bull. Astron. Inst. Czechoslovakia, vol. 11, no. 1, 8 pp.

BAADE, W. A.
1951. Galaxies—Present day problems. Publ. Obs. Univ. Michigan, vol. 10, pp. 7–17.
1955. *In* Transactions of the International Astronomical Union, vol. 9, p. 482.
1958. Large-scale structure of spiral nebulae. *In* N. G. Roman, ed., Comparison of the large-scale structure of the galactic system with that of other stellar systems. International Astronomical Union Symposium No. 5, Cambridge University Press, Cambridge, pp. 1–3.

BLAAUW, A.
1952. The velocity distribution of the interstellar calcium clouds. Bull. Astron. Inst. Netherlands, vol. 11, pp. 459–472.

BLAAUW, A.; GUM, C. S.; PAWSEY, J. L.; AND WESTERHOUT, G.
1959. Definition of the new I.A.U. system of galactic co-ordinates. Astrophys. Journ., vol. 130, pp. 702–703.

BOK, B. J.
1959. The spiral structure of our galaxy. Observatory, vol. 79, pp. 58–62.

AVIES, R. D.
1956. The relation between interstellar gas, dust and the emission from neutral hydrogen at 21 cm. Monthly Notices Roy. Astron. Soc., vol. 116, pp. 443–452.
1958. Twenty-one-cm studies of some interstellar clouds. Rev. Modern Phys., vol. 30, pp. 931–934.

DAVIS, R. J.
1957. 21-centimeter observations near galactic longitude 120°. Astrophys. Journ., vol. 125, pp. 391–407.

DENISSE, J. F.; LEQUEUX, J.; AND LE ROUX, E.
1957. Nouvelles observations du rayonnement du ciel sur la longeur d'onde 33 cm. Comptes Rendus, vol. 244, pp. 3030–3033.

DIETER, N. H.
1960. Neutral hydrogen in OB associations. Astrophys. Journ., vol. 132, pp. 49–57.

DRAKE, F. D.
1958. Neutral hydrogen in galactic clusters. Doctoral thesis, Harvard University, 111 pp.

GUM, C. S.
1955. A survey of seven H II regions. Memoirs Roy. Astron. Soc., vol. 67, pp. 155–177.

HEESCHEN, D. S.
1955. Some features of interstellar hydrogen in the section of the galactic center. Astrophys. Journ., vol. 121, pp. 569–584.

HOWARD, W. E., III
1957. A study of stellar association I Lacertae. Paper presented at 99th meeting of the American Astronomical Society, Indianapolis, Ind., December 27–30, 1957. (Abstract in Astron. Journ., vol. 63, pp. 50–51, 1958.)

KASSIM, M. A. K.
1958. A study of neutral hydrogen in a region in Cygnus. Doctoral thesis, Harvard University, 85 pp.

KERR, F. J.; HINDMAN, J. V.; AND GUM, C. S.
1959. A 21 cm survey of the Southern Milky Way. Australian Journ. Phys., vol. 12, pp. 270–292.

KWEE, K. K.; MULLER, C. A.; and WESTERHOUT, G.
1954. The rotation of the inner parts of the galactic system. Bull. Astron. Inst. Netherlands, vol. 12, pp. 211–222.

LILLEY, A. E.
1955. Association of gas and dust from 21 cm hydrogen radio observations. Astrophys. Journ., vol. 121, pp. 559–568.

MATTHEWS, T. A.
1956. The distribution of neutral hydrogen between galactic longitudes 60° and 135°. Doctoral thesis, Harvard University, 128 pp.

MENON, T. K.
1955. A 21-cm investigation of NGC 2244 and NGC 2264. Paper presented at the 93d meeting of the American Astronomical Society, Troy, N.Y., November 9–12, 1955. (Abstract in Astron. Journ., vol. 61, pp. 9–10, 1956.)
1958. Interstellar structure of the Orion region. I. Astrophys. Journ., vol. 127, pp. 28–47.
MULLER, C. A., AND WESTERHOUT, G.
1957. A catalogue of 21-cm line profiles. Bull. Astron. Inst. Netherlands, vol. 13, pp. 151–195.
MURRAY, J. D., AND MCGEE, R. X.
1958. A new hydrogen cloud in Pyxis-Hydra. Observatory, vol. 78, pp. 242–244.
OORT, J. H.; KERR, F. T.; AND WESTERHOUT, G.
1958. The galactic system as a spiral nebula. Monthly Notices Roy. Astron. Soc., vol. 118, pp. 379–389.
PURCELL, E. M., AND FIELD, G. B.
1956. Influences of collisions upon population of hyperfine states in hydrogen. Astrophys. Journ., vol. 124, pp. 542–549.
RAIMOND, E., AND VAN WOERDEN, H.
1959. Personal communication to M. Schmidt.
SCHMIDT, K. H.
1958. Verzeichnis von 62 O- und B-Sterngruppen. Astron. Nachr., vol. 284, pp. 76–78.
SCHMIDT, M.
1956. A model of the distribution of mass in the galactic system. Bull. Astron. Inst. Netherlands, vol. 13, pp. 15–41.
1957. Spiral structure in the inner parts of the galactic system derived from the hydrogen emission at 21 cm wave length. Bull. Astron. Inst. Netherlands, vol. 13, pp. 247–268.
SPITZER, L., JR.
1954. Behavior of matter in space. Astrophys. Journ., vol. 120, pp. 1–17.
VAN DE HULST, H. C.; MULLER, C. A.; AND OORT, J. H.
1954. The spiral structure of the outer part of the galactic system derived from the hydrogen emission at 21 cm wave length. Bull. Astron. Inst. Netherlands, vol. 12, pp. 117–149.
WADE, C. M.
1957a. A 21-cm line study of an expanding H II region. Paper presented at the 97th meeting of the American Astronomical Society, Cambridge, Mass., May 8-11, 1957. (Abstract in Astron. Journ., vol. 62, p. 148.)
1957b. A 21-cm study of an expanding H II region. Doctoral thesis, Harvard University, 67 pp.
1959. Personal communication.
WEAVER, H.
1954. The distance to the galactic center and the zero point of the Cepheid period-luminosity relation. Astron. Journ., vol. 59, pp. 375–384.
1955. The value of the Oort A parameter derived from radial velocities of Cepheid variable stars. Astron. Journ., vol. 60, pp. 202–208.
1956. Some observational problems in galactic structure. *In*, Fred L. Whipple, ed., New horizons in astronomy. Smithsonian Contr. Astrophys., vol. 1, no. 1, pp. 149–157.
WESTERHOUT, G.
1957. The distribution of atomic hydrogen in the outer parts of the galactic system. Bull. Astron. Inst. Netherlands, vol. 13, pp. 201–246.
1958. A survey of the continuous radiation from the galactic system at a frequency of 1390 Mc/s. Bull. Astron. Inst. Netherlands, vol. 14, pp. 215–260.

Abstract

The George R. Agassiz radio telescope of Harvard College Observatory was used to obtain profiles of intensity versus radial velocity at 88 centers in the 21-cm line of neutral hydrogen. These centers were separated by 10° in galactic longitude between longitudes 200° and 265°, and by 5° in galactic latitudes between +15° and −15°, with additional centers in the vicinities of OB associations Monoceros I and II, Canis Major I, Puppis I, and Puppis II, and of the very young cluster NGC 2362. These observations indicate that there is probably an excess of neutral hydrogen associated with Canis Major I, and possibly with Monoceros I, Puppis I, Puppis II, Vela I, and NGC 2362. There is probably no neutral hydrogen associated with Monoceros II. The observations also confirm the conclusions of previous investigators that the spiral arms in our galaxy are trailing.

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