

IV. 21-CENTIMETER ABSORPTION MEASUREMENTS ON LOW-LATITUDE SOURCES SOUTH OF DECLINATION -46°

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ABSTRACT

Twenty-one low-latitude sources in the range $280^\circ < l < 340^\circ$ have been observed for 21-cm absorption by using the Parkes 64-m telescope; twelve of these sources were also investigated with the 64-m/18-m interferometer. Distance estimates and detailed notes are presented for each source, together with profiles and tables summarizing all the data on the sources. The H I evidence on two of these sources is in support of the view that they are extragalactic.

I. INTRODUCTION

This paper is the fourth of a series dealing with 21-cm absorption in the spectra of discrete radio sources. Previous papers in this series have described the methods of observation and reduction. In particular, Paper I (Radhakrishnan, Brooks, Goss, Murray, and Schwarz 1971), outlines the operation of the Parkes 21-cm interferometer, and Paper II (Radhakrishnan, Murray, Lockhart, and Whittle 1971) deals with measurements on sources at intermediate and high galactic latitudes. Paper III (Radhakrishnan, Goss, Brooks, and Murray 1971) elaborates on the problems associated with measurements at low galactic latitudes and discusses absorption profiles for 41 galactic sources north of declination -48° . The observations reported in this paper also refer to low-latitude sources, in particular those lying along that part of the galactic plane inaccessible to most northern observers ($280^\circ < l < 340^\circ$). All the characteristics of the profiles discussed in Paper III were present here; similar difficulties were experienced and the same techniques were applied to overcome these difficulties.

The survey in this southern quadrant of the Milky Way has yielded data on the neutral-hydrogen absorption in the directions of 21 sources. Continuum investigations on these sources by various authors have established the type of radio source (e.g., H II region, supernova remnant [SNR], etc.), their positions, and flux densities. Some evidence on the distances was already available for most of the sources. For H II regions there were kinematic distances from H109 α data, and for supernova remnants there were distance estimates based on the continuum brightness temperatures; for some identified sources there were optical distance determinations. In most cases information was also available on the spectra of OH and H₂CO in the directions of these sources.

The importance of the gradient of radial velocity with distance (dV/dr) in determining the form of the hydrogen profile in the galactic plane has been stressed by Rohlfs (1971). At $l = 0^\circ$ and $l = 180^\circ$, and on the circle of maximum radial velocity within the solar circle, this gradient vanishes, producing the well-known crowding of velocities in these directions. The value of the radial-velocity gradient determines to some extent the ability to recognize separate absorption features. For comparison we have calculated the average absolute value of this gradient for each source. In the case of sources with a low velocity gradient (e.g., G282.0-1.2 in Fig. 2a) it is almost impossible to assess the number of absorption components making up the profile. On the other hand, for sources with larger values of the gradient (e.g., G326.2-1.7 in Fig. 2b) the number of absorption features is more obvious.

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II. OBSERVATIONS

Single-dish absorption measurements with the Parkes 64-m telescope were made on all of the 21 sources in the present investigation, and for 12 of them interferometer absorption observations were also obtained. For single-dish observations the half-power beamwidth was $15'$ while for the interferometer observations the primary beamwidth was $18'.5$. All reference emission profiles were obtained with the single-dish configuration. In this mode of operation the ratio of point-source flux density to antenna temperature was 1.66 and the beam efficiency 0.80. The filter bandwidth used was 10 kHz (2.1 km s^{-1}) for all the measurements.

Table 1 lists the 21 sources investigated for absorption, together with their positions, common names, and types. The H109 α data in column (6) were taken from the southern survey made by Wilson *et al.* (1970). In column (7) we give a distance estimate for each source, with the appropriate reference in column (8). It will be seen that the present work has provided distances for many of the sources. A discussion of the interpretation of H I absorption data in terms of source distances will be found in Paper III of this series. The antenna temperature of the source used for the determination of the optical depth in single-dish measurements is listed in column (9), and whether an observation was made with the single dish only or with the interferometer as well is indicated in column (12). The average absolute value of the radial-velocity gradient between the Sun and the source is given in column (13); this has been calculated by using the Schmidt rotation curve and the estimated distance (col. [7]). For those sources having only a lower limit for the distance, this limit has been used for the calculation. To assist in finding the profiles, the appropriate figure numbers have been listed in the last column.

Figures 1a–1g show the 21 sources discussed in the present paper; each source is marked by an arrow on the 11-cm continuum contour maps. These contour maps were taken from the Parkes 11-cm survey of the galactic plane made with a half-power beamwidth of $\sim 8'$. The section covering the longitude range 280° – 290° (Fig. 1a) is taken from Day (1971), while the remaining sections are taken from the *Australian Journal of Physics, Astrophysical Supplement*, Number 11 (1969 October) and from Beard (1966). The profiles are presented in Figures 2a–2v and are discussed individually in § IV. Figure 3 depicts the quadrant of the galactic disk in which all the sources are located; their approximate positions based on the distance estimates are shown in the figure.

III. ANALYSIS

Absorption profiles obtained on 14 of the sources were either simple enough in form or had a high enough signal-to-noise ratio to justify an attempt to fit Gaussian components. As stated earlier in this series of papers, a very conservative philosophy has been adopted in fitting Gaussian components, and in general the smallest number of components needed to fit the data has been used. Such components enable us to make estimates of the physical parameters of what might well be individual clouds of neutral hydrogen. These include optical depths and linewidths which lead directly to the calculation of the column densities (N_{H}), by assuming a spin temperature for the hydrogen. The individual radial velocities obtained for each component in conjunction with the kinematical model permit an estimate of distance to be made. The details for the 14 sources are given in Table 2. Footnotes comment on cases where the measured velocities are impossible on the Schmidt kinematical model.

In those cases where the observed width of a component exceeded twice the filter width (2.1 km s^{-1}), a correction for smoothing was made in deriving the maximum optical depth (τ_{max}) and full width at half optical depth ($\Delta V_{1/2}$); those cases for which no correction was attempted are shown in brackets. Where some components in the

TABLE 1
SOURCES OBSERVED FOR H I ABSORPTION

Galactic Name (1)	Common Name (2)	R.A. 1950 (3)	Decl. 1950 (4)	Source Type (5)	H109 α Velocity (km s ⁻¹) (6)	Dist. (kpc) (7)	Ref. (8)	T _A (°K) (9)	Other Absorption- Line Data (10)	Absorption Measure- ment (12)	dV/dr (km s ⁻¹) (kpc) (13)	Figure Number (14)
G282.0-1.2	...	10 ^h 04 ^m 53 ^s *	-56°58'	H II	22.4	6.9	1,11	18.5	OH	SD, I	5.1	2a
G284.3-0.3	RCW 49	10 22 20	-57 32	H II	- 0.7	6.0	4	110.5	H ₂ CO OH	SD, I	3.2	2b
G285.3-0.0	...	10 29 37	-57 47	H II	- 1.6	5.0	11	11	H ₂ CO	SD, I	3.6	2c
G287.4-0.6	Carina Nebula	10 42 18	-59 24	H II	-18.1 -23.6	2.7	5	80.5*	H ₂ CO OH	SD, I	4.0	2d
G290.1-0.8	...	11 00 22	-60 39	SNR	...	>3.4	11,6	18	...	SD	4.6	2e
G291.3-0.7	NGC 3576	11 09 50	-61 03	H II	-23.4	3.6	7	40	H OH	SD, I	5.2	2f, h
G291.6-0.5	NGC 3603	11 12 51	-60 59	H II	9.4	8.4	7	113	H ₂ CO H OH	SD, I	6.3	2g, h
G292.0+1.8	MSH 11-54	11 22 20	-58 59	SNR	...	>3.7	11,6	7.5	...	SD	4.8	2i
G298.2-0.3	...	12 07 24	-62 33	H II	30.6	11.9	1,11	21.4	H H ₂ CO	SD, I	7.8	2j
G298.9-0.4	...	12 12 45	-62 45	H II	24.2	11.6	1,11	24.7	OH H ₂ CO	SD, I	8.1	2k
G305.3+0.2	...	13 09 05	-62 22	H II	-39.1	8.0	1,11	45.5	H OH	SD	7.3	2l
G307.1+1.2	...	13 23 01	-61 07	NT	...	>6	11	6.1	H ₂ CO	SD, I	8.8	2m
G309.7+1.7	13S6A	13 43 08	-60 11	NT	...	>6.5	11	43	...	SD	9.3	2n

* The reference regions for the expected profile contain some absorption.
REFERENCES:
(1) Wilson *et al.* (1970).
(2) Manchester, Robinson and Goss (1970).
(3) Whiteoak and Gardner (1970).
(4) Westerlund (1960).
(5) Sher (1965).
(6) Shaver and Goss (1970).
(7) Goss and Radhakrishnan (1969).
(8) Kerr and Knapp (1970).
(9) Robinson, Caswell, and Goss, in preparation.
(10) Goss, Manchester, and Robinson (1970).
(11) This paper.

TABLE 1—Continued

Galactic Name (1)	Common Name (2)	R.A. 1950 (3)	Decl. 1950 (4)	Source Type (5)	H109 α Velocity (km s ⁻¹) (6)	Dist. (kpc) (7)	Ref. (8)	T_A (°K) (9)	Absorption- Line Data (10)	Other Ref. (11)	Absorption Measure- ment (12)	$ dV/d\tau $ (km s ⁻¹) (13)	Figure Number (14)
G316.8-0.1.....	...	14 ^h 41 ^m 32 ^s	-59°37'	H II	-36.1	12.0	1,11	21.4	H OH	8 9	SD, I	9.7	2o
G326.2-1.7.....	MSH 15-56	15 48 23	-56 03	SNR	...	>3.1	11	28*	H ₂ CO	3	SD	14.0	2p
G326.6+0.6.....	...	15 40 56	-53 57	H II	-44.5	3.1	1,11	22.7	H OH	8 9,10	SD, I	14.0	2q
G327.3-0.6.....	RCW 97	15 49 12	-54 27	H II	-48.8	3.4	1,11	23.8	H ₂ CO	3	SD, I	14.0	2r
G331.5-0.1.....	...	16 08 22	-51 19	H II	-88.7	6.5	11	24.7*	H OH H ₂ CO	3 10 8	SD	13.7	2s
G333.1-0.4.....	...	16 17 16	-50 29	H II	-55.8	4.1	11	38.7*	H OH H ₂ CO	3 8 10	SD	13.3	2t
G333.6-0.2.....	...	16 18 26	-49 59	H II	-48.3	4-5	11	37.0*	H ₂ CO OH H ₂ CO	3 10 3	SD	12.5	2u
G338.4+0.1.....	...	16 37 10	-46 18	H II	-36.9	>6	11	39.2*	H OH	8 9	SD	11.3	2v

NOTES TO FIG. 1.—The 21 sources investigated for H I absorption in the longitude range 282° – 338° . Each source is shown by an arrow on the 11-cm continuum contour maps taken from the Parkes survey of the galactic plane.

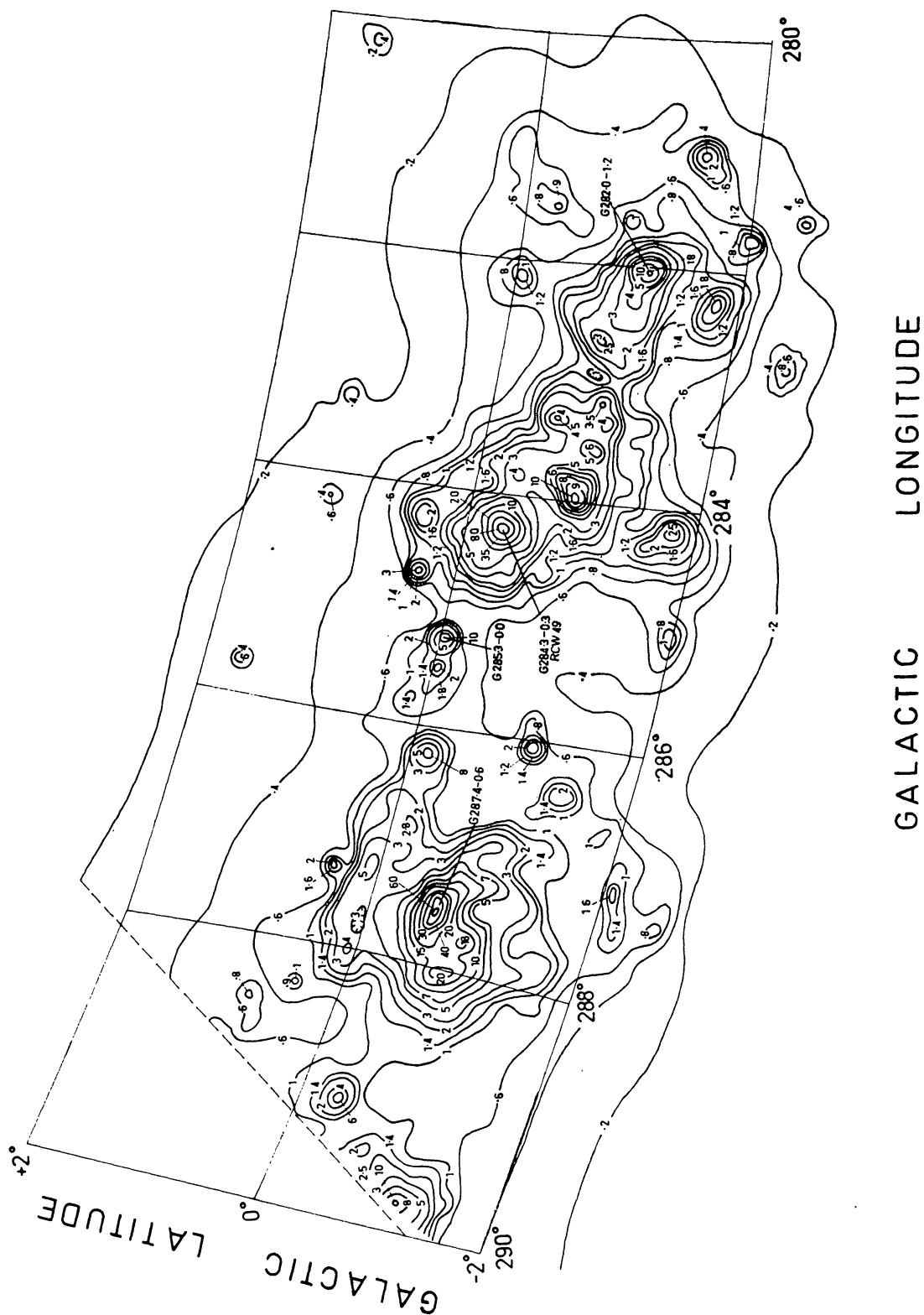


FIG. 1a.—11-cm map for $290^{\circ} < l < 280^{\circ}$

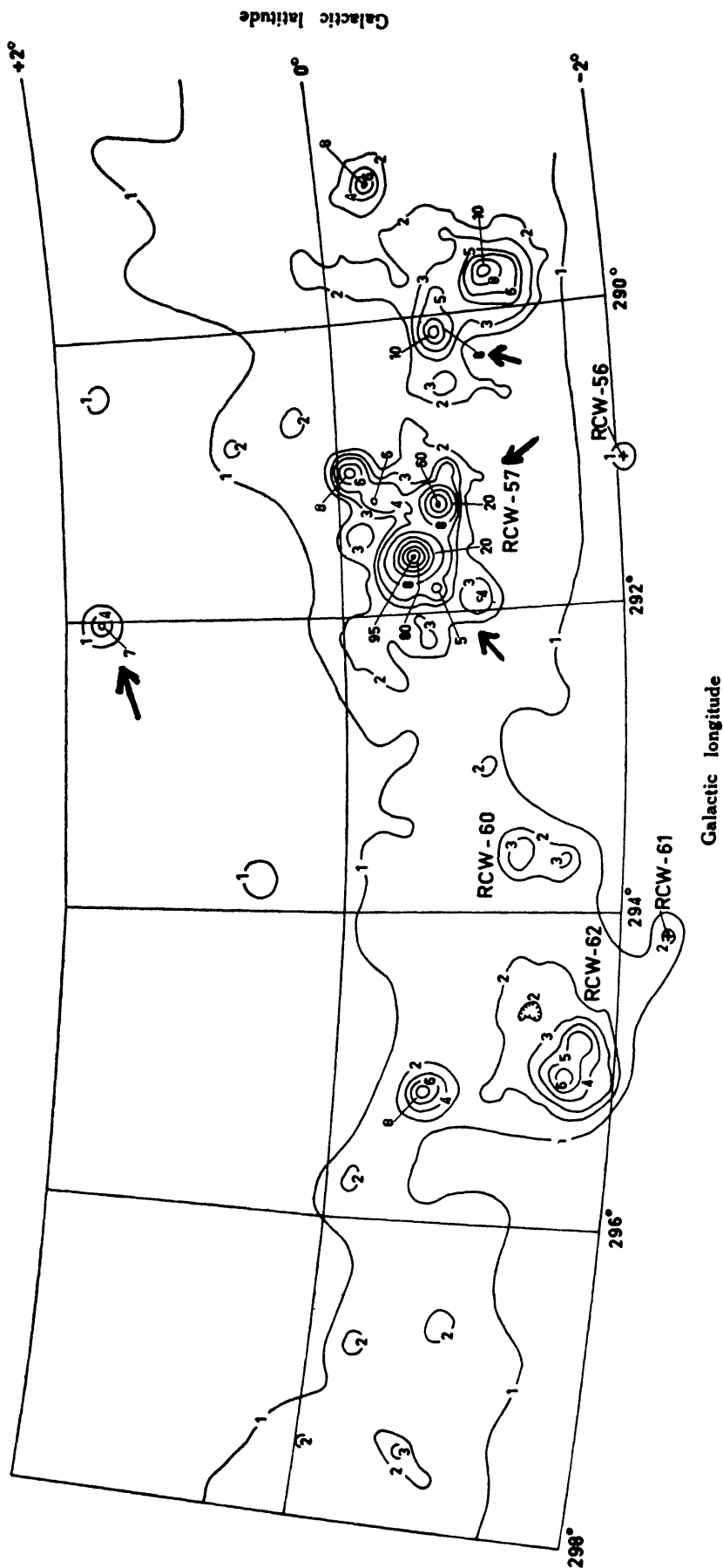
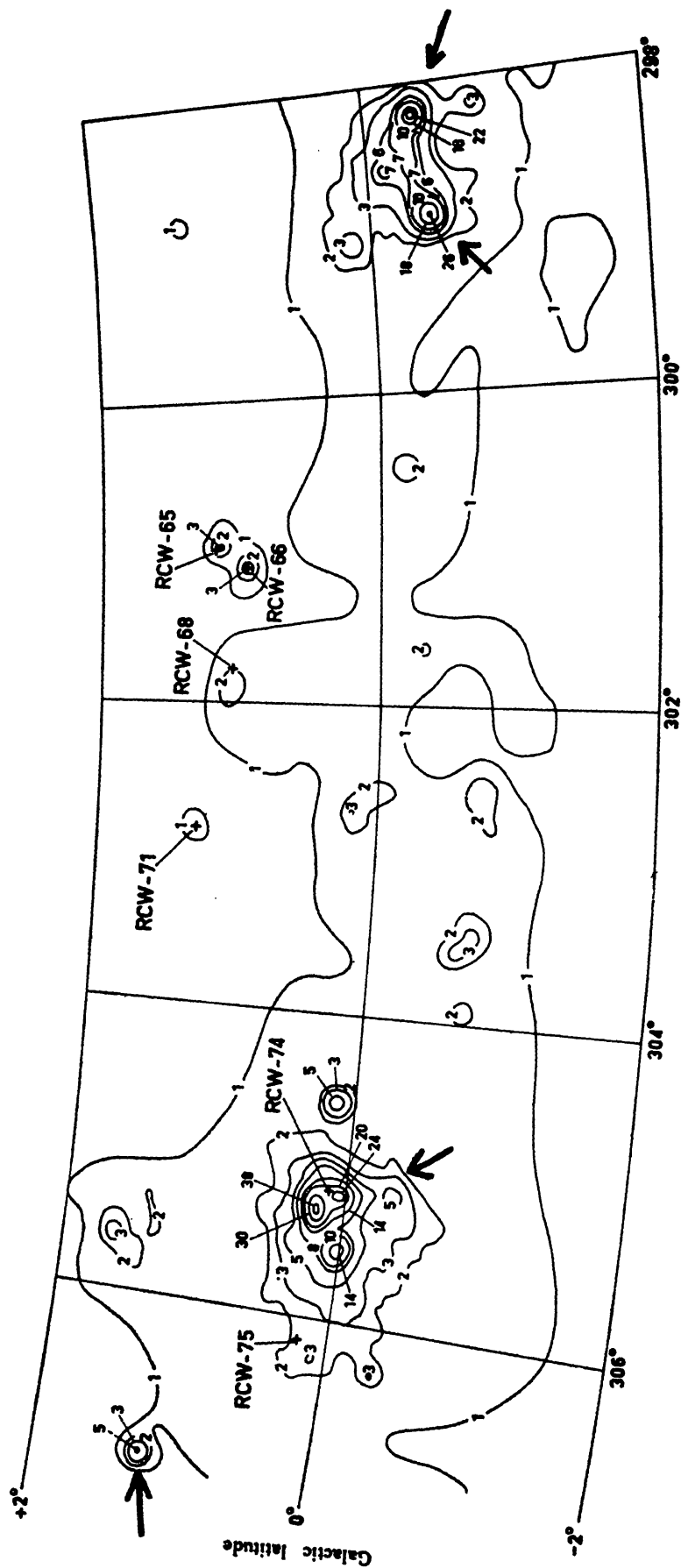
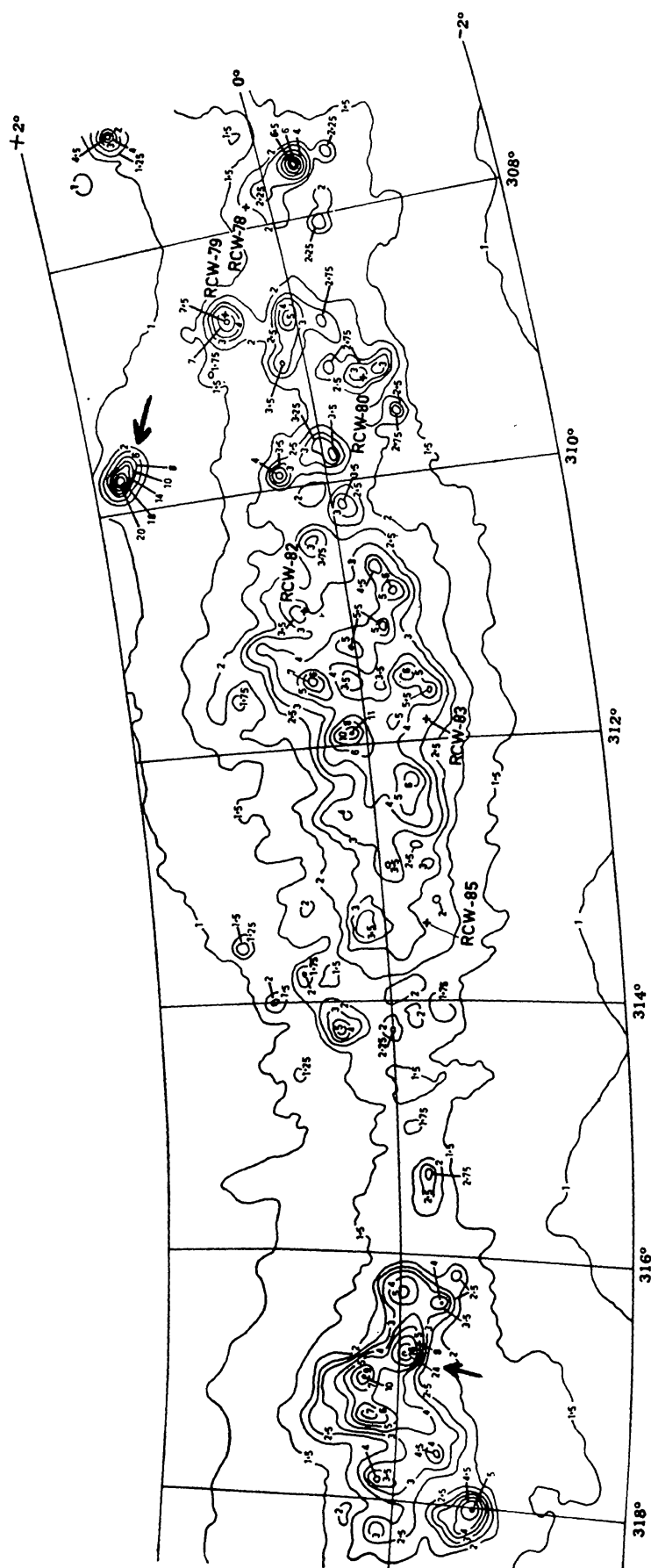


Fig. 1b.—11-cm map for $298^\circ < l < 288^\circ$



Galactic longitude
FIG. 1c.—11-cm map for $305^\circ < l < 298^\circ$



Galactic longitude

FIG. 1*d*.—11-cm map for $318^\circ < l < 307^\circ$

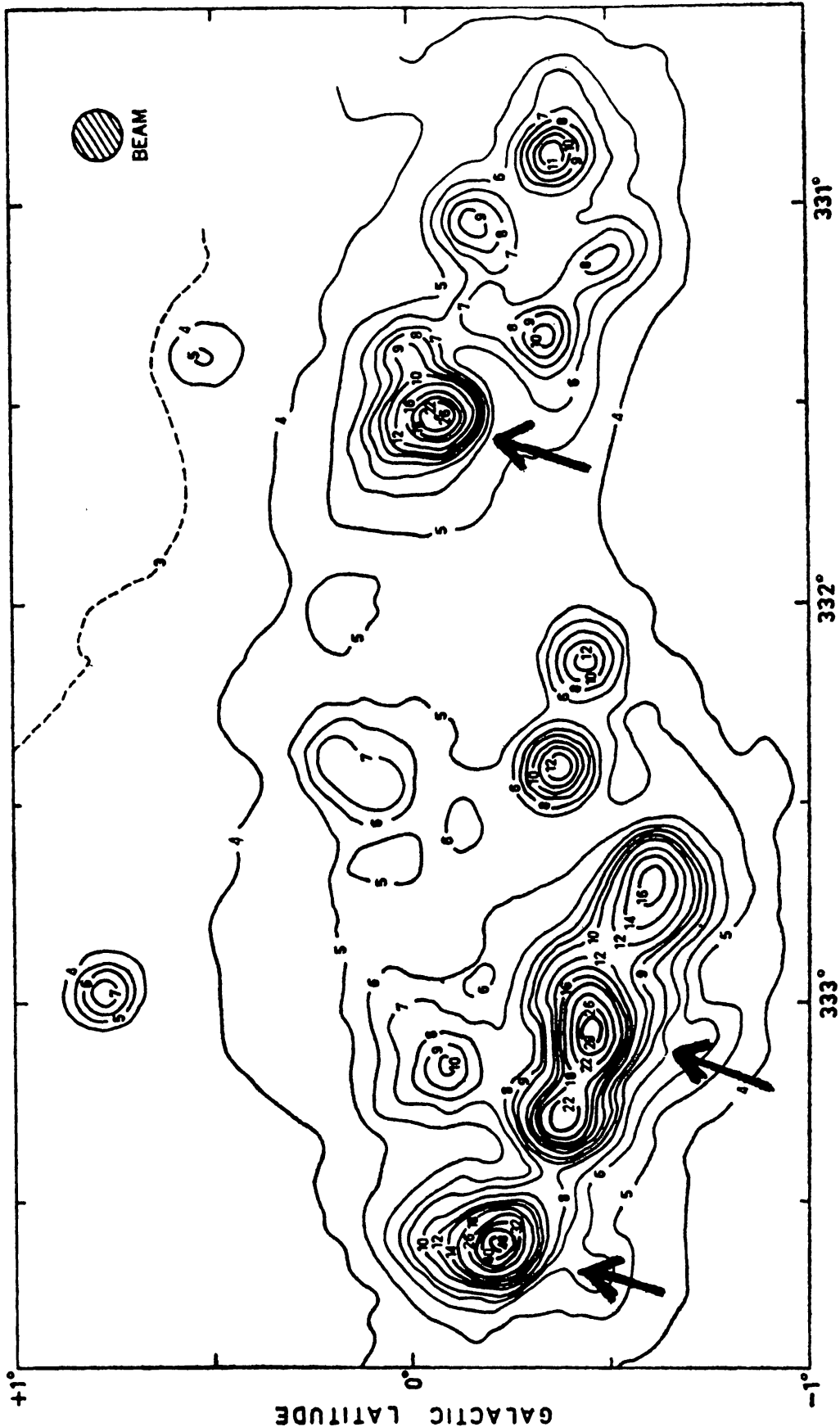
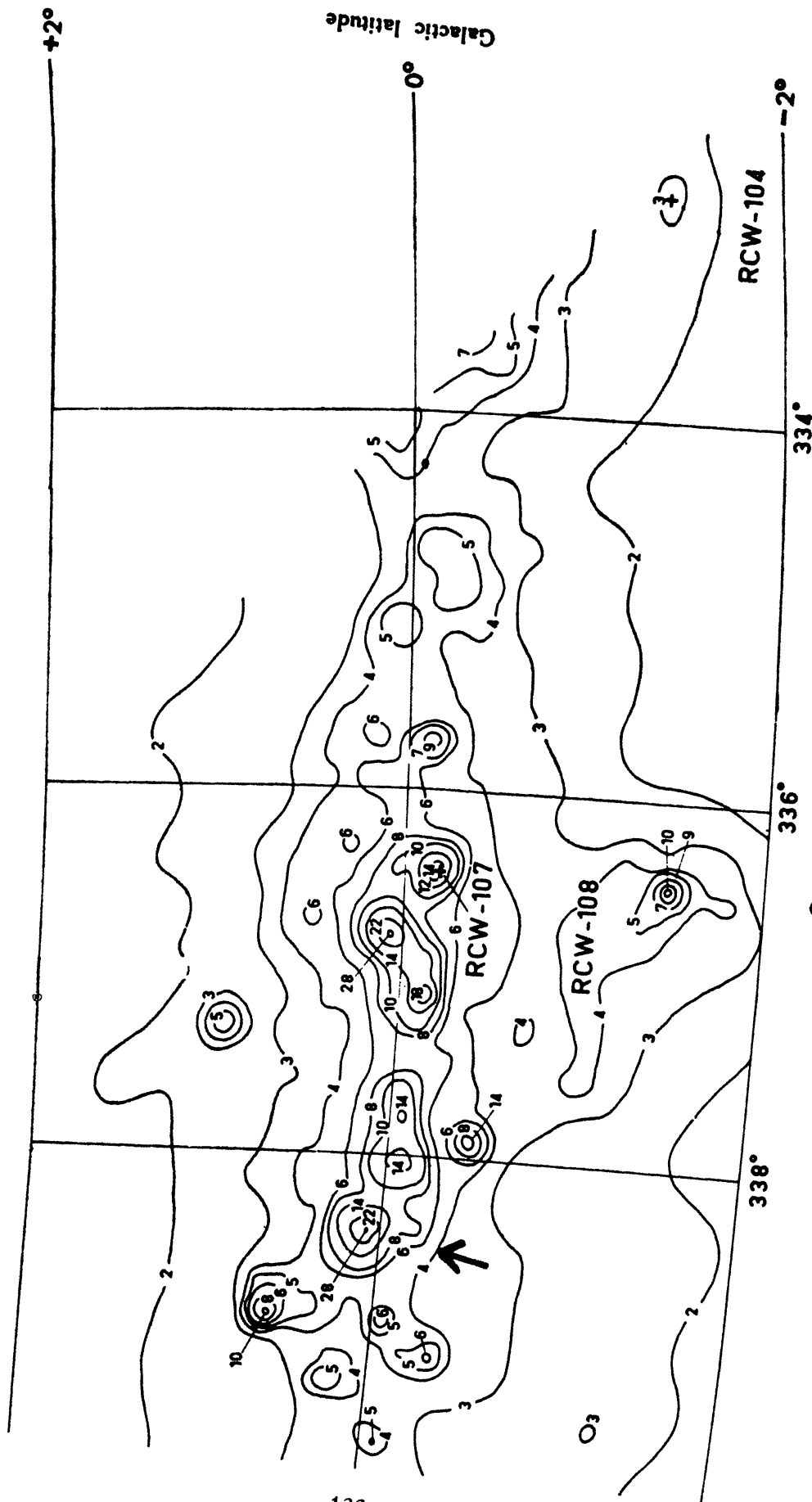


FIG. 1f.—11-cm map for $334^\circ < l < 331^\circ$



Galactic longitude

Fig. 1g.—11-cm map for $334^\circ < l < 332^\circ$

absorption profile had antenna temperatures close to or greater than the value corresponding to infinite optical depth, these components were truncated before the Gaussian fitting. As in Paper III, the parameters for these components are shown in Table 2 without any error estimates. Column (6) lists a quantity obtained by integrating under the particular component of the absorption profile. Multiplication of this quantity by an assumed spin temperature of 50°K for the absorbing hydrogen yields the column density listed in column (7).

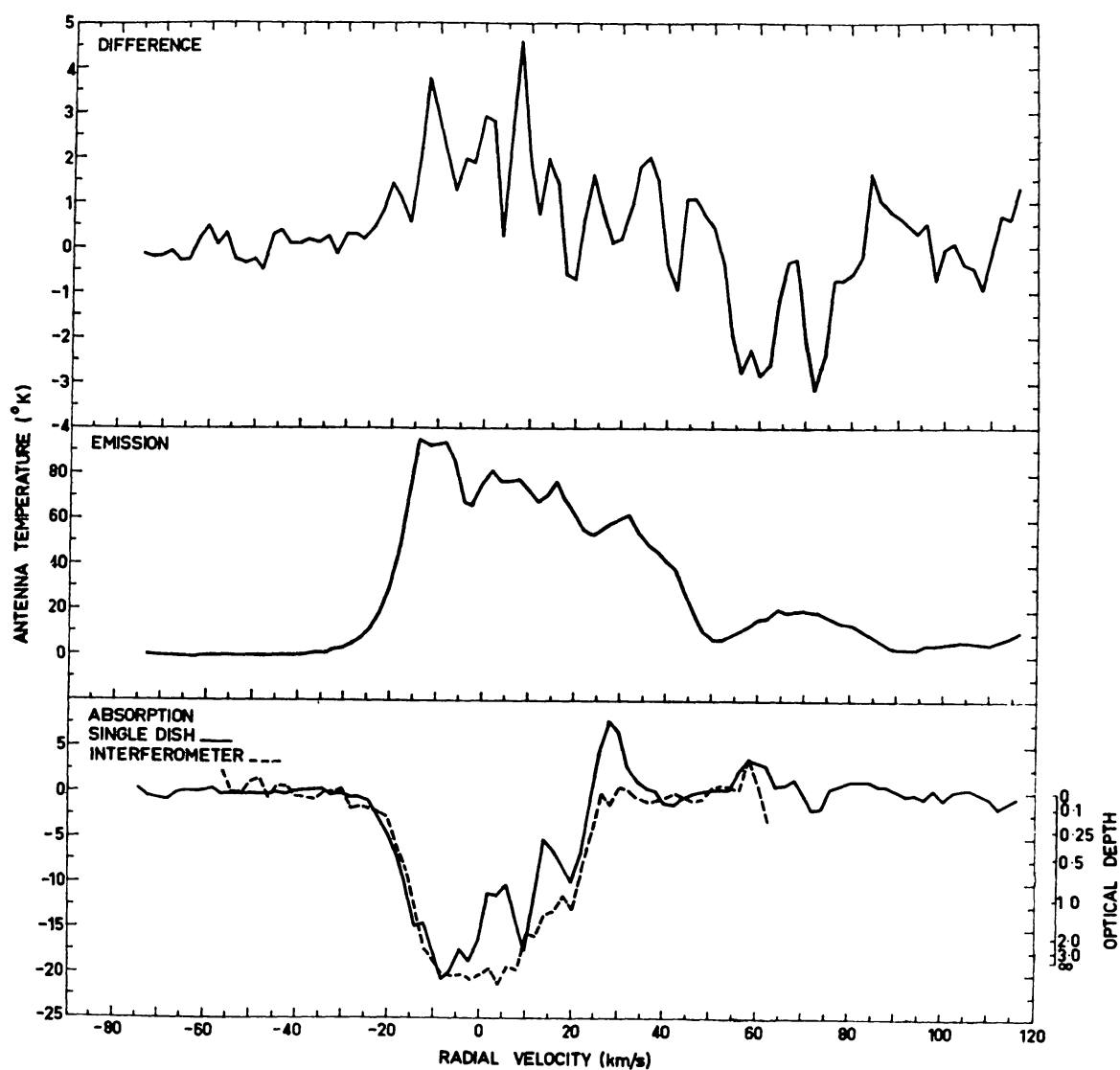


FIG. 2a.—G282.0—1.2

NOTES TO FIG. 2.—H I emission and absorption profiles in the directions of 21 low-latitude sources. The filter resolution was 9.5 kHz (2.0 km s^{-1}). In some cases (2e, 2j, 2o, 2p, 2q, 2r, 2s, 2t, 2u, and 2v) each of the profiles that make up the reference emission profile (the average of the surrounding emission profiles) is shown separately. For the other sources the reference profile is shown (labeled “emission”), and also a “difference” profile (the difference between the reference profile and the average of the north and south profiles). The “difference” profile gives an indication of the nonlinear variations in the emission near the source. The single-dish absorption profile is the on-source profile minus the reference emission profile. For sources with only a single-dish measurement the designation “single dish” is omitted in the figure. The scales on the left are in antenna temperature for all profiles; the absorption profiles also have an optical-depth scale on the right. The interferometer profiles have been plotted such that the optical-depth scale on the right-hand side applies to both single-dish and interferometer measurements. All radial velocities are with respect to the local standard of rest.

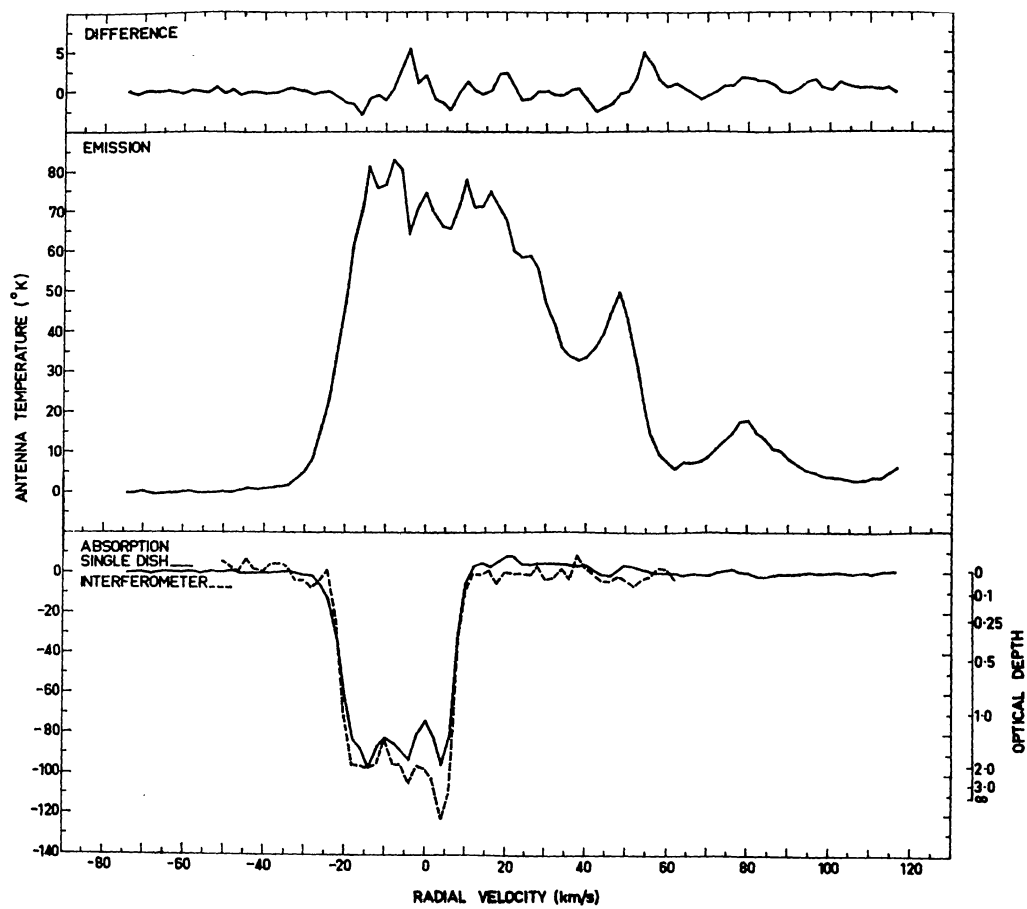


FIG. 2b.—RCW 49

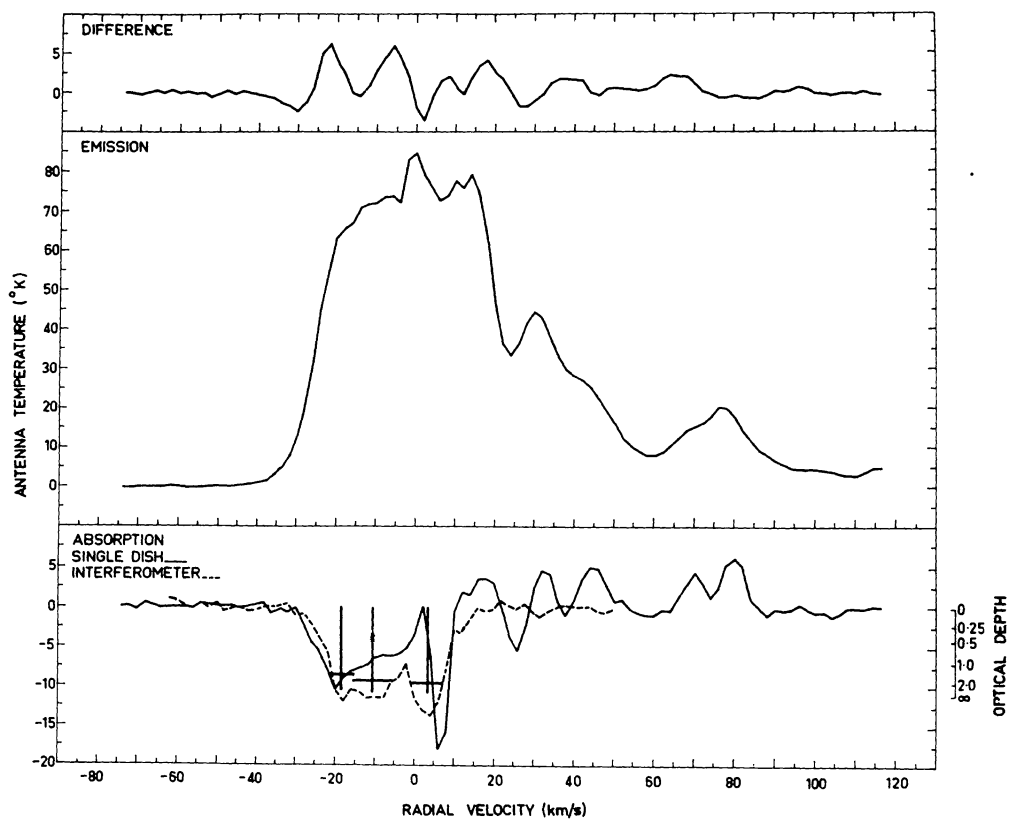


FIG. 2c.—G285.3-0.0

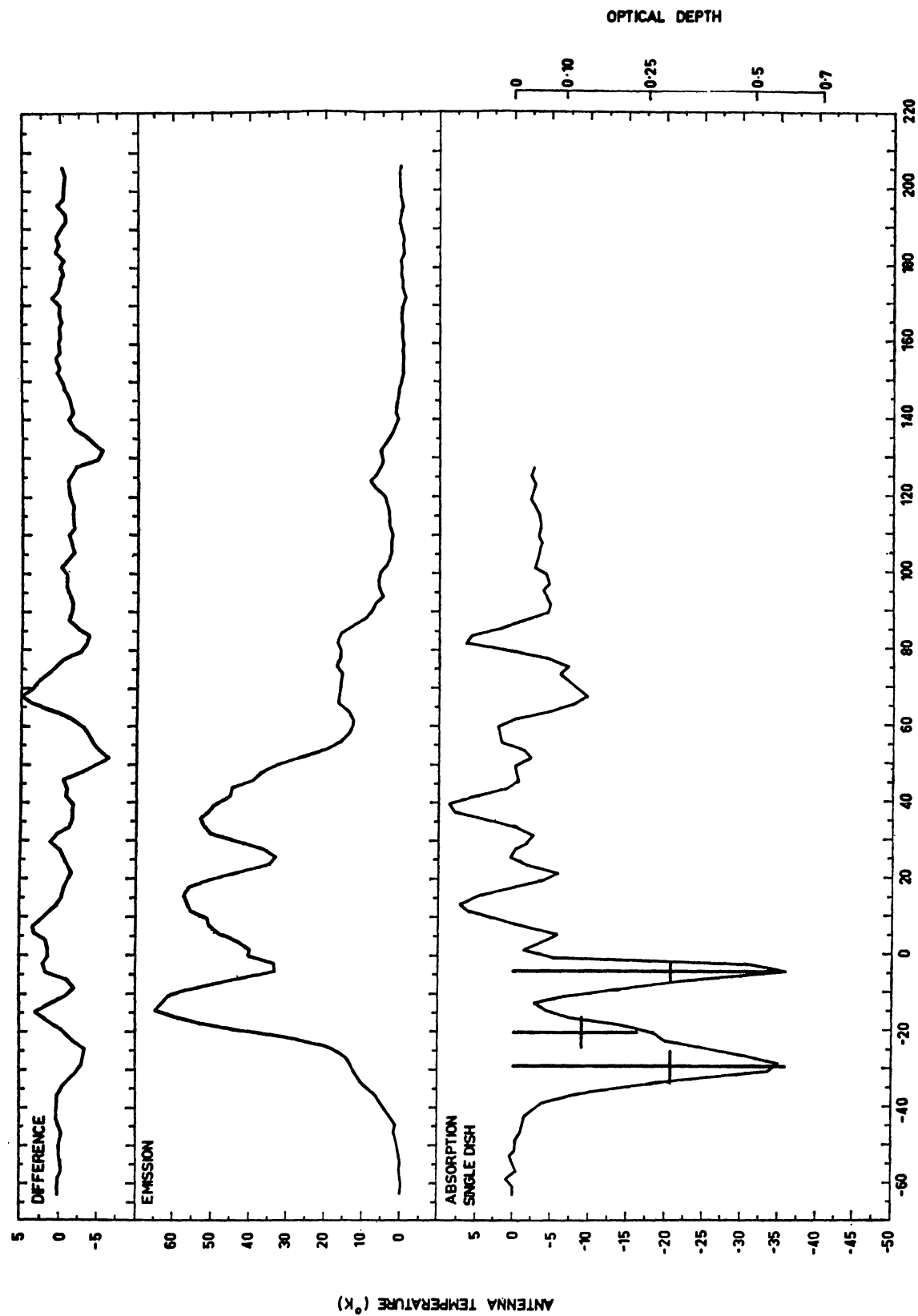


FIG. 2d.—Carina Nebula

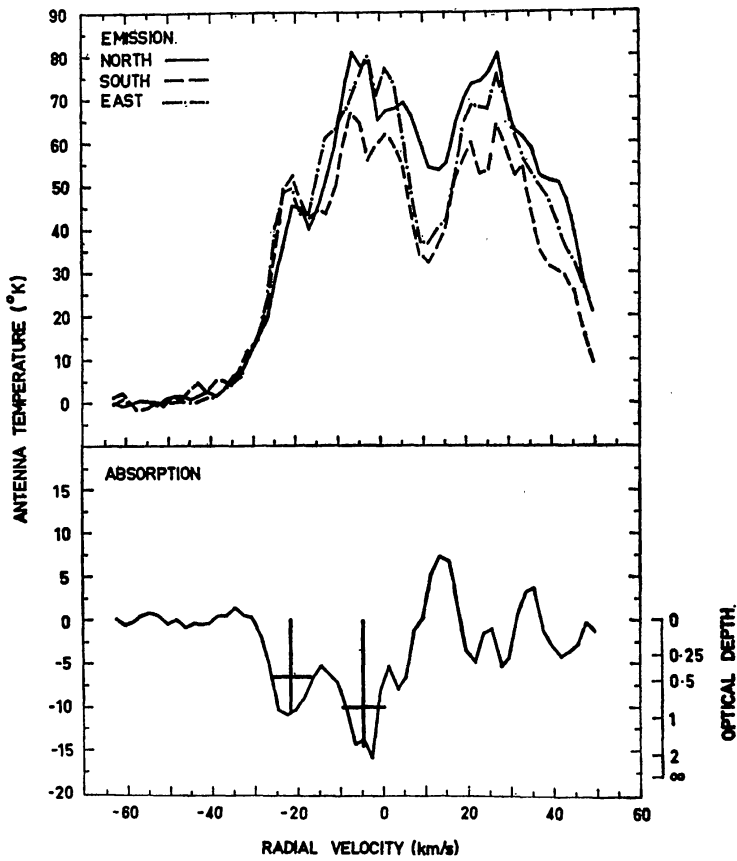


FIG. 2e.—G290.1—0.8

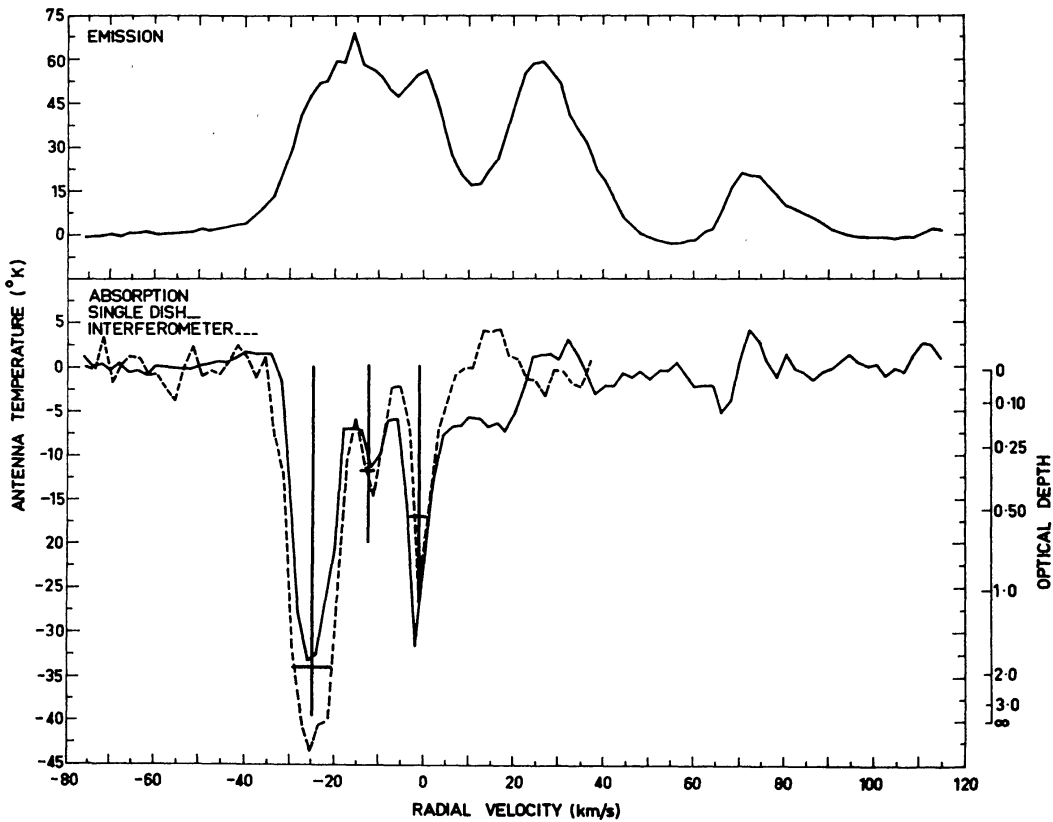


FIG. 2f.—NGC 3576

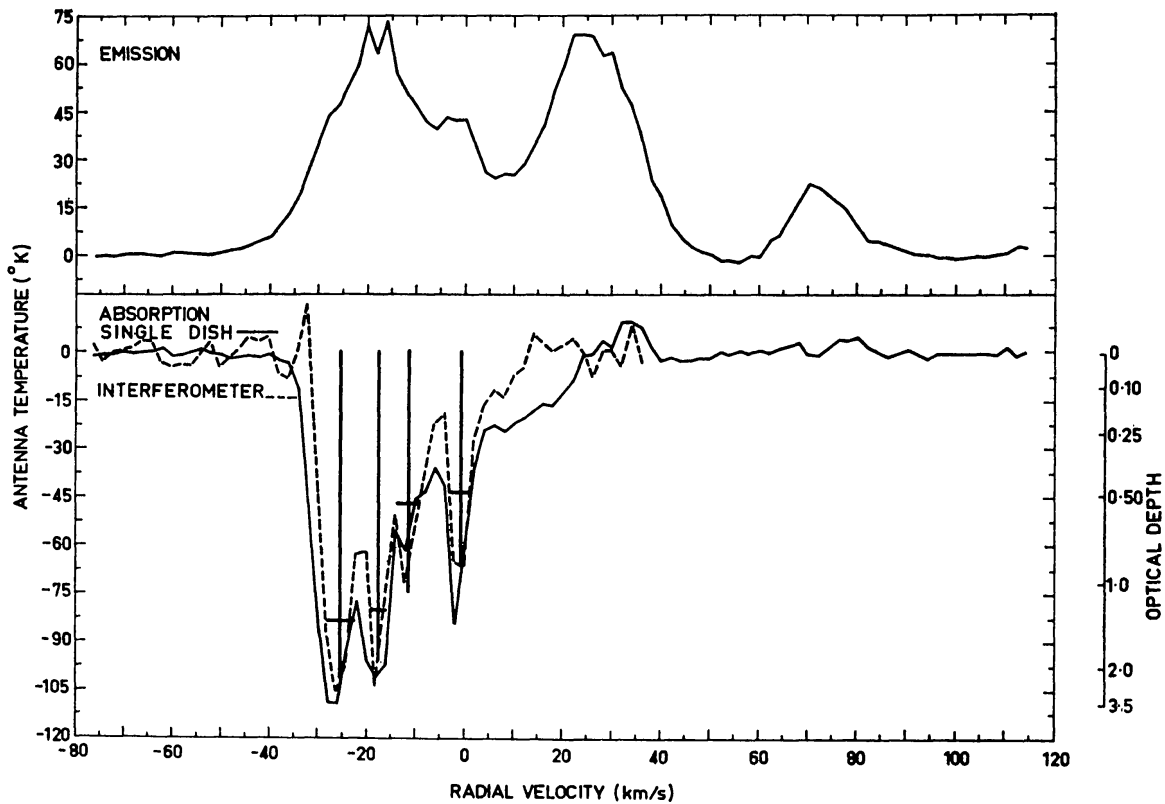


FIG. 2g.—NGC 3603

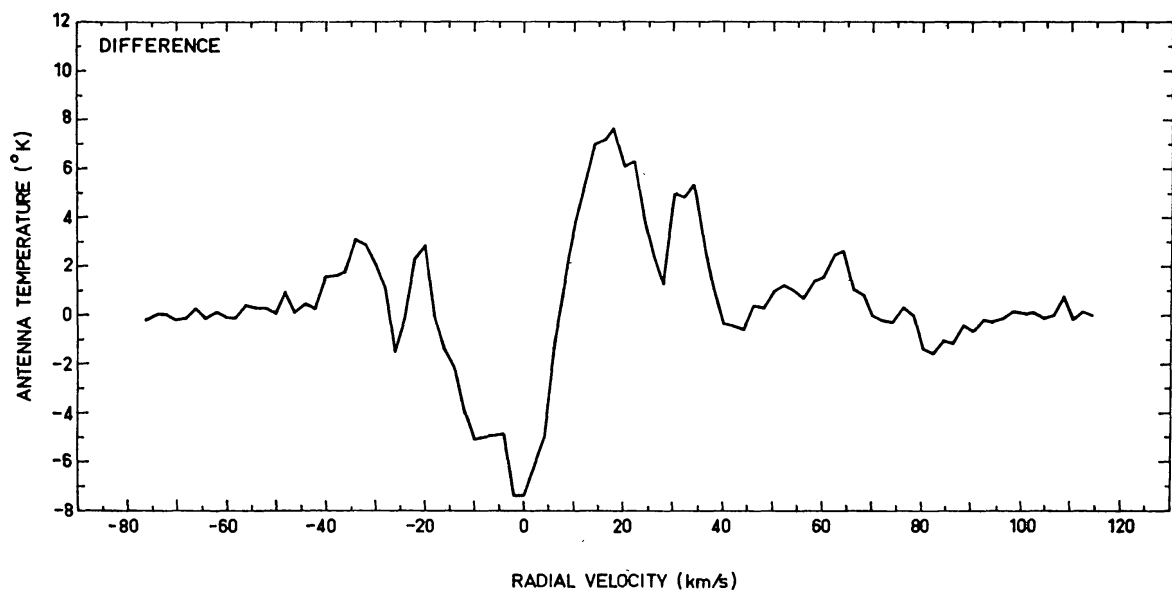


FIG. 2h.—NGC 3576, NGC 3603 (see Notes)

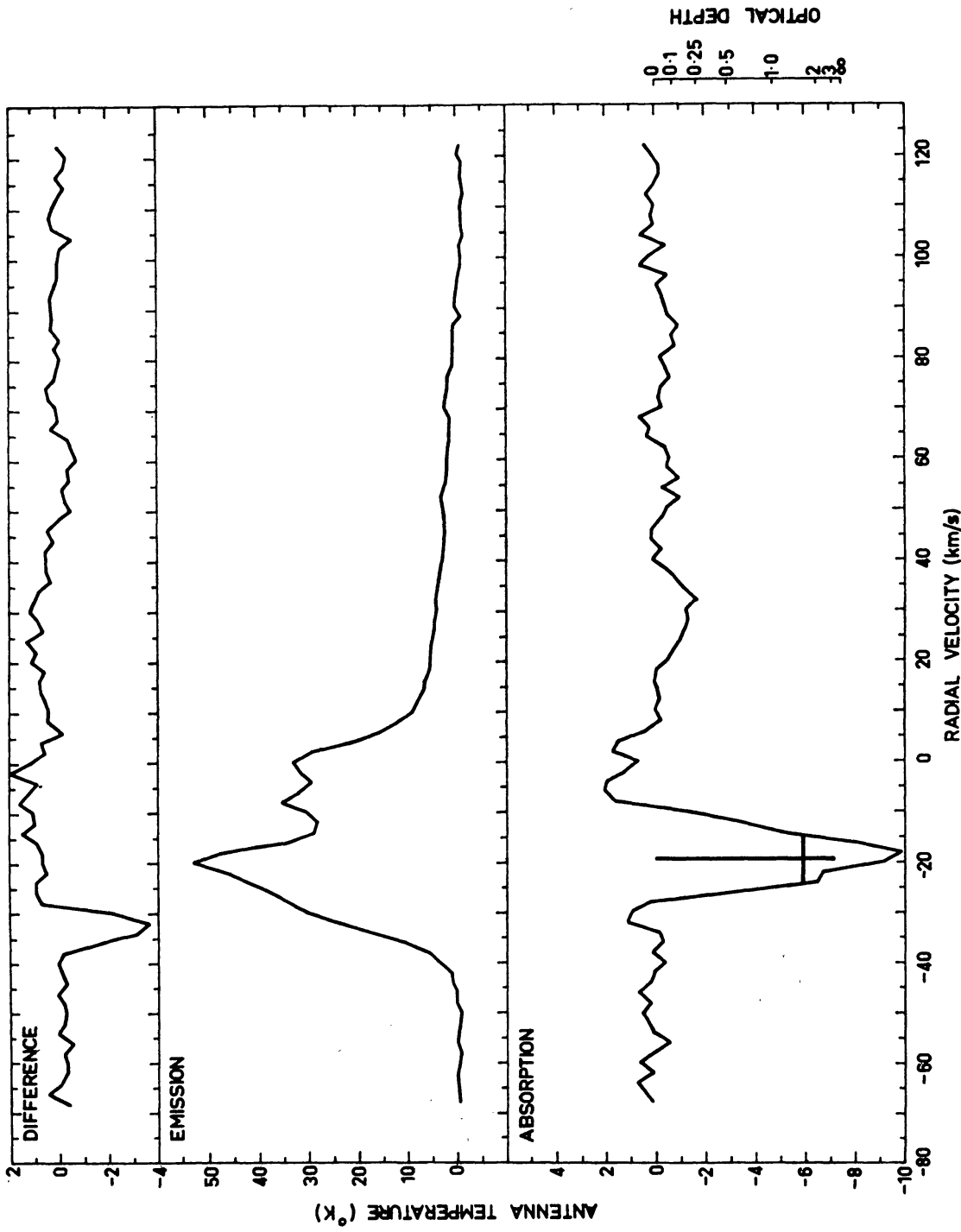


FIG. 2*i*.—G292.0+1.8

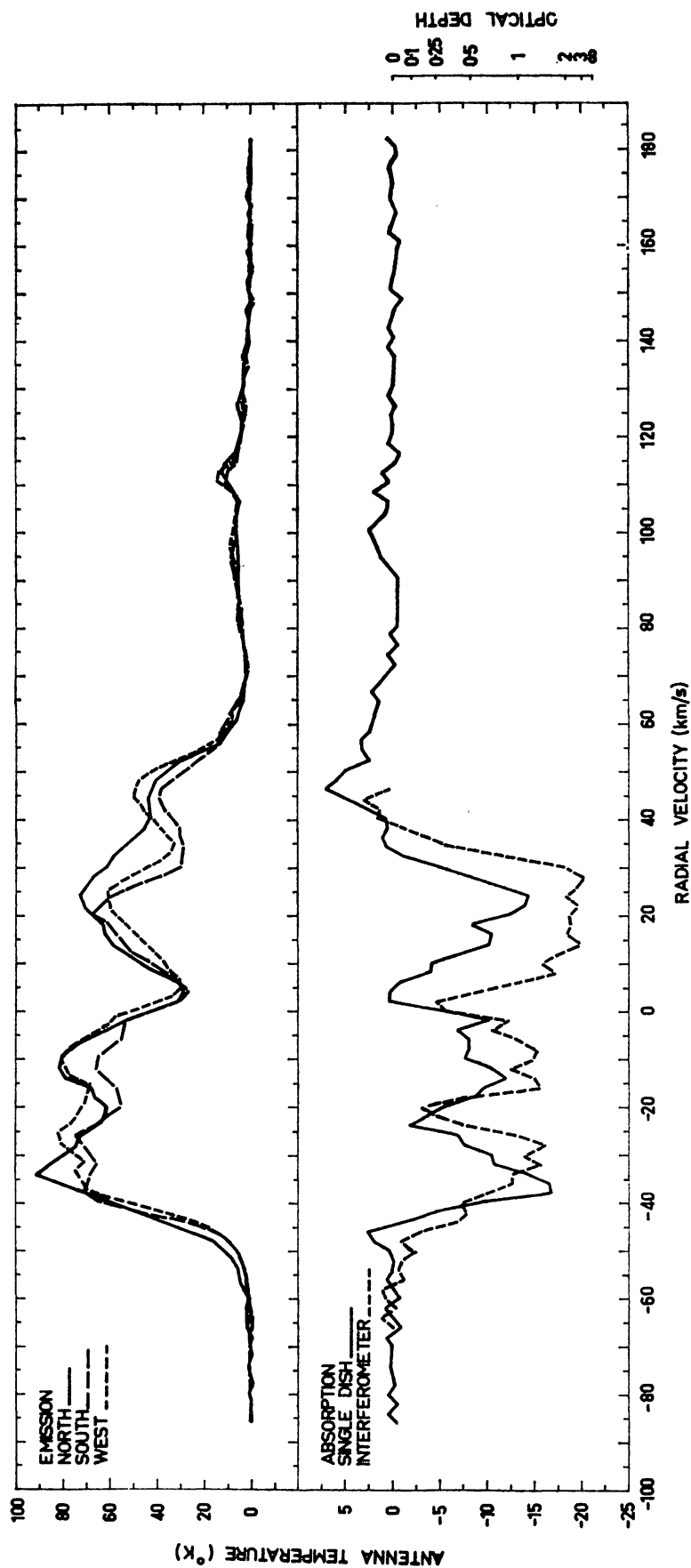


FIG. 2j.—G298.2—0.3

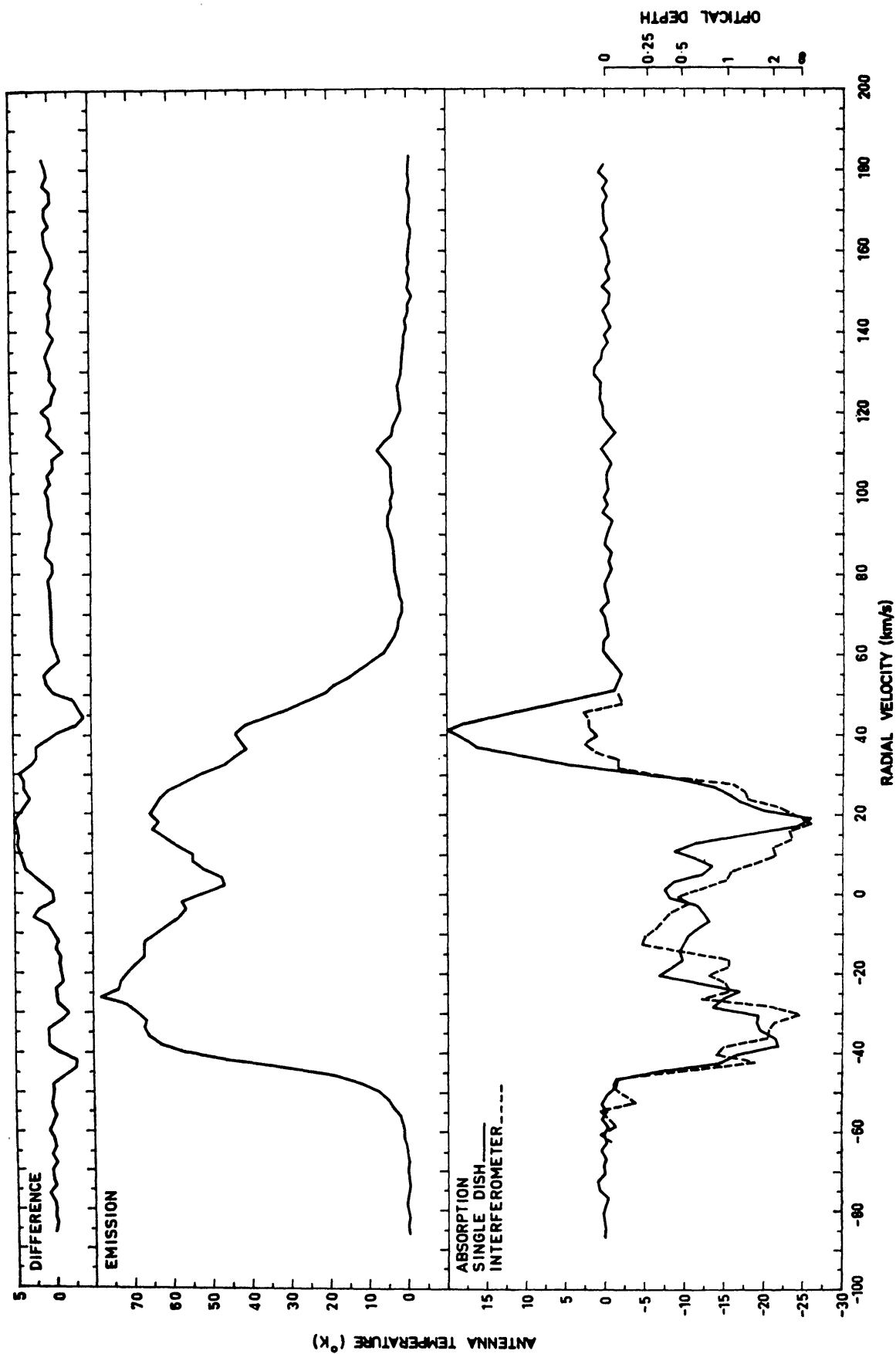


FIG. 2*k*.—G298.9—0.4

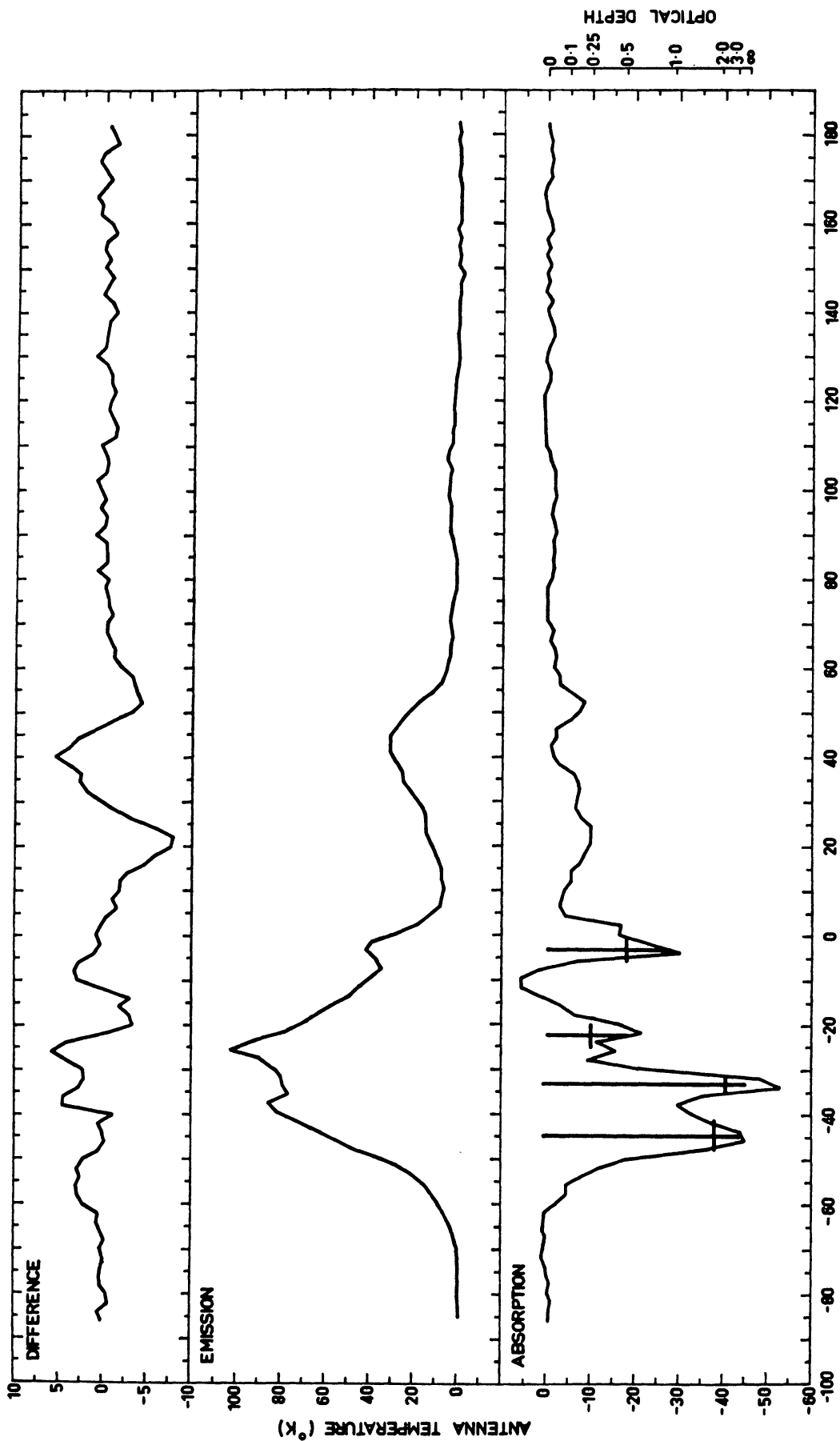


FIG. 2L.—G305.3+0.2

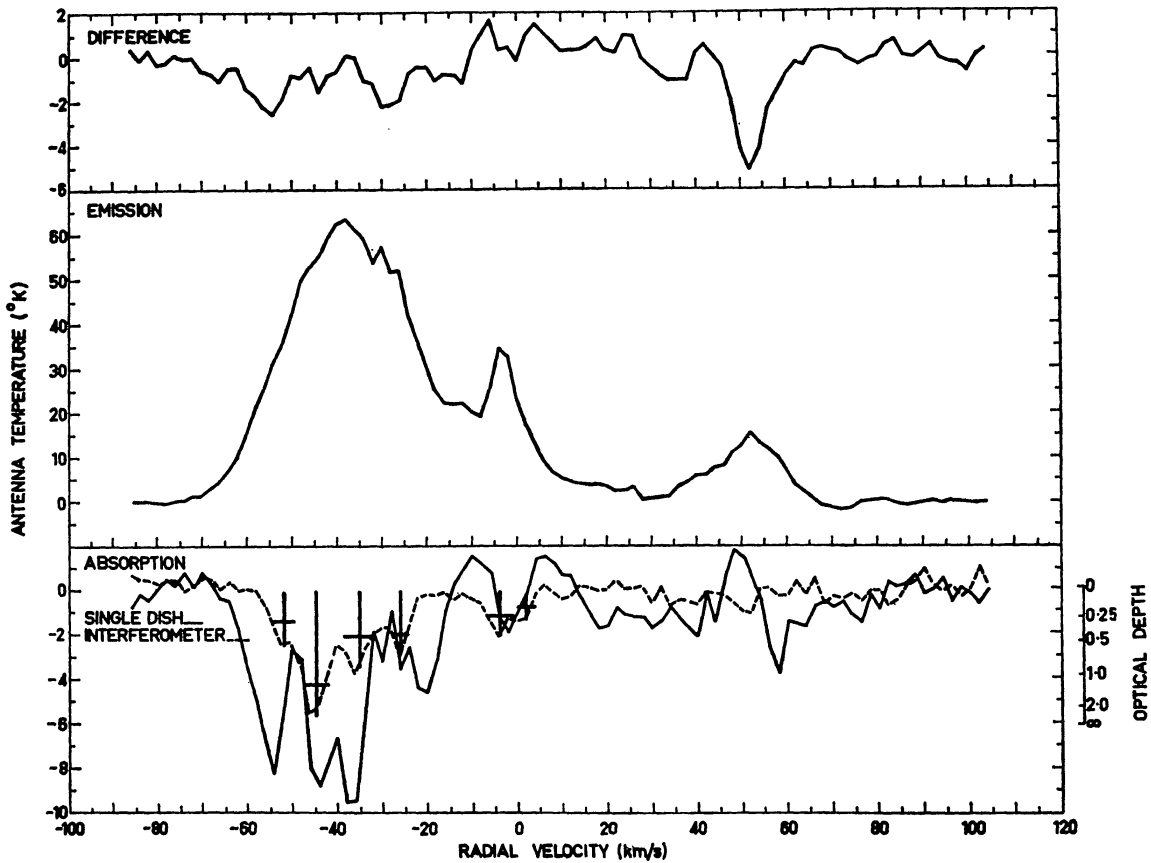


FIG. 2m.—G307.1+1.2

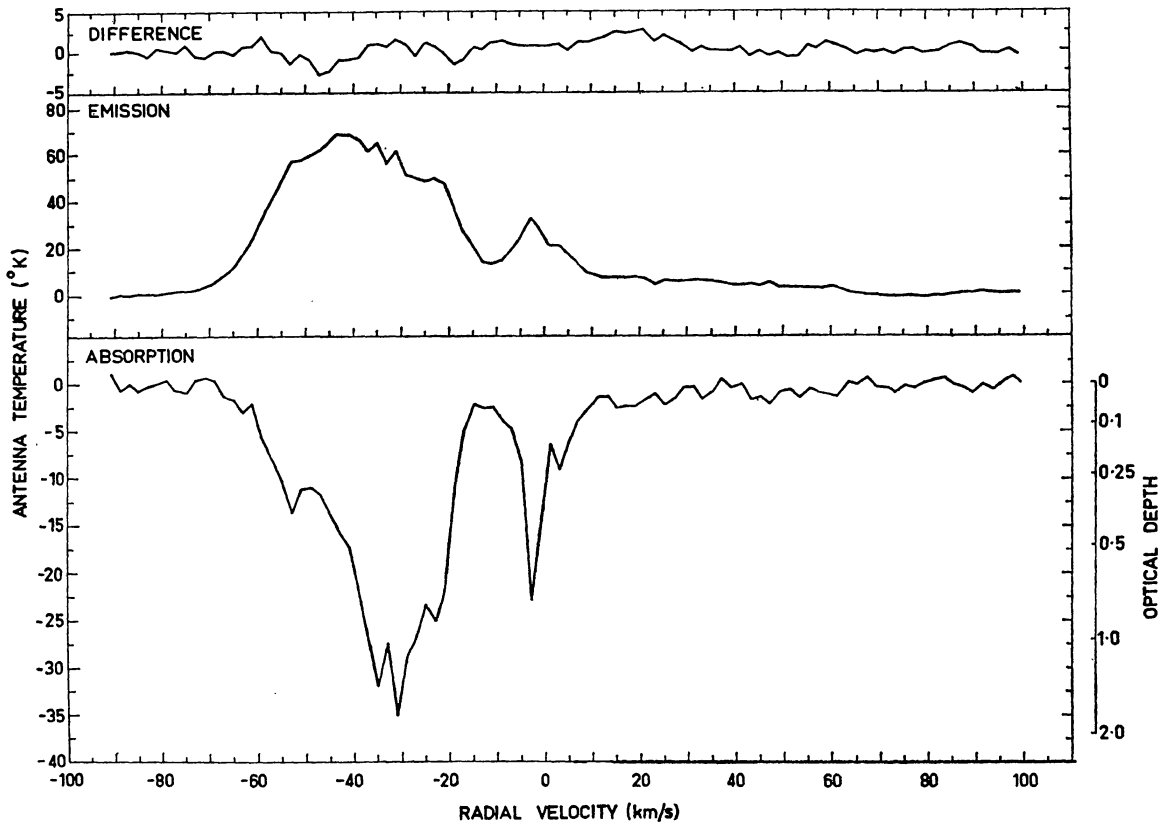


FIG. 2n.—G309.7+1.7

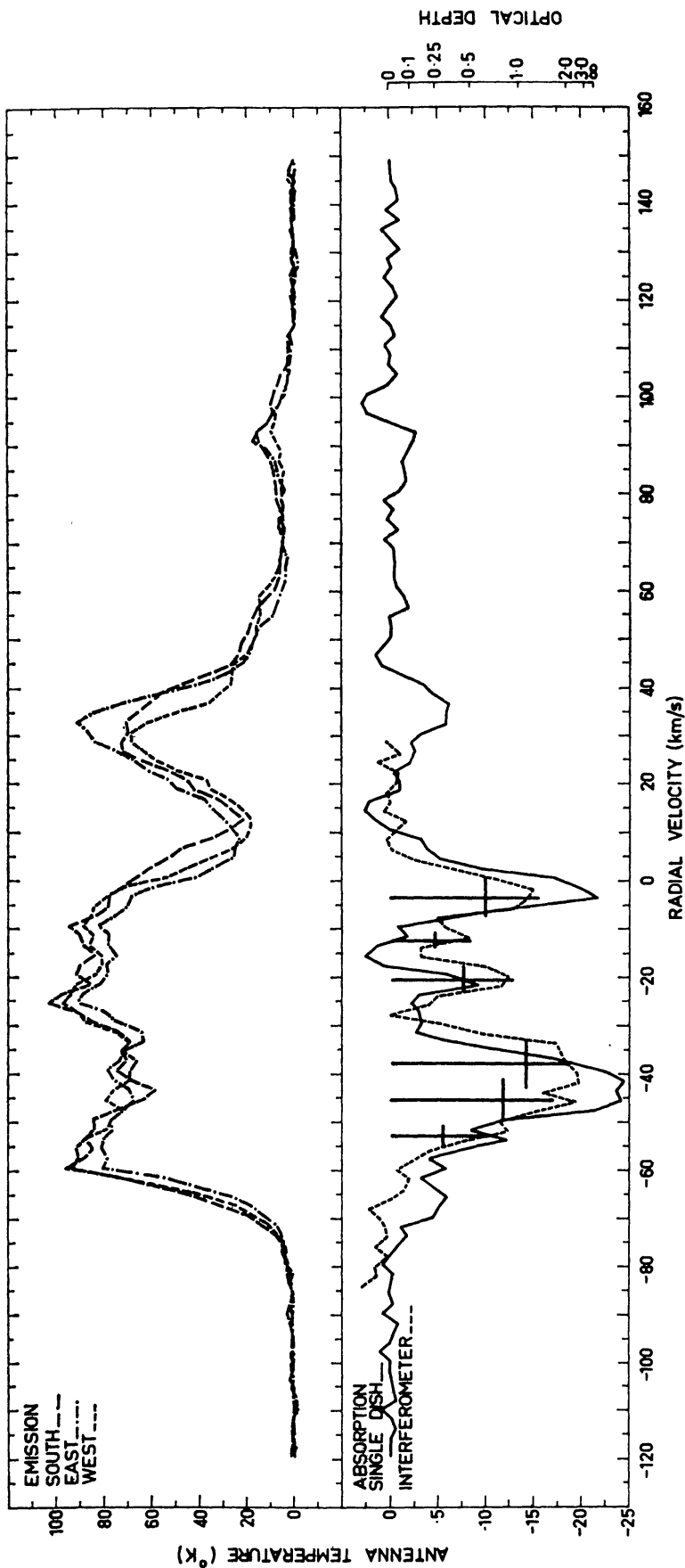


FIG. 20.—G316.8—0.1

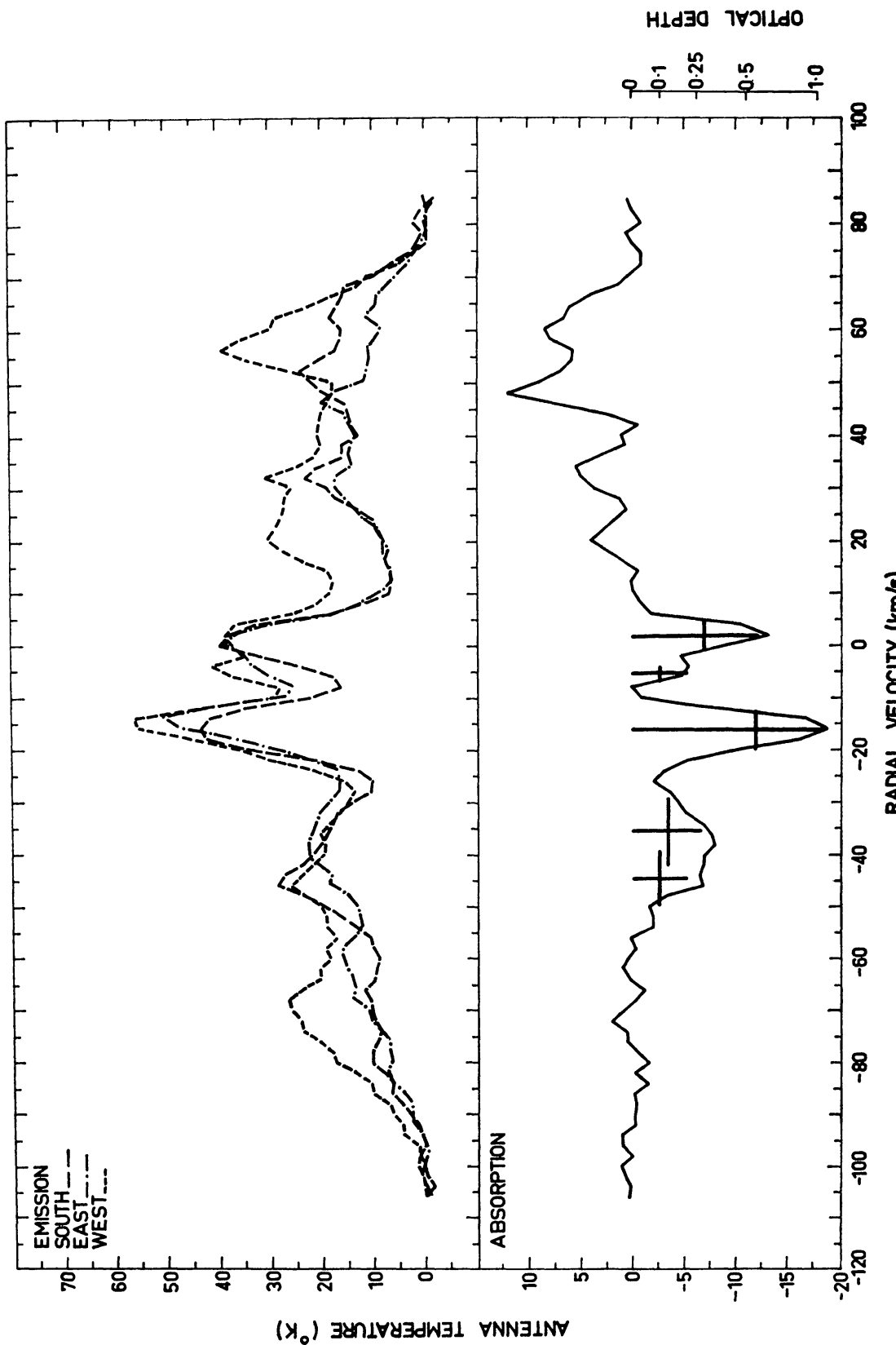


FIG. 2*p*.—G326.2—1.7

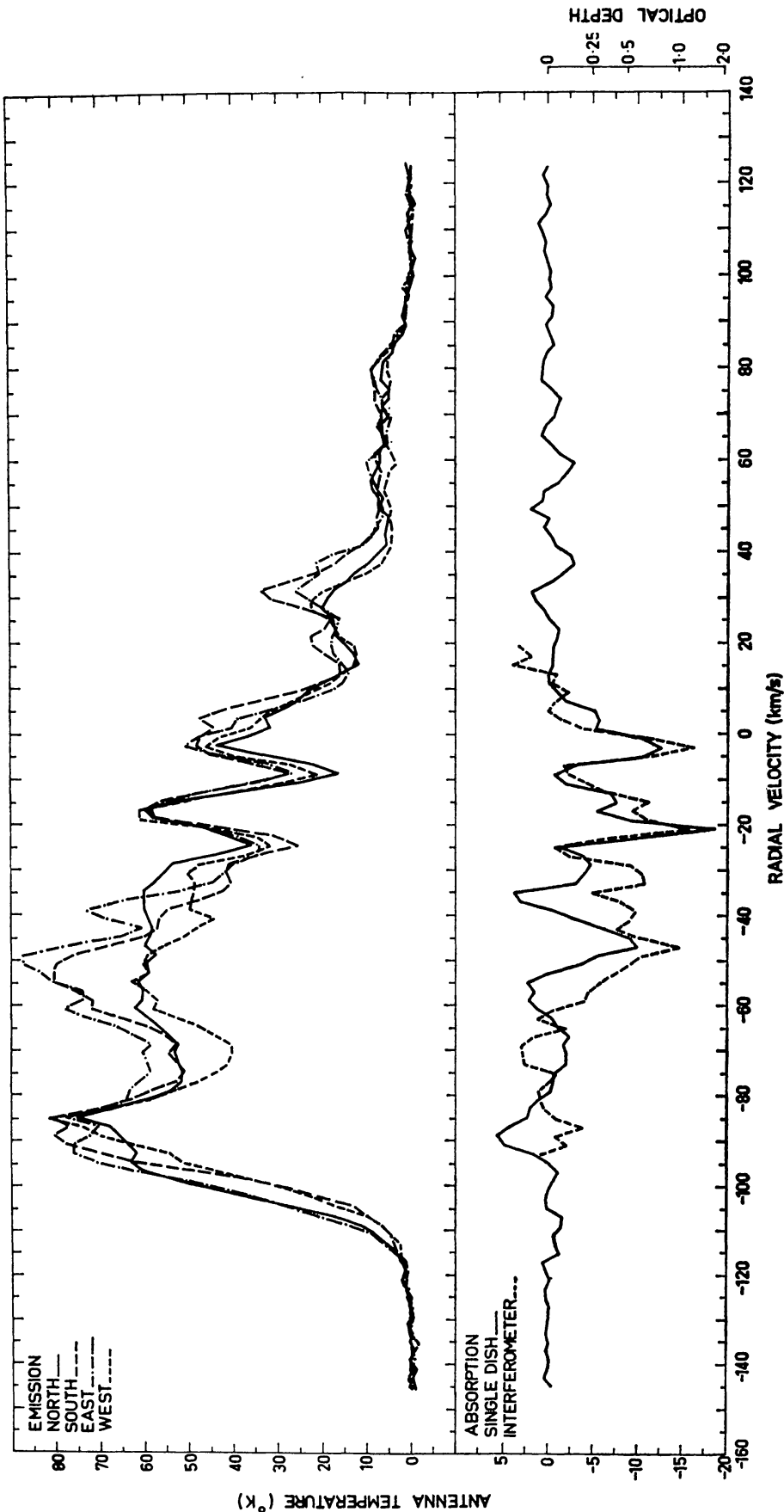


FIG. 2*q*.—G326.6+0.6

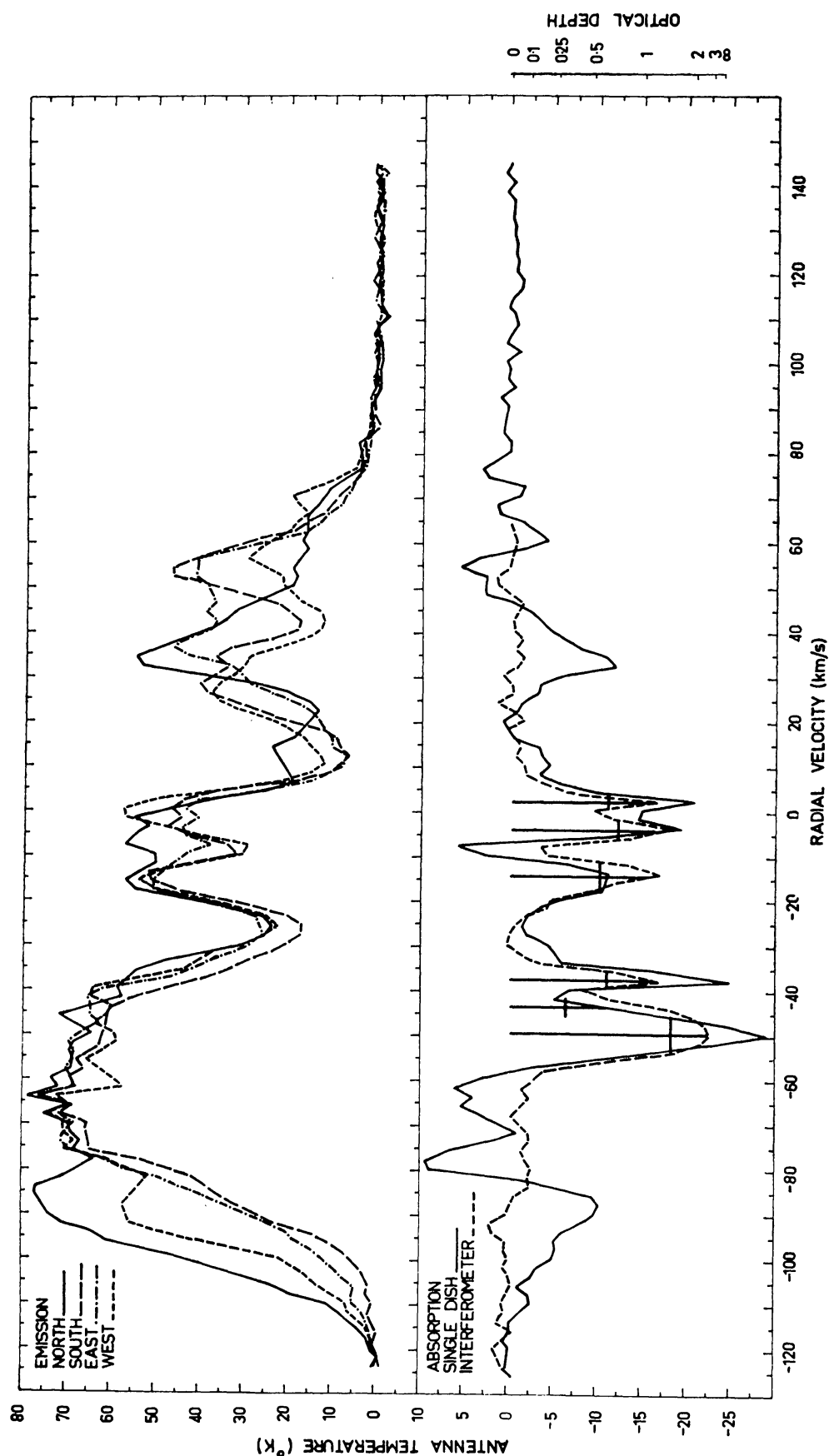


FIG. 2r.—G327.3—0.6

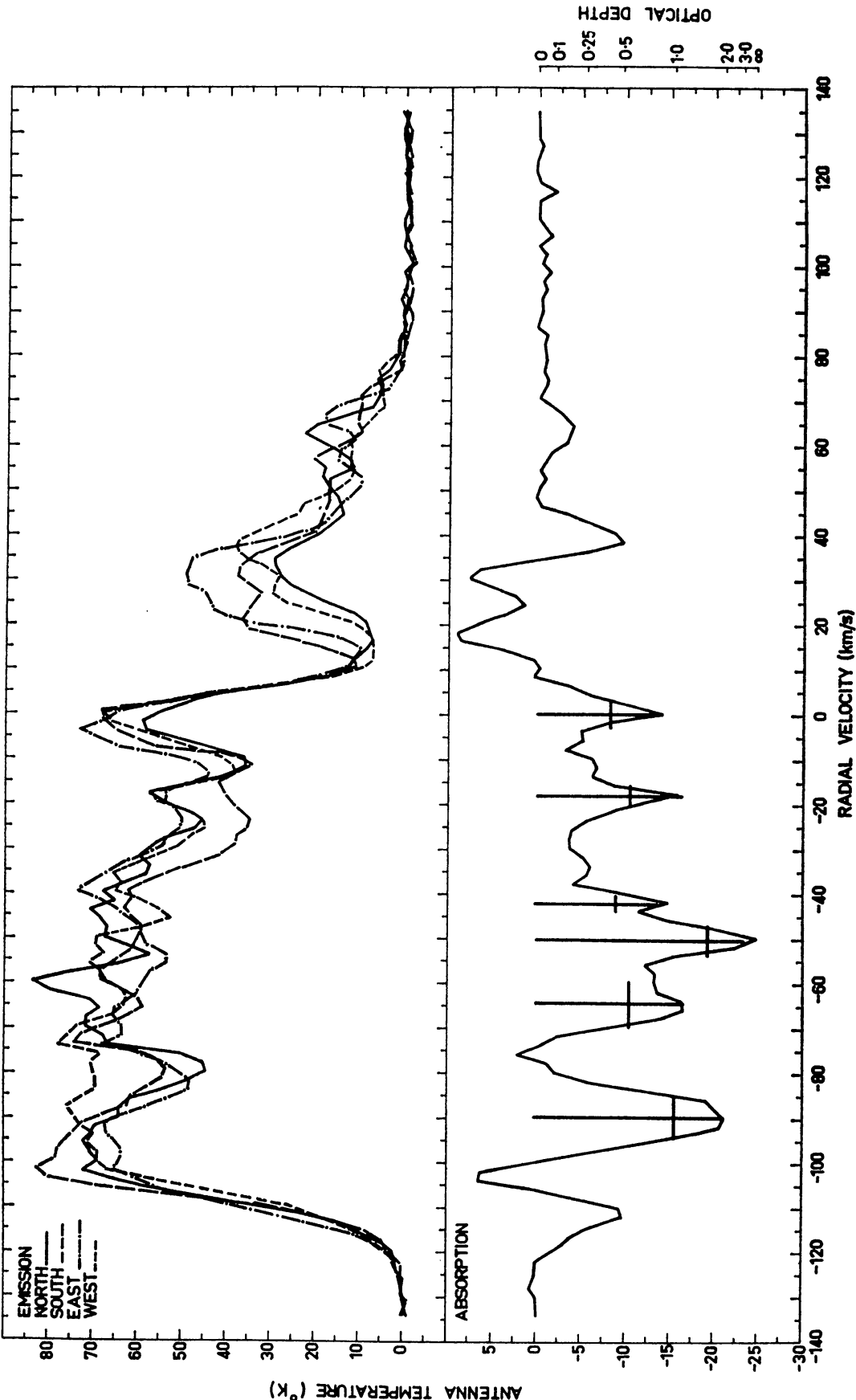


FIG. 2s.—G331.5—0.1

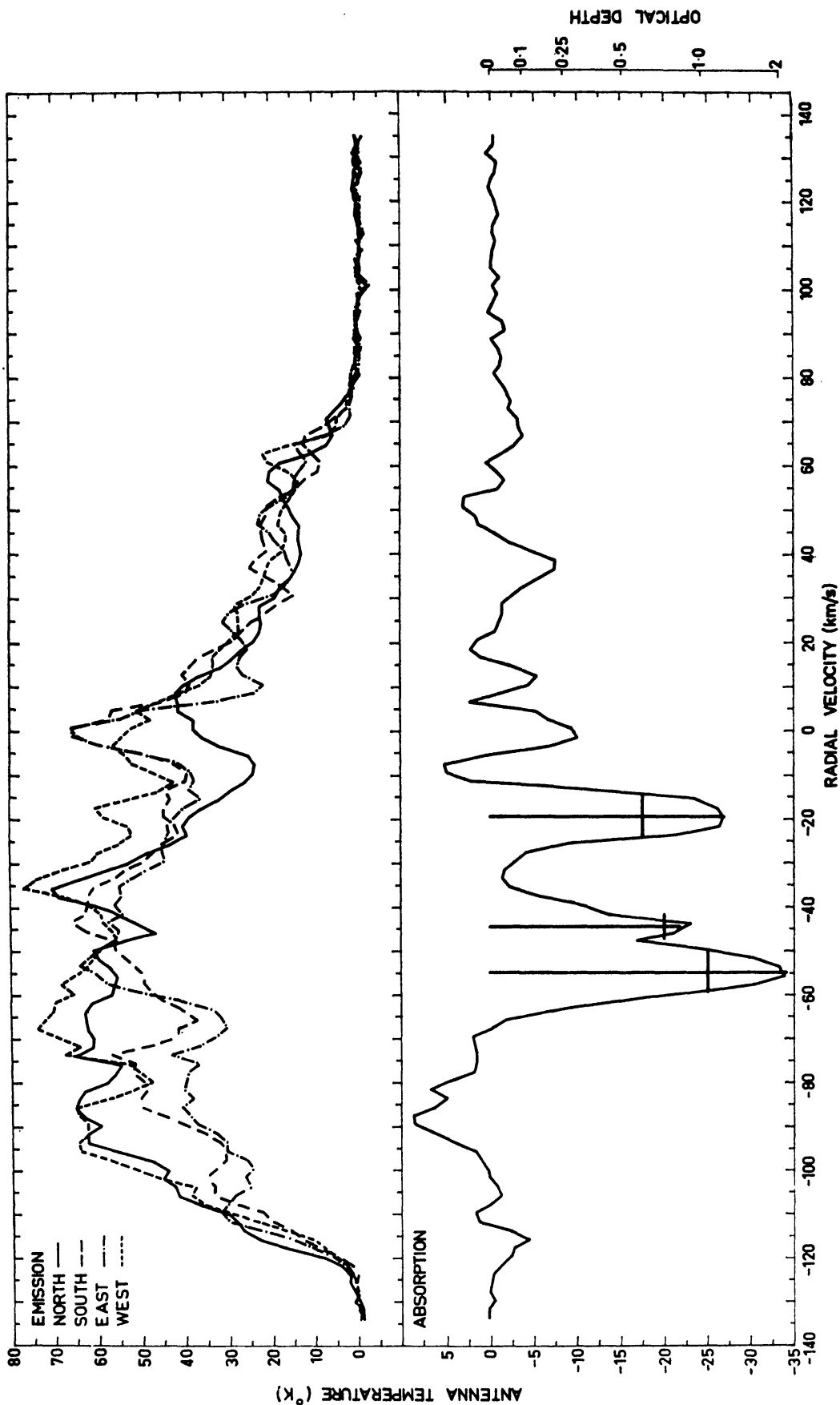


FIG. 2*t*.—G333.1—0.4

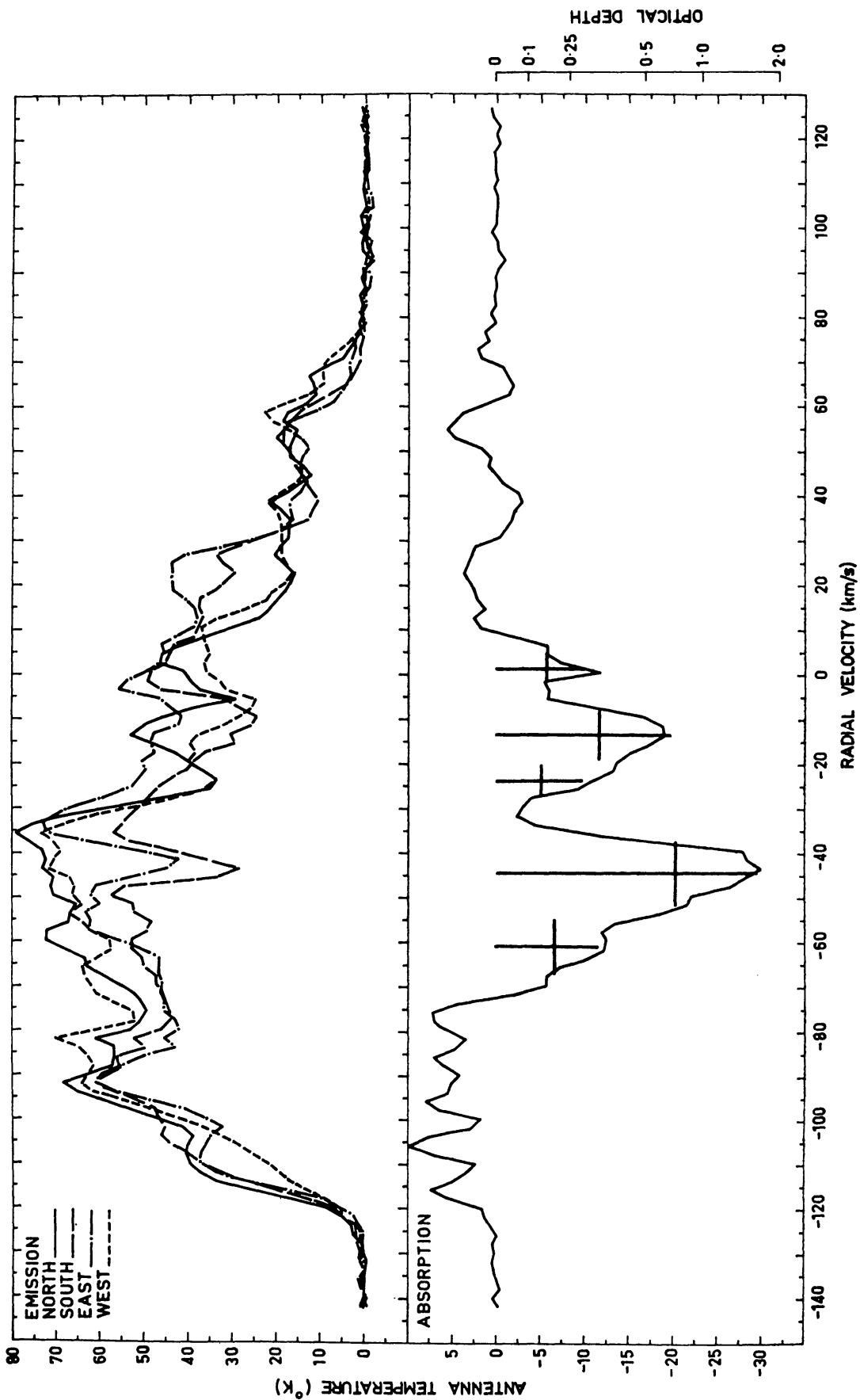


FIG. 2*u*.—G333.6—0.2

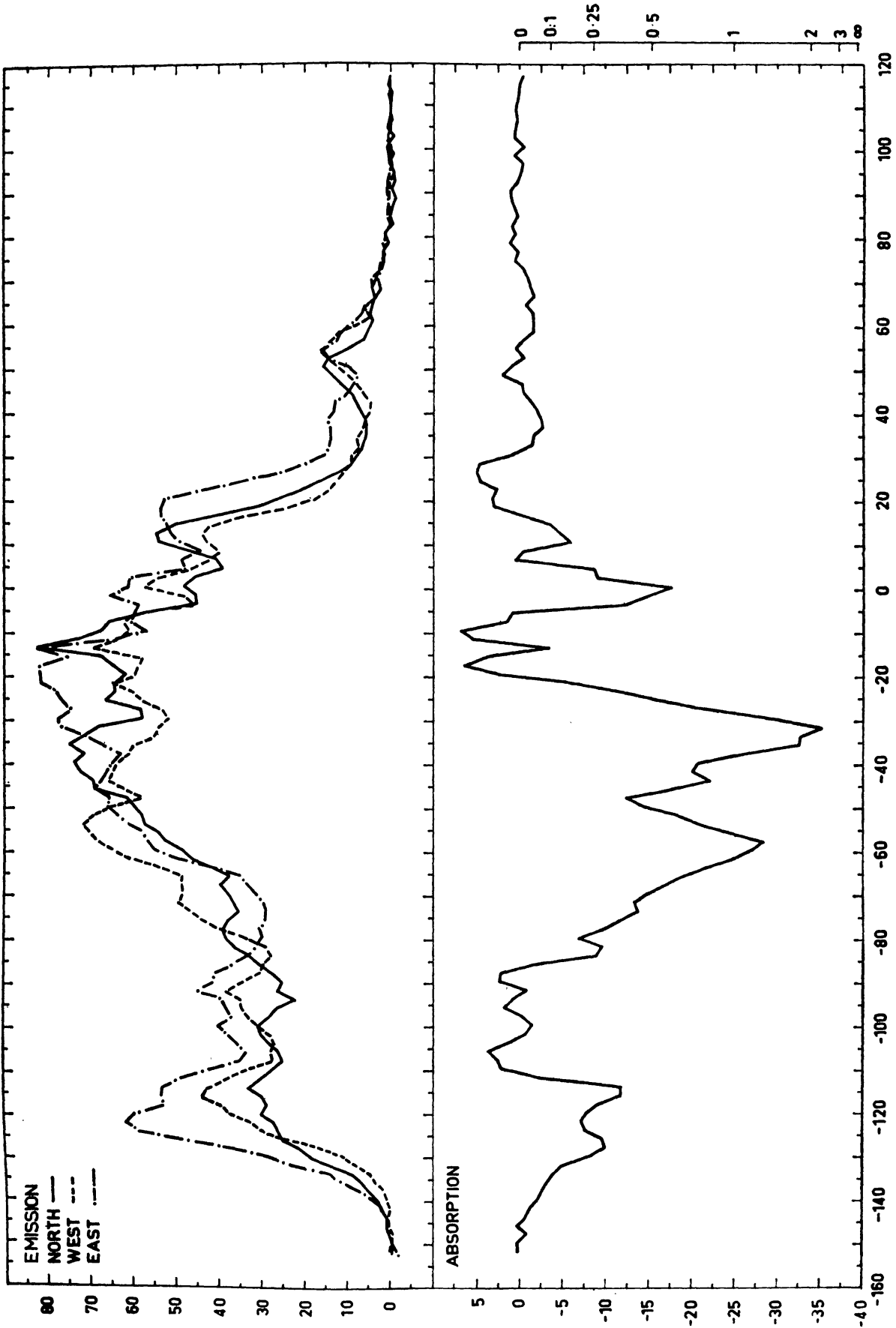


FIG. 2*v.*—G338.4+0.1

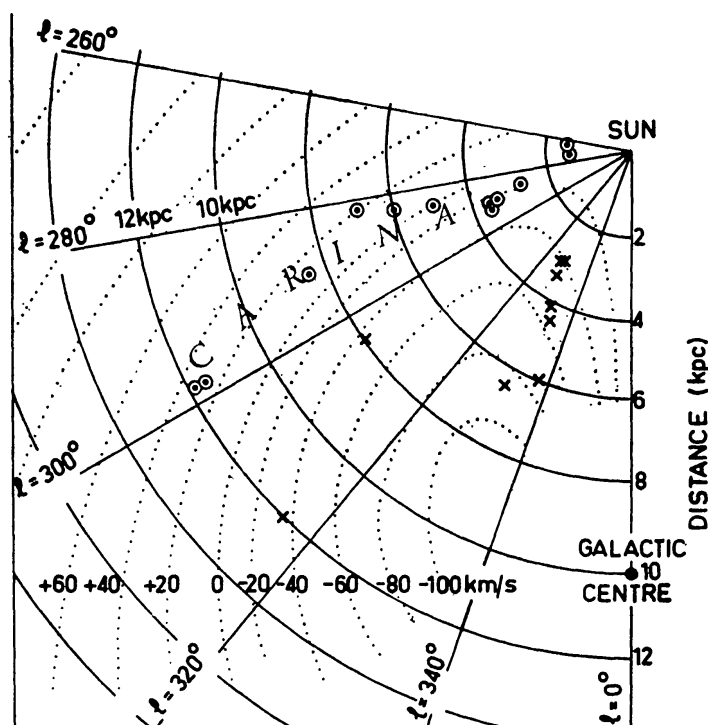


FIG. 3.—Spatial distribution of the sources in the galactic plane. *Circles*, the 12 sources in the Vela-Carina-Centaurus region from $l = 260^\circ$ to 300° ; *crosses*, the remaining sources. Most of the distances have been determined in the present work. For the sources where only lower limits to the distances were determined, the sources are shown at the lower limits. Two sources in Vela from Paper III have been added, and two sources from this paper which are believed to be extragalactic have been omitted. *Dotted lines*, contours of radial velocity calculated on the Schmidt model.

Data from the Gaussian analyses in Papers III and IV have been combined in a note following this paper to obtain estimates of the parameters characterizing the absorbing hydrogen concentrations.

IV. NOTES ON INDIVIDUAL SOURCES

a) G282.01–1.2 (Fig. 2a)

This moderately intense H II region has no visible optical counterpart. The H109 α velocity of 22.4 km s^{-1} (Wilson *et al.* 1970) implies a distance of 6.9 kpc, thus putting the source *beyond* the solar circle. The interferometer absorption profile (Fig. 2a) appears featureless and quite saturated from -10 to $+6 \text{ km s}^{-1}$. That the absorption extends up to a velocity of $\approx 26 \text{ km s}^{-1}$ confirms the H109 α distance estimate.

Note that the single-dish absorption profile has a characteristically jagged appearance, due undoubtedly to variations in the emission. This contrast between the single-dish and the interferometer profiles is a common phenomenon for sources at low galactic latitudes (see discussion in Paper III).

b) G284.3–0.3 (Fig. 2b)

The prominent optical nebosity RCW 49 is associated with this intense H II region whose continuum properties have been discussed by Shaver and Goss (1970). Westerlund (1960) has derived a distance of 6 kpc for the small cluster which is believed to excite this H II region; the optical absorption in this direction is very high (6.5 mag). A kinematic distance of 5 kpc was derived by Manchester, Goss, and Robinson (1969) from a comparison of the OH absorption and H109 α velocities. The H I absorption

TABLE 2
GAUSSIAN FITTING OF H I ABSORPTION LINES*

Source (1)	Type of Measure- ment (2)	Radial Velocity (km s ⁻¹) (3)	Optical Depth $\tau_{\max}$ (4)	$\Delta V_{1/2} \dagger$ (km s ⁻¹) (5)	$N_H/Ts \ddagger$ (cm ⁻² °K ⁻¹) (6)	$N_H \S$ (cm ⁻²) (7)	Kinematic Distance (kpc) (8)	Remarks (9)
G285.3-0.0.....	I	-18.4±0.4 -10.4±0.3	3.1 3.8	5.6 9.2	3.4×10 ¹⁹ 6.8×10 ¹⁹	1.7×10 ²¹ 3.4×10 ²¹	2.6# 2.6#	a a
G287.4-0.6.....	SD	3.3±0.2 -29.4±0.5 -20.2±0.5	4.3 0.6 ±0.1 0.24±0.06	7.7 8.7±1.0 8.1±1.0	6.4×10 ¹⁹ 9.8×10 ¹⁸ (12) 3.8×10 ¹⁸ (20)	3.2×10 ²¹ 4.9×10 ²⁰ 1.9×10 ²⁰	...	b b
G290.1-0.8.....	SD	-4.5±0.3 -21.6±1.2	0.65±0.09 0.9 ±0.4	5.5±0.7 9.0±2.8	7.0×10 ¹⁸ (9) 1.7×10 ¹⁹ (30)	3.5×10 ²⁰ 8.5×10 ²⁰	3.0# 3.0# 0.6	c
G291.3-0.7.....	I	-4.4±0.6 -25.2±0.3 -13.0±0.3	1.6 ±0.3 4.2 [0.7 ±0.4]	9.4±1.4 8.2 [2.2±0.7]	3.1×10 ¹⁹ (10) 6.7×10 ¹⁹ 2.9×10 ¹⁸ (60)	1.6×10 ²¹ 3.4×10 ²¹ 1.5×10 ²⁰	3.4# 3.6# 1.8 (5.5)	d d e
G291.6-0.5.....	I	-1.8±0.2 -25.6±0.1 -17.8±0.1	[1.1 ±0.3] 3.0 [2.5 ±0.2]	[3.3±0.5] 4.9 [3.3±0.2]	7.1×10 ¹⁸ (22) 2.8×10 ¹⁹ 1.6×10 ¹⁹ (5)	3.6×10 ²⁰ 1.4×10 ²¹ 8.0×10 ²⁰	0.2 (7.1) 3.6# 2.9 4.5	d
G292.0+1.8.....	SD	-11.6±0.1 -1.0±0.1	1.3 ±0.1 1.2 ±0.1	3.7±0.2 3.7±0.2	9.0×10 ¹⁸ (7) 8.8×10 ¹⁸ (7)	4.5×10 ²⁰ 4.4×10 ²⁰	1.5 5.9 0.1 7.3	
G305.3+0.2.....	SD	-19.3±0.3 -44.9±0.2 -33.2±0.1	3.1 3.8 ±0.4 4.9	9.4 6.3±0.2 3.9	5.5×10 ¹⁹ 4.6×10 ¹⁹ (7) 3.7×10 ¹⁹	2.8×10 ²¹ 2.3×10 ²¹ 1.9×10 ²¹	3.7# 5.8# 2.9 (8.7)	f
		-22.4±0.1 -3.3±0.1	0.5 ±0.1 1.1 ±0.1	5.3±0.1 5.4±0.1	5.4×10 ¹⁸ (30) 1.2×10 ¹⁹ (11)	2.7×10 ²⁰ 6.0×10 ²⁰	1.8 (9.7) 0.3(11.3)	

* Errors are based on twice r.m.s. errors of Gaussian fit.

† Full width at half optical depth.

‡ The percentage errors are shown in parentheses.

§ Based on $T_s = 50^\circ \text{K}$.

|| In some cases there are two possible distances, and if one of these is less likely it is enclosed in parentheses.

Velocity is close to the tangential velocity; the feature has been placed at the tangential point.

REMARKS:

a) The velocity is more negative than the Schmidt Model tangential velocity of -10 km s^{-1} .

b) The velocity is more negative than the Schmidt Model tangential velocity of -12 km s^{-1} .

c) The velocity is more negative than the Schmidt Model tangential velocity of -17 km s^{-1} .

d) The velocity is more negative than the Schmidt Model tangential velocity of -19 km s^{-1} .

e) This feature is very uncertain since it is so close to the strong line at -25.2 km s^{-1} . The tangential velocity is -48 km s^{-1} and the tangential point is at 5.8 kpc .

f) The velocity is more negative than the Schmidt tangential velocity of -52 km s^{-1} .

g) The Schmidt Model tangential velocity is -76 km/s and the tangential point is 7.3 kpc distant.

i) Uncertain if real absorption feature. If real, the kinematic distance is greater than the source distance.

j) Uncertain if real absorption feature.

TABLE 2—Continued

Source (1)	Type of Measure- ment (2)	Radial Velocity (km s ⁻¹) (3)	Optical Depth τ_{max} (4)	$\Delta V_{1/2} \uparrow$ (km s ⁻¹) (5)	$N_{\text{H}}/T_{\text{s}} \uparrow$ (cm ⁻² °K ⁻¹) (6)	$N_{\text{H}} \S$ (cm ⁻²) (7)	Kinematic Distance (kpc) (8)	Remarks (9)
G307.1+1.2.....	I	-52.5±0.7	0.6 ±0.2	4.0±1.6	4.4×10 ¹⁸ (30)	2.2×10 ²⁰	6.1#	g
		-45.1±0.1	2.5	4.7	2.3×10 ¹⁹	1.2×10 ²¹	4.1 8.0	
		-35.6±0.1	0.86±0.07	6.2±0.3	1.0×10 ¹⁹ (7)	5.0×10 ²⁰	3.0 9.1	
		-26.3±0.1	[0.73±0.11]	[3.6±0.3]	5.1×10 ¹⁸ (12)	2.6×10 ²⁰	2.1 10.0	
		-4.3±0.1	[0.44±0.05]	5.4±0.3	4.5×10 ¹⁸ (13)	2.3×10 ²⁰	0.3 11.7	
G316.8-0.1.....	I	1.4±0.1	[0.25±0.07]	[3.7±0.3]	1.8×10 ¹⁸ (30)	9.0×10 ¹⁹	<0.3 12.2	h
		-52.9±1.5	0.7 ±0.4	3.6±3.0	4.8×10 ¹⁸ (60)	2.4×10 ²⁰	3.8 10.7	
		-45.4±0.7	1.7	8.1	2.7×10 ¹⁹	1.4×10 ²¹	3.2 11.3	
		-38.1±0.5	2.2	9.7	4.2×10 ¹⁹	2.1×10 ²¹	2.7 11.9	
		-20.7±0.5	1.0 ±0.2	5.4±1.2	1.1×10 ¹⁹ (20)	6.0×10 ²⁰	1.5(13.1)	
G326.2-1.7.....	SD	-12.3±0.5	[0.5 ±0.3]	[3.5±1.2]	3.2×10 ¹⁸ (50)	1.6×10 ²⁰	0.9(13.7)	
		-3.4±0.5	1.4 ±0.2	7.5±1.2	1.9×10 ¹⁹ (8)	1.0×10 ²¹	0.3(14.3)	
		-44.4±3.0	0.21±0.15	10.3±7.0	4.3×10 ¹⁸ (50)	2.2×10 ²⁰	3.1(13.5)	
		-35.1±2.0	0.28±0.12	12.5±5.0	6.8×10 ¹⁸ (30)	3.4×10 ²⁰	2.5(14.1)	
		-16.1±0.4	1.2 ±0.2	6.4±0.9	1.5×10 ¹⁹ (6)	8.0×10 ²⁰	1.2(15.4)	
G327.3-0.6.....	I	-5.3±0.4	[0.21±0.16]	[3.1±0.9]	1.3×10 ¹⁸ (7)	7.0×10 ¹⁹	0.4(16.2)	
		1.9±0.4	0.61±0.11	5.1±0.9	6.0×10 ¹⁸ (14)	3.0×10 ²⁰	<0.3(16.8)	
		-49.5±0.1	2.9	8.0	4.5×10 ¹⁹	2.3×10 ²¹	3.5	
		-43.7±0.1	0.7 ±0.1	3.6±0.2	4.9×10 ¹⁸ (17)	2.5×10 ²⁰	3.1	
		-37.5±0.1	[1.2 ±0.1]	[3.6±0.2]	8.5×10 ¹⁸ (6)	4.3×10 ²⁰	2.7	
G331.5-0.1.....	SD	-14.2±0.1	1.16±0.06	6.0±0.2	1.3×10 ¹⁹ (4)	7.0×10 ²⁰	1.1	
		-3.9±0.1	1.6 ±0.1	3.7±0.2	1.2×10 ¹⁹ (4)	6.0×10 ²⁰	0.3	
		2.2±0.1	[1.2 ±0.1]	[2.9±0.2]	6.7×10 ¹⁸ (6)	3.4×10 ²⁰	<0.3	
		-89.5±0.5	2.1 ±0.3	9.2±1.2	3.7×10 ¹⁹ (10)	1.9×10 ²¹	6.6	
		-64.0±0.4	1.1 ±0.2	9.9±1.0	2.3×10 ¹⁹ (12)	1.2×10 ²¹	4.6	
G333.1-0.4.....	SD	-50.0±0.2	3.2	6.1	3.8×10 ¹⁹	1.9×10 ²¹	3.7	
		-41.9±0.2	[0.9 ±0.3]	[3.0±0.5]	5.5×10 ¹⁸ (30)	2.8×10 ²⁰	3.1	
		-17.8±0.2	1.3 ±0.3	4.1±0.5	9.6×10 ¹⁸ (14)	4.8×10 ²⁰	1.4	
		0.4±0.2	0.9 ±0.1	5.0±0.5	8.7×10 ¹⁸ (14)	4.4×10 ²⁰	<0.3	
		-54.9±0.3	2.2 ±0.2	5.6±0.3	3.6×10 ¹⁹ (6)	1.8×10 ²¹	4.1	
G333.6-0.2.....	SD	-44.5±0.2	0.9 ±0.1	8.4±0.2	9.5×10 ¹⁸ (13)	4.8×10 ²⁰	3.4	i
		-19.6±0.2	1.2 ±0.1	9.0±0.2	2.2×10 ¹⁹ (5)	1.1×10 ²¹	1.6	
		-60.7±1.6	0.4 ±0.2	11.8±3.7	9.0×10 ¹⁸ (26)	4.5×10 ²⁰	4.5	
		-44.2±0.4	1.6 ±0.1	13.3±0.9	4.3×10 ¹⁹ (4)	2.2×10 ²¹	3.4	
		-23.5±0.4	0.3 ±0.1	6.3±0.9	3.9×10 ¹⁸ (30)	2.0×10 ²⁰	1.9	
		-13.1±0.3	0.78±0.07	10.4±0.7	1.6×10 ¹⁹ (6)	8.0×10 ²⁰	1.1	j
		1.6±0.3	1.35±0.06	8.0±0.7	5.5×10 ¹⁸ (16)	2.8×10 ²⁰	<0.3	

profiles are shown in Figure 2*b*; the absorption extends approximately from -20 to $+5$ km s $^{-1}$, leading to a distance of ~ 6 kpc, in good agreement with the optical determination. As in the case of G282.0 -1.2 , the H I absorption profile is quite saturated; hence it is impossible to make a reliable estimate of the number of absorption components present in it.

*c) G285.3 -0.0 (Fig. 2*c*)*

This H II region, of angular diameter $\sim 2'$ (Shaver and Goss 1970), is identified with a knot of nebulosity in the outlying regions of the Carina Nebula. The H109 α velocity of -1.6 km s $^{-1}$ implies a kinematic distance of either 0.2 or 5.0 kpc. The H I absorption spectrum (Fig. 2*c*) clearly rules out the nearer distance. As mentioned in the footnotes to Table 2, the Schmidt model does not give a good representation of the velocity field in this part of the Galaxy. The positive-velocity absorption feature, which probably arises in the local gas, is quite different in appearance on the single-dish and interferometer profiles. This difference is due to variations in the emission which are large compared to the antenna temperature of the weak source. At velocities between 5 and 10 km s $^{-1}$ the emission appears to have a local minimum near the position of the source. The angular scale of this depression is presumably $< 15'$, since the difference profile does not show any prominent feature near this velocity.

*d) G287.4 -0.6 (Fig. 2*d*)*

This strong radio source is associated with the Carina Nebula. High-resolution maps of the continuum radiation (Shaver and Goss 1970; Gardner *et al.* 1970) show that the central source is double with a separation of $\sim 10'$. The distance to the Carina Nebula has been discussed in detail by Sher (1965), who adopts 2.7 kpc as the most likely photometric distance. A kinematic distance from the H109 α velocity also places it near the tangential point at 3.0 kpc. The H I absorption profiles are shown in Figure 2*d*. The reference profiles were obtained as usual by moving $15'$ from the source maximum, but because of the large angular extent of the low-lying continuum radiation (Hill 1968) the emission profile probably contains some absorption effects. A surprising characteristic of the absorption profile for this source is its relatively low optical depth in both the local-velocity gas (-4.5 km s $^{-1}$) and in the two features in the range -20 to -30 km s $^{-1}$. No other low-latitude source in the present investigation or in the 41 sources investigated in Paper III shows such a low maximum optical depth. In fact, most of them have at least one absorption feature with $\tau > 1$.

It is well known that within 2 kpc of the Sun there are no prominent spiral-arm tracers at this longitude (Sher 1965; Bok, Hine, and Miller 1970). It is possible that the absence of extreme Population I objects is reflected in a somewhat lower abundance of interstellar gas; however, other sources in this longitude range (e.g., G285.3 -0.0 , G291.3 -0.7 , G291.6 -0.5) show large optical depths. The most likely explanation is that dense H I clouds in any given velocity range cover only one of the sources in the Carina Nebula. If this were the case, the measured optical depths would be diluted, thus accounting for the low observed values.

*e) G290.1 -0.8 (Fig. 2*e*)*

According to Shaver and Goss (1970) this radio source is nonthermal (NT); on the assumption that it is a supernova remnant its surface brightness leads to a probable distance of 3.9 kpc. The absorption profile (Fig. 2*e*) indicates that the source is at or beyond the tangential point at 3.4 kpc.

*f) G291.3 -0.7 and G291.6 -0.5 (Figs. 2*f*, *g*, *h*)*

Goss and Radhakrishnan (1969) have already discussed in detail single-dish observations and distance determinations for both G291.3 -0.7 (NGC 3576) and G291.6 -0.5 (NGC 3603). In addition to the earlier observations we present here interferometer

profiles for both sources. These new observations confirm the previously determined distances for the two sources, i.e., 3.6 kpc for G291.3–0.7 and 8.4 kpc for G291.6–0.5. The profiles are shown in Figures 2*f* and 2*g*. The interferometer profiles do not confirm the apparent absorption between +5 and +20 km s^{–1} in both single-dish profiles. For NGC 3603 the single-dish and interferometer profiles are otherwise in reasonable agreement; for NGC 3576 the interferometer absorption profile indicates a greater optical depth than obtained with the single-dish observation. These differences are presumably due to emission variations in the immediate neighborhood of the sources, combined with our inability to obtain four symmetrically disposed reference profiles for each source. Some idea of the variability of the H I emission in this region can be gained from Figure 2*h*, where we have plotted half the difference between the reference profiles for these two sources, which are separated by only 23'.

g) G292.0+1.8 (Fig. 2i)

This source of relatively high latitude has a nonthermal spectrum and an angular extent of 4'.8. Goss and Shaver (1970) discuss its surface brightness and, by assuming that it is a typical supernova remnant, obtain a distance of 7.9 kpc. The single-dish absorption profile (Fig. 2*i*) indicates no more than that the source is near or beyond the tangential point at 3.7 kpc. The H I gas seen in emission in the velocity range –10 to +10 km s^{–1} does not appear in absorption, although this gas is presumably quite close to the Sun. We conclude that the low optical depth in this velocity range is due to the high spin temperature of the gas.

h) G298.2–0.3 and G298.9–0.4 (Figs. 2j, k)

On high-resolution maps (e.g., Goss and Shaver 1970) these two sources appear to be part of the same complex of H II regions. Both sources have high positive recombination-line velocities. The H I absorption profiles (Figs. 2*j*, 2*k*) confirm the large estimated distances for both sources (~12 kpc). These two sources are among the most distant galactic sources known; they are presumably located in the far part of the Carina arm where this arm is no longer observed tangentially (Bok *et al.* 1970). The source G298.2–0.3 has a more positive recombination-line velocity than G298.9–0.4 (30.6 versus 24.2 km s^{–1}) and shows H I absorption to a higher positive velocity (~40 versus ~30 km s^{–1}). The interferometer absorption profiles for both sources show wide deep lines at ~–30 and ~+20 km s^{–1}. The source G298.2–0.3 has a separate feature at ~–10 km s^{–1} which is not evident on the G298.9–0.4 profile. The single-dish absorption profile for G298.9–0.4 shows a positive feature at ~+40 km s^{–1}, indicating an emission excess of 20° K at the position of the source. This feature, due to H I at approximately 13 kpc from the Sun, must have an angular scale ≤15', corresponding at that distance to a linear size ≤60 pc.

i) G305.3+0.2 (Fig. 2l)

The complex of thermal sources G305.3+0.2 has been associated by various authors with RCW 74. However, it seems to us that RCW 74 is a foreground H α emission region having no connection with the radio source. From the H I profiles (Fig. 2*l*) it appears certain that the source is at or beyond the tangential point; when this assumption is combined with the H109 α velocity of –39.1 km s^{–1}, the resultant kinematic distance is 8.0 kpc.

As pointed out by Kerr and Kerr (1970), the longitude range near 305° is important in deciding between the two alternative spiral patterns proposed by Weaver (1970) and Kerr (1970). Weaver's interpretation places this group of sources in a small spur close to the Sun while Kerr's model places these sources in the tangentially observed part of the Sagittarius arm. The measured distance of 8 kpc would rule out a spur close to the Sun. Either the spur is quite distant or this prominent group of sources lies in the

far part of the Sagittarius arm beyond the tangential part at 5.7 kpc. (Note that at 8 kpc the Sagittarius arm is still observed more or less tangentially.)

j) G307.1+1.2 (Fig. 2m)

Shaver and Goss (1970) have advanced several reasons for concluding that this source is extragalactic. The angular size is $<1'$, and the continuum spectrum has a steep slope (-0.8). The absorption spectrum (Fig. 2m) indicates that the source is at or beyond the tangential point (6.1 kpc). Some of the contribution to the secondary emission feature at -3 km s^{-1} could be from gas situated near the solar circle at ~ 12 kpc. The weak absorption features at this velocity could therefore originate either at this distance or close to the Sun. However, all of the emission velocities near 52 km s^{-1} must arise in gas at a distance of approximately 16 kpc. At this distance the gas must be at least 300 pc above the galactic plane, and at least 500 pc above the centroid of the hydrogen density in this part of the Galaxy (Kerr 1969). Our interferometer profile shows that the optical depth at the velocity of this feature is less than 0.25. No significant conclusions concerning the distance of the source can be drawn from this limit to the optical depth; for the peak brightness temperature of the emission feature is less than 20° K , and any spin temperature greater than 80° K would reduce the optical depth of this gas to below the observed limit.

k) G309.7+1.7 (Fig. 2n)

Various authors (Milne 1969; Goss and Shaver 1970) have suggested that this high-latitude object is a Fornax-A type of extragalactic source. The profiles shown in Figure 2n are unusual in that no other source near the galactic plane shows such remarkable correspondence between the features on the emission and absorption profiles. All the velocities seen in emission also appear in absorption. The source is certainly beyond the tangential point at 6.5 kpc. In contrast to the previous source, the distant spiral arm at 16 kpc is no longer seen in emission at this latitude (1.7°). This is not too surprising, since the line of sight passes 500 pc above the galactic plane at that distance. For the same reason, we feel that the secondary emission feature peaking at -3 km s^{-1} originates in local gas and has no contribution from the far point at 13 kpc distance. Whatever its location, the brightness temperature combined with the optical depth suggests that all of the hydrogen seen in emission at that velocity is also seen in absorption.

l) G316.8-0.1 (Fig. 2o)

The $\text{H}109\alpha$ velocity of -36.1 km s^{-1} implies a distance of either 2.6 or 12.0 kpc. The absorption profiles in Figure 2o indicate that the source is at or beyond the tangential point, and hence the most likely distance is 12 kpc. This is in close agreement with the distance determined by Whiteoak and Gardner (1970) from H_2CO absorption measurements.

m) G326.2-1.7 (Fig. 2p)

Hill (1967) and Milne (1969) have investigated the continuum characteristics of this nonthermal source; assuming that the source is a typical supernova remnant, Milne (1970) derives a distance of 3.2 kpc. The single-dish absorption profile in Figure 2p is undoubtedly affected by the emission variations and is of marginal reliability. It has at least five components, of which the most negative velocity component (-44.4 km s^{-1}) is at a distance of 3 kpc. We consider this latter figure a lower limit to the distance of the source.

n) G326.6+0.6 (Fig. 2q)

Shaver and Goss (1970) have associated this H II region with four concentrations of nebulosity not listed in the Rodgers, Campbell, and Whiteoak (1960) catalog of $\text{H}\alpha$

emission. The H109 α velocity of -44.5 km s^{-1} implies a distance of either 3.1 or 13.6 kpc; the definite cutoff in the interferometer absorption profile at a velocity of -60 km s^{-1} (Fig. 2*q*) is strong evidence against any distance greater than 4 kpc. Our choice of the near distance alternative is at variance with that of Whiteoak and Gardner (1970), who chose the far distance based on an H₂CO absorption velocity of -60 km s^{-1} .

We did not consider the signal-to-noise ratio of the interferometer profile good enough to warrant an attempt at Gaussian fitting.

*o) G327.3-0.6 (Fig. 2*r*)*

The source RCW 97 is the optical counterpart of the radio source G327.3-0.6. The interferometer absorption profile (Fig. 2*r*) shows that absorption stops well short of the emission cutoff at $\sim -90 \text{ km s}^{-1}$. The most negative velocity component in the H I profile (-49.5 km s^{-1}) is in excellent agreement with the H109 α velocity (-48.8 km s^{-1}); hence the near distance of 3.4 kpc is most likely. Note the characteristic "jagged" appearance of the single-dish absorption profile in the velocity range -100 to -70 km s^{-1} as compared to the relative smoothness of the interferometer profile. This is due to the large variations in the H I emission originating near the tangential point in this direction.

*p) G331.5-0.1 (Fig. 2*s*)*

The source is associated with one of the strongest known OH emitters (Goss *et al.* 1970). Whiteoak and Gardner (1970), who have investigated the H₂CO absorption spectrum of this source, report a strong feature at -89.6 km s^{-1} . An H I feature is found at almost precisely this velocity (-89.5 km s^{-1}). Further, these authors find a wing extending to -105 km s^{-1} ; any possible H I counterpart of this wing would be masked by the severe variations clearly recognizable in Figure 2*s* at the negative-velocity end of the profile. Nevertheless, it seems to us that the last significant H I absorption feature is at -89.5 km s^{-1} and that the corresponding figure of 6.5 kpc is the best choice of distance for the source.

*q) G333.1-0.4 (Fig. 2*t*)*

OH emission is also associated with this source (Goss *et al.* 1970). The H I absorption profile (Fig. 2*t*) shows that the absorption stops well short of the cutoff velocity at $\sim -110 \text{ km s}^{-1}$. This, combined with the H109 α velocity of -55.8 km s^{-1} , implies a distance of 4.1 kpc. Whiteoak and Gardner (1970) arrive at a similar conclusion from a study of the H₂CO absorption spectrum of this source. We do not agree with the 13.4-kpc distance proposed by Wilson *et al.* (1970). The feature near 0 km s^{-1} Figure 2*t* could arise from real absorption, but cannot be unambiguously distinguished from the emission variations at the positive-velocity end of the absorption profile.

*r) G333.6-0.2 (Fig. 2*u*)*

This is yet another source associated with prominent OH emission (Goss *et al.* 1970). Whiteoak and Gardner (1970) have assigned a distance of 14.2 kpc based on an H₂CO absorption line at -84.4 km s^{-1} . No distinguishable line can be seen at this velocity in the H I absorption profile (Fig. 2*u*). Although the H I absorption terminates well short of the cutoff velocity (-115 km s^{-1}), it appears to extend to more negative velocities than that of the recombination line from the source; the last H I absorption feature is at -61 km s^{-1} whereas the H109 α velocity is -48 km s^{-1} . We attribute this discrepancy to peculiar motions in the H I, or the H II, or in both regions, and favor a near distance of 4-5 kpc for the source.

*s) G338.4+0.1 (Fig. 2*v*)*

The H109 α velocity of this H II region is -36.9 km s^{-1} . If one assumes strictly circular motions, this leads to a distance of either 3.2 or 15.4 kpc. The asymmetric continuum

distribution around this source necessitated using only three references (north, east, west) for the H I emission profiles. The resulting absorption profile shown in Figure 2*v* is clearly of only marginal reliability and poses a problem in interpretation. The strong absorption line at ~ -60 km s⁻¹ shows that there is a major H I feature with a radial velocity ~ 23 km s⁻¹ more negative than that of the H II region itself. However, we are unable to differentiate between true absorption and emission variations at velocities more negative than -80 km s⁻¹ and can assert only that the source is at a minimum distance of 6 kpc, assuming circular motions for the intervening H I. If the H II region is also in circular motion, its distance must then be 15.4 kpc.

V. SPIRAL STRUCTURE IN VELA-CARINA

In recent work (e.g., Bok *et al.* 1970) the importance of the longitude range 260°–305° in determining the spiral structure in the solar neighborhood has been discussed. Because of the low extinction in the 280°–300° range, the Carina spiral feature can be studied optically up to distances of 8–9 kpc. In this paper we have investigated 10 sources in the Carina region and discussed their distances. Five of these sources are optically identified with H II regions. In Figure 3 we have shown (as circles) the spatial distribution of these 10 sources and two sources in Vela from Paper III (G265.1+1.5 and G267.9–1.0). They clearly delineate the important Carina spiral feature. Since this feature is viewed tangentially, its extent along the line of sight varies from 2.7 to 9 kpc (because of peculiar motions there is an uncertainty of about 1 kpc in the distance). The two very distant sources (G298.2–0.3 and G298.9–0.4) at ~ 12 kpc must be located in the far portion of this spiral feature where it has bent over and is no longer observed tangentially.

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REFERENCES

- Beard, M. 1966, *Australian J. Phys.*, **19**, 141.
 Bok, B. J., Hine, A. A., and Miller, E. W. 1970, *I.A.U. Symposium No. 38*, p. 246.
 Day, G. A. 1971, *Australian J. Phys.*, *Ap. Suppl.* (in press).
 Gardner, F. F., Milne, D. K., Wilson, T. L., and Mezger, P. G. 1970, *Astr. and Ap.*, **7**, 349.
 Goss, W. M., Manchester, R. N., and Robinson, B. J. 1970, *Australian J. Phys.*, **23**, 559.
 Goss, W. M., and Radhakrishnan, V. 1969, *Ap. Letters*, **4**, 199.
 Goss, W. M., and Shaver, P. A. 1970, *Australian J. Phys.*, *Ap. Suppl.*, No. 14, p. 1.
 Hill, E. R. 1967, *Australian J. Phys.*, **20**, 297.
 ———. 1968, *ibid.*, **21**, 735.
 Kerr, F. J. 1969, *Ann. Rev. Astr. and Ap.*, **7**, 39.
 ———. 1970, *I.A.U. Symposium No. 38*, p. 95.
 Kerr, F. J., and Kerr, M. 1970, *Ap. Letters*, **6**, 175.
 Kerr, F. J., and Knapp, Gillian R. 1970, *Australian J. Phys.*, *Ap. Suppl.*, No. 18, p. 9.
 Manchester, R. N., Goss, W. M., and Robinson, B. J. 1969, *Ap. Letters*, **3**, 11.
 Manchester, R. N., Robinson, B. J., and Goss, W. M. 1970, *Australian J. Phys.*, **23**, 751.
 Milne, D. K. 1969, *Australian J. Phys.*, **22**, 613.
 ———. 1970, *Australian J. Phys.*, **23**, 425.
 Radhakrishnan, V., Brooks, J. W., Goss, W. M., Murray, J. D., and Schwarz, U. J. 1971, Paper I, this supplement.
 Radhakrishnan, V., Goss, W. M., Brooks, J. W., and Murray, J. D. 1971, Paper III, this supplement.
 Radhakrishnan, V., Murray, J. D., Lockhart, Peggy, and Whittle, R. P. J. 1971, Paper II, this supplement.
 Rodgers, A. W., Campbell, C. T., and Whiteoak, J. B. 1960, *M.N.R.A.S.*, **121**, 103.
 Rohlfs, K. 1971, *Astr. and Ap.* (in press).
 Shaver, P. A., and Goss, W. M. 1970, *Australian J. Phys.*, *Ap. Suppl.*, No. 14, p. 133.
 Sher, D. 1965, *Quart. J.R.A.S.*, **6**, 299.
 Weaver, H. 1970, *I.A.U. Symposium No. 38*, p. 126.
 Westerlund, B. E. 1960, *Ark. f. Astr.*, **2**, 419.
 Whiteoak, J. B., and Gardner, F. F. 1970, *Ap. Letters*, **5**, 5.
 Wilson, T. L., Mezger, P. G., Gardner, F. F., and Milne, D. K. 1970, *Astr. and Ap.*, **6**, 364.