

III. 21-CENTIMETER ABSORPTION MEASUREMENTS ON 41 GALACTIC SOURCES NORTH OF DECLINATION -48°

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ABSTRACT

Forty-one galactic sources north of declination -48° have been observed for 21-cm absorption by using the single-dish and/or interferometer methods. The difficulties encountered by both methods on sources in the galactic plane are discussed. Detailed notes are presented for each source, together with the reference emission and absorption profiles and tables summarizing all the data.

I. INTRODUCTION

This is the third paper in a series on measurements of 21-cm absorption in the spectra of discrete sources. Paper I dealt with the Parkes hydrogen-line interferometer; Paper II, with measurements on extragalactic sources. All the sources in Paper II had values of $|b|$ greater than 6° , and only a minority of them showed unambiguous 21-cm absorption. In this paper we describe measurements on 41 galactic sources, most of which are situated at very low galactic latitudes. Thirty-one of them are within 1° of the galactic equator, and five more are within 2° . The consequent increase in the measured optical depths is dramatic. In the case of the extragalactic sources of Paper II, all the hydrogen seen in emission in the direction of a source could be assumed to be in the path of its radiation. With galactic sources, on the other hand, only a fraction of the hydrogen in the direction of the source might lie between the Sun and the source. Nevertheless, our observations suggest that, irrespective of the distance to the source, the optical depth at some velocity is greater than unity. The precise measurement of this optical depth, however, poses major difficulties that arise from a variety of causes.

II. MEASUREMENT DIFFICULTIES

We shall consider some of these difficulties, starting first with single-dish observations. As described in Paper II, profiles are obtained in the direction of the source and in directions one full beamwidth ($15'$) away to the north, south, east, and west. The four off-source profiles are then averaged to give the reference emission profile. Subtraction of this average from the on-source profile gives the absorption profile. In the figures showing the results for each source these two derived profiles have been labeled "emission" and "absorption," respectively, although each may contain some effects of the opposite type. A profile labeled "difference," representing half the difference between the north-south and east-west averages, is also shown for most sources. This profile provides some idea of the errors to be expected in the "absorption" profile due to nonlinear gradients of the hydrogen emission in the region of the source. If the gradients at each frequency are absolutely linear, the "difference" profile will not depart from zero by more than the noise. In some cases where the variation of emission with position can be seen directly, we have shown all four emission profiles obtained at the reference positions. In the case of weak sources it is difficult to separate true absorption from emission variations, and in the case of strong sources it is difficult to distinguish between moderate and high optical depths.

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An example of the emission variations is shown in Figure 1. We have followed the usual procedure for a source at the position $l = 293^\circ 0$, $b = 0^\circ 0$. There is in fact no source at this position, but the variations produce an "absorption" profile not too unlike many obtained at the positions of weak sources. This region was picked for its absence of continuum radiation and with no knowledge of the emission structure there. It may therefore not be representative of the worst situations that could be encountered. Its implications should be borne in mind when examining any of the single-dish profiles presented in this paper or in other publications of 21-cm absorption measurements.

a) Complex Sources

Where the source is one of a complex distribution of sources, it is difficult, if not impossible, to find suitable reference regions situated symmetrically about the source. In these cases we have attempted to make the best possible approximation to a symmetric distribution of reference regions. Most of the observations relied heavily on a detailed knowledge of the structure of the continuum sources as revealed by surveys with far greater resolution. Where such surveys have shown the continuum source under investigation to be small, we have sometimes used the beam "slope" method. In this method profiles are obtained slightly off source, in directions which place the source at the top and bottom of the linear portion of the antenna beam pattern. The difference between these two profiles will show absorption effects proportional to the change in continuum antenna temperature between these two positions. The procedure can be repeated for pairs of points with different orientations to the source. By virtue of using the highest-resolution components in the antenna pattern this method provides better discrimination against the emission variations. Profiles were obtained this way for the double source W49.

b) Large-Diameter Sources

Sources of large angular diameter are the most difficult to observe. The increased separation between the reference regions makes the reference emission profile even less accurate than otherwise. If a strong source of small diameter is situated in a large source of relatively uniform continuum emission, reference profiles can be obtained in the usual manner by moving a beamwidth away from the small source. The so-called emission profile may include absorption effects from the large source, but the measurement of optical depth to the small-diameter source is still possible. The galactic-center source, Sgr A, is such a case.

c) The Interferometer Method

The interferometer method has been discussed in detail in Paper I. We mention here some special difficulties with its use on low-latitude galactic sources. The minimum spacing available with the Parkes interferometer was 120 m, and at this separation most galactic sources are partially resolved. If the opacity distribution is very nonuniform, as in the case of Orion A (Paper I), complicated responses may be obtained. All the interferometer observations reported in this paper were made with a north-south baseline. The majority of them were obtained close to transit at the minimum antenna separation of 120 m. For sources having large zenith angles at transit, the projected baseline was smaller and consequently more favorable.

Where several sources are grouped together in a complex, separated by less than the primary beamwidth ($18'.5$) of the interferometer, it is hard to discriminate against unwanted responses. Measurements were sometimes made off axis to attenuate preferentially an unwanted source less than a beamwidth away from the source under observation. In every case the relative phase of the line signal in each channel was monitored for deviations of the response from the expected one; no significant deviations were detected.

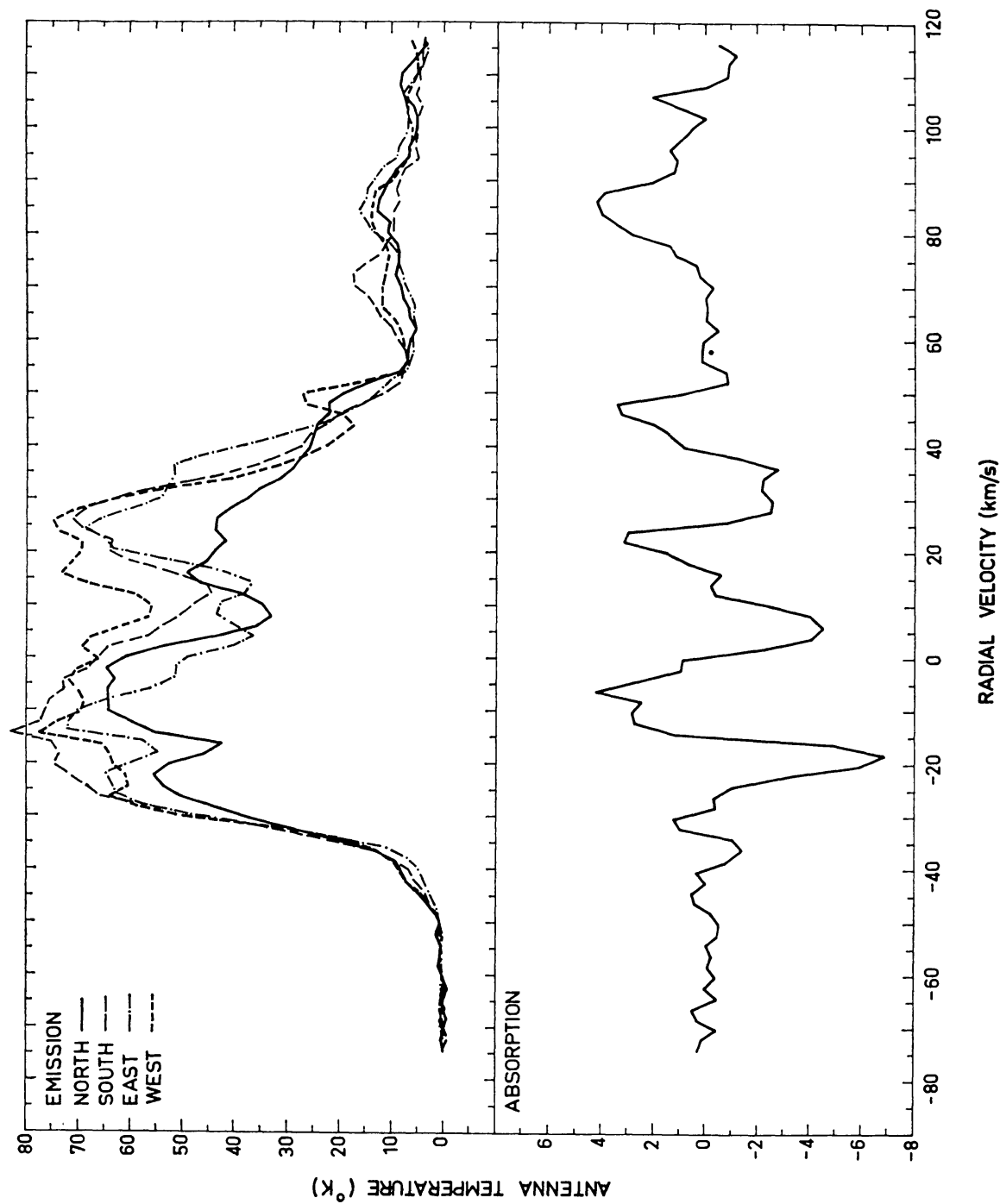


FIG. 1.—An “absorption” profile (*lower*) obtained at $l = 293^{\circ}0$, $b = 0^{\circ}0$, by subtracting the average of the four surrounding profiles (displaced by $15'$ north, south, east, and west) from the profile at this position. There is no continuum source at this position. The amplitude of the fluctuations in the lower profile gives some idea of the errors to be expected in single-dish absorption measurements in the galactic plane. Radial velocities are with respect to the local standard of rest.

Interferometer fringes from unresolved fine structure in the emission would have arbitrary phase angles with respect to those from the continuum source and can thus be distinguished. No signals significantly larger than noise with a phase measurably different from that of the source were found in any of the observations reported here. We therefore consider the interferometer profiles in this paper to be free of any residual responses from emission structure within the primary beam.

d) Selection of Type of Observation

A knowledge of the continuum structure was used in selecting sources for observation with either the single dish or the interferometer or both. In general it may be said that single-dish measurements were limited by confusion and the interferometer measurements by signal-to-noise ratio. In all cases where we obtained reasonable observations with both methods, we have placed greater reliance on the interferometer observations. Significant discrepancies between the results of the two methods may be due to problems with the single-dish measurements or to opacity variations across resolved sources. Future observations at other spacings should establish the true cause of the discrepancies. For the present we have assumed that partial resolution of the sources has not significantly affected the results. Some small-diameter continuum concentrations have been observed with the interferometer only. For these weak sources a determination of the absorption spectrum with the single dish would have been out of the question because of the large emission variations encountered in the galactic plane.

III. RESULTS

The results are presented in Figures 2–41. All radial velocities shown are with respect to the local standard of rest. Most of the observations were made with filters of width 2 km s^{-1} (9.5 kHz). In special cases we have made single-dish observations with narrower filters of width 0.21 km s^{-1} (1 kHz). For such sources the high-resolution profile follows the corresponding low-resolution one; the figures have the same number but are designated “a” and “b,” respectively.

The absorption profiles are always shown in the lower part of a figure. Where absorption profiles were obtained by both single-dish and interferometer methods, the profiles have been superposed and the scales of optical depth made to agree. The upper half of a figure shows emission profiles obtained at beamwidth away at points around the source position, or an average of these. The ordinate for all emission profiles is antenna temperature.

For weak sources with only interferometer absorption profiles, the left-hand ordinate indicates the relative intensity in the line as compared with that in the continuum. A relative intensity (line-to-continuum ratio) of -1 corresponds to total absorption ($\tau = \infty$), whereas 0 corresponds to no absorption ($\tau = 0$). A corresponding optical-depth scale is provided on the right-hand side as usual. For these weak sources the emission profile shown in the upper half of each figure was obtained by observing directly in the direction of the source with the single dish. Because of the low antenna temperature of the source, such a profile is a better approximation to the true emission spectrum in that direction than the average of profiles taken a beamwidth away from the source.

The sources observed are listed in order of increasing galactic longitude in Table 1, where column (5) denotes the type of source. Radial velocities measured in the 109α hydrogen recombination line are listed in column (6), with the appropriate reference number in column (7). Any known distance and its reference are given in columns (8) and (9), respectively. The antenna temperature of the source (or fraction thereof) used for the determination of the optical depth in single-dish measurements is listed in column (10), and whether a measurement was made with the single dish or with the interferometer is

indicated in column (13). Other absorption measurements on the source are listed in column (11) by the substance producing the spectral line, and the relevant references for them are in column (12). To facilitate finding the profiles we have listed the appropriate figure numbers in the last column.

Most of the single-dish observations have been made more than once and sometimes with different receivers. Two different antenna feeds have been used in the observations, but not all of the sources have been observed with both. The two feeds had slightly different aperture efficiencies. The ratios of flux density to antenna temperature for them were 1.5 and 1.66 flux units per degree. As described in Paper II, the conversion of antenna temperature to brightness temperature was determined by observations on the Moon; the antenna temperatures shown for the emission profiles in the various figures can be converted to brightness temperatures by multiplying by 1.25. The beam efficiencies of the two feeds agreed much more closely than their aperture efficiencies, and the conversion factor of 1.25 applies to all the measurements. Profiles obtained on the standard regions S8 and S9 recommended by the IAU are reproduced in Paper II for comparison with the brightness-temperature scales used by other observers.

IV. GAUSSIAN ANALYSIS

It is obvious from the appearance of most absorption profiles that they are composed of several features separated in velocity. It is natural to associate these components with different concentrations of hydrogen along the line of sight, and to attempt to separate them with a view to learning the characteristics of these concentrations. A convenient and traditional method of separating the components is to fit the sum of Gaussian functions of the optical depth to the profile. Although it is by no means clear to us that each concentration of hydrogen produces a Gaussian-shaped feature, we have nevertheless, as a first approximation, fitted Gaussian components to many of the absorption profiles by using a computer program. This has not been attempted on those profiles that we considered either too noisy or too complicated. From our observations we feel that there is no structure in either H I emission or H I absorption profiles that is not completely resolved with 1-kHz filters. On the other hand, the filter bandwidth used for most of the observations (9.5 kHz) is definitely too coarse, particularly for the absorption spectra. The number of Gaussians fitted to the profiles obtained with a bandwidth of 9.5 kHz is therefore a lower limit to the number of components that must exist. It is possible that even the components distinguishable with the 1-kHz filters are blends of closely spaced features with similar widths. If they are, they can no more be separated than the components making up an emission profile in the galactic plane.

The components of the Gaussian fit are indicated in the figures by crosses showing the peak optical depth and the width at half optical depth. As the plots are linear in temperature but not in optical depth, the appearances of the crosses vary one from the other. As a result of one or more of the errors discussed above, the single-dish absorption temperatures for some sources apparently exceed the antenna temperatures of the sources, i.e., the optical depth apparently exceeds ∞ . In these cases the absorption profile has been truncated before fitting, at an antenna temperature which is above that corresponding to infinite optical depth by the estimated noise. The values of the parameters obtained for the truncated features will, of course, be a strong function of the truncation and grossly in error. Where there are several features, this procedure enables a reasonable estimate to be made of the parameters for the other features in the profile not so severely affected by noise or emission variations. In Table 2, which lists the fitted Gaussians, we have indicated the truncated features by omitting the errors associated with all parameters other than the velocity.

EXPLANATORY NOTES TO FIGURES 2 TO 41
(excluding Figs. 15*b*, 15*c*, 15*d* [Pls. 1 and 2], and 38*f*)

Profiles have been designated emission, absorption, or difference, and have been obtained in the manner described in the text. In those figures depicting an absorption measurement made only with the interferometer (e.g., Figs. 9, 14*b*, 25*a*, 30, 34, 38*e*, and 39), the ordinate is relative intensity with a corresponding scale of optical depth at the right. In all other cases the ordinate is in units of antenna temperature with a corresponding scale of optical depth shown for absorption profiles. Where both types of absorption profiles have been superposed, the scales of optical depth have been made to agree. The frequency resolution used for the profiles shown in Figures 2*b*, 3*b*, 4*b*, 6*b*, 22*b*, 25*b*, 27*b*, and 31*b* was 1 kHz (0.21 km s^{-1}). In all other cases a resolution of 9.5 kHz (2.0 km s^{-1}) was employed. Gaussian components fitted to some absorption profiles are shown by crosses indicating the maximum optical depth of each component and its full width at half optical depth. In a few cases (Figs. 2*b*, 4*b*, and 6*b*) the sum of the computed Gaussians is plotted as a dotted profile to show the quality of the fit.

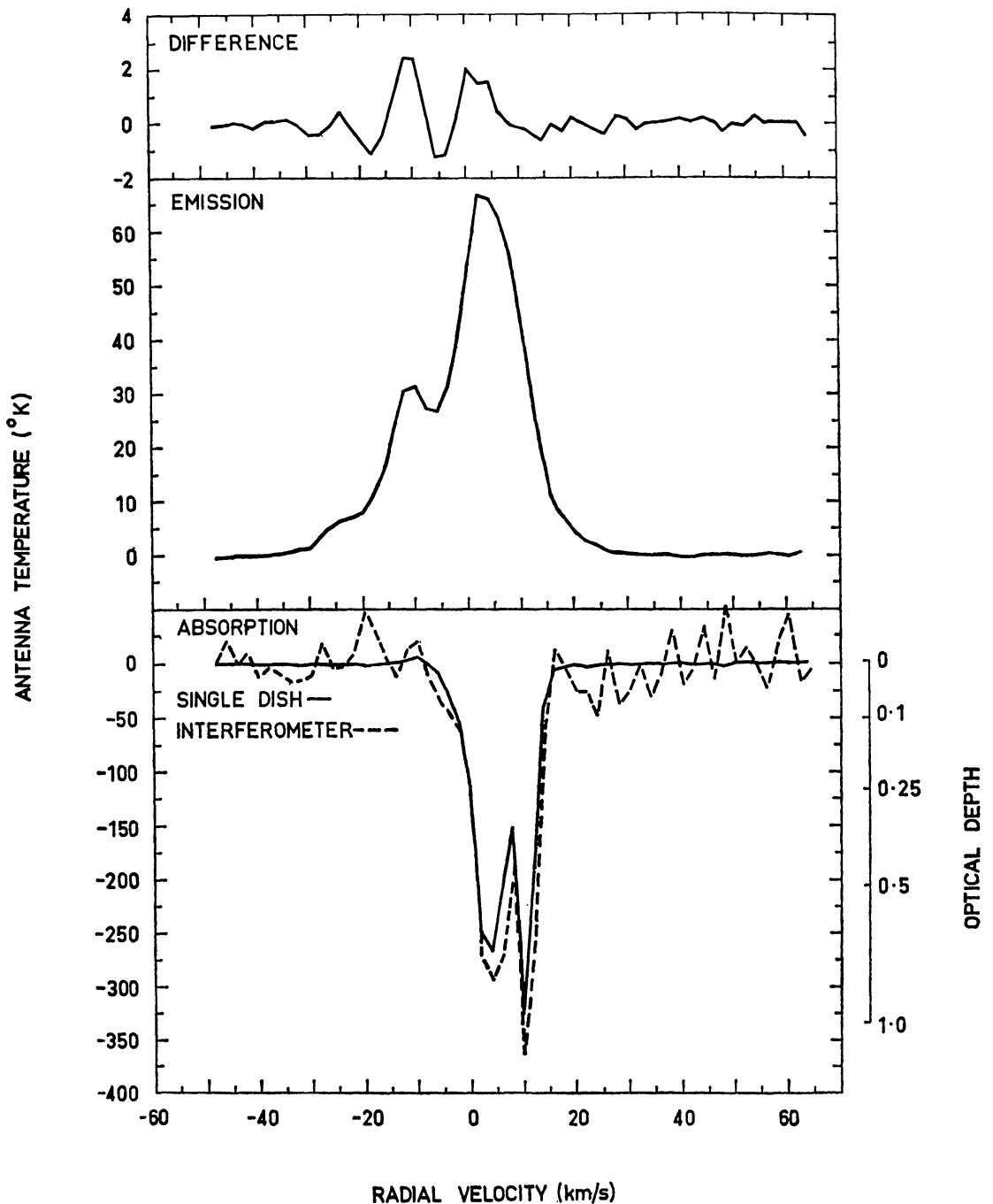


FIG. 2*a*.—Crab Nebula

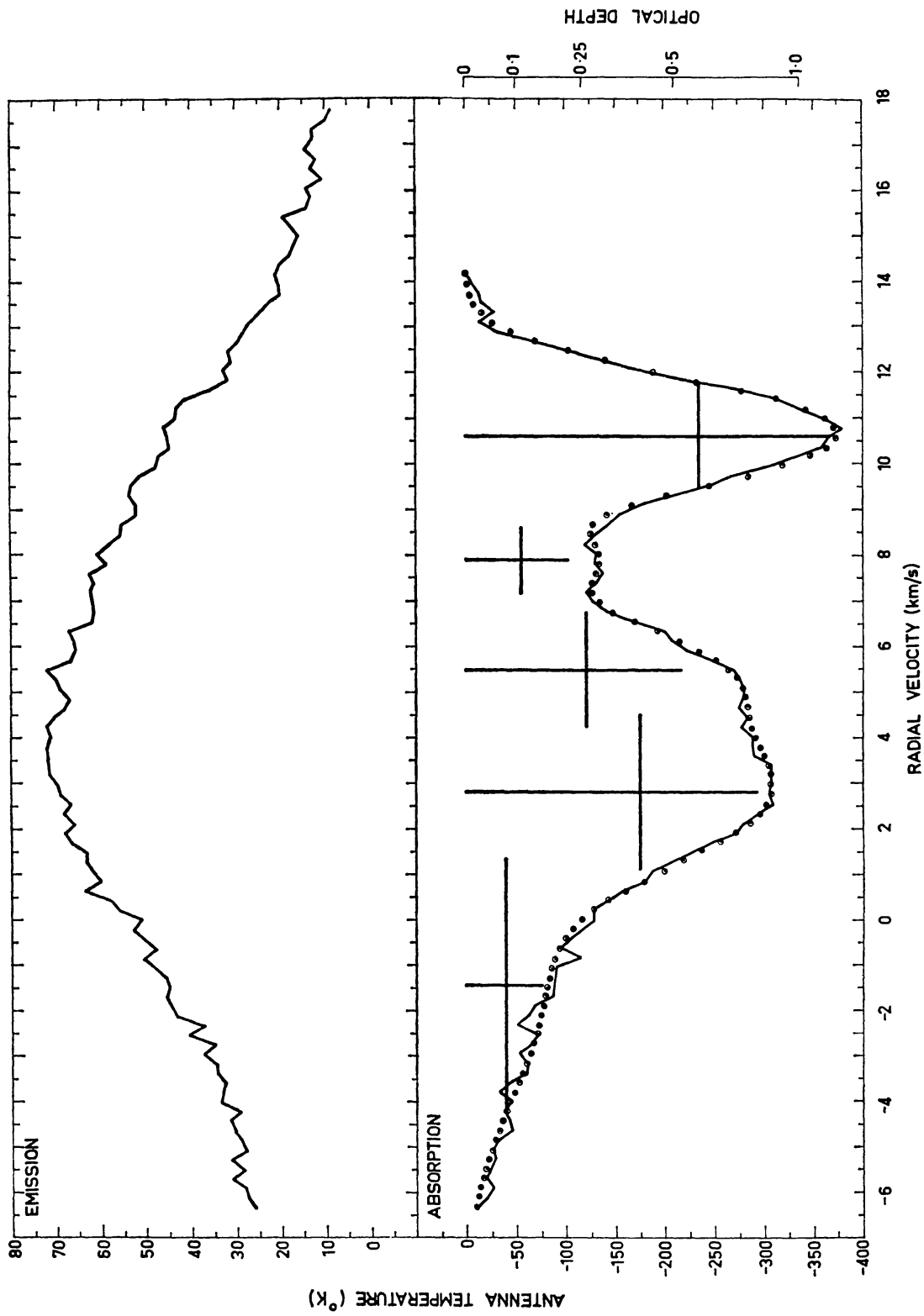


FIG. 2*b*.—Crab Nebula

The Gaussian components obtained from the calculation are listed in Table 2. The type of measurement is indicated in column (3). The mean radial velocity of the component is listed in column (4), together with its error. Column (5) shows the maximum optical depth of the feature, and column (6) the full width at half optical depth. For components with half-widths greater than twice the instrumental resolution, correction for bandwidth smoothing has been applied. In those cases where no correction has been attempted, the values are shown in brackets. Column (7) lists a quantity obtained by integrating under the component; it is equal to the column density of hydrogen divided by the spin temperature. In column (8) we have listed the column density of hydrogen obtained by multiplying the value in column (7) by an assumed spin temperature of 50°K for the absorbing clouds. The last column shows the kinematic distance corresponding to the radial velocity of the component in the standard galactic-rotation model. In some cases there are two possible distances, and the one that is less likely is enclosed in parentheses.

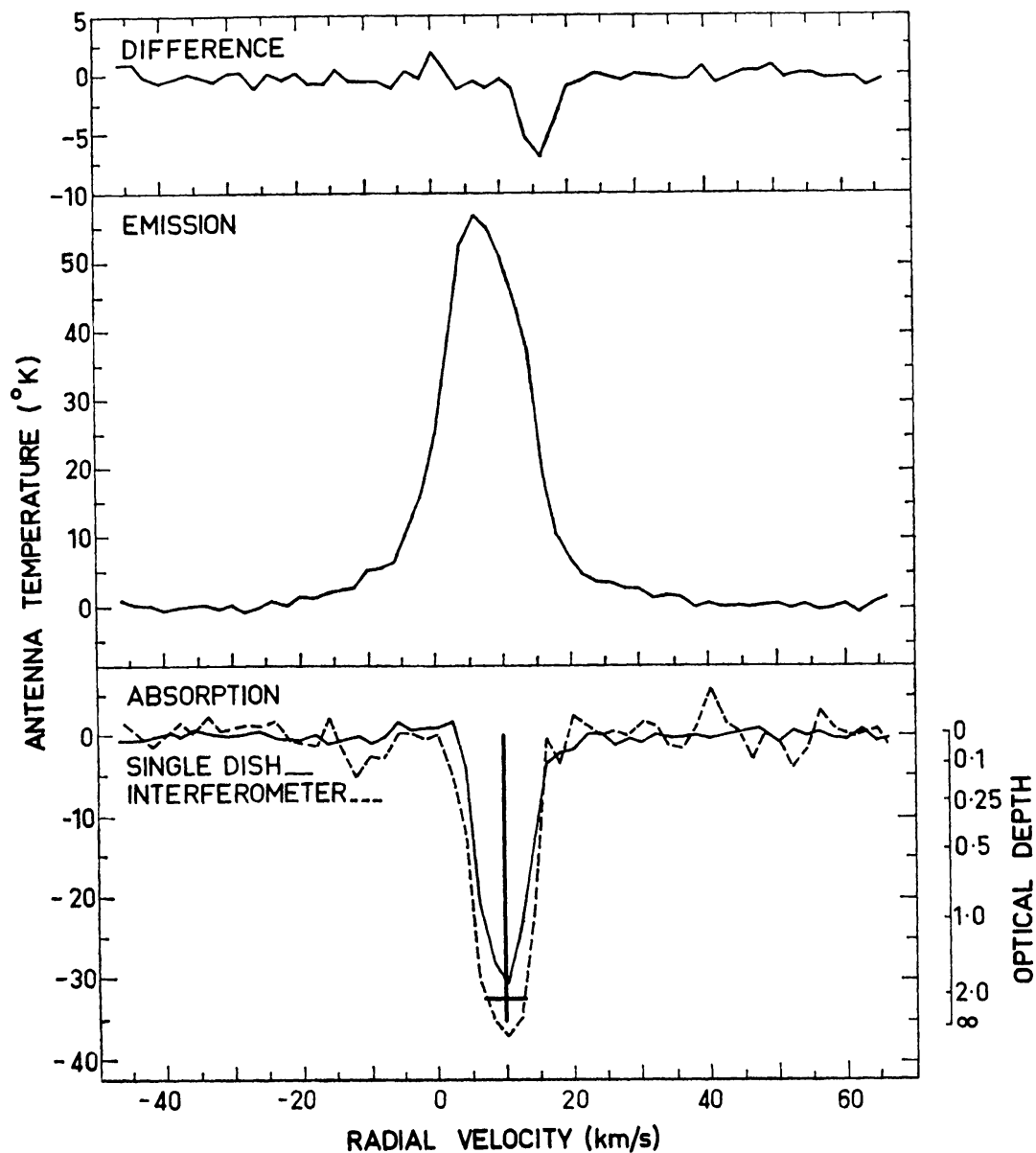


FIG. 3a.—W12

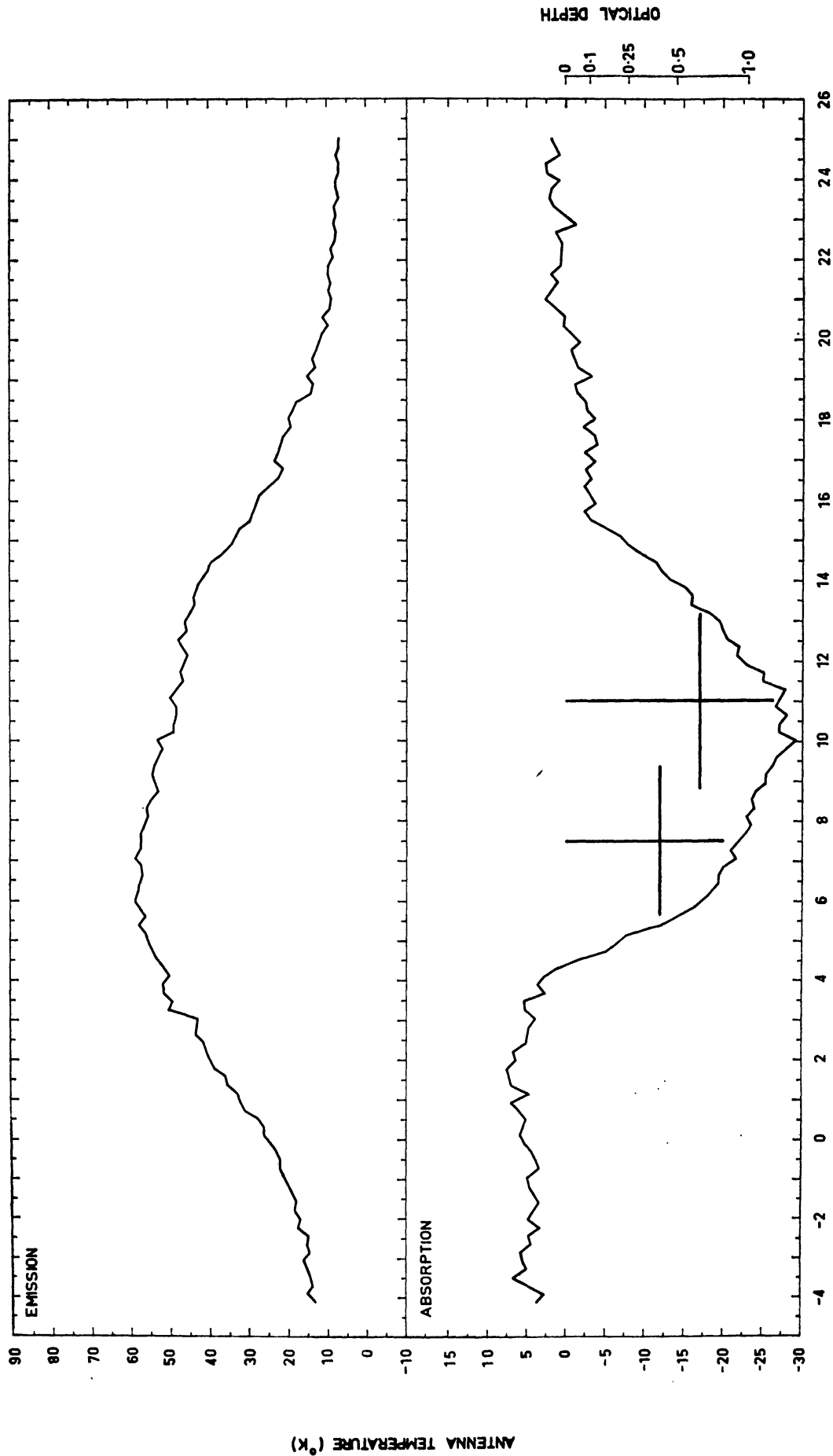


FIG. 3b.—W12

V. DISTANCE INTERPRETATION

A short discussion of the statistics of absorbing H I clouds in the galactic disk will be found in a note following Paper IV in this series. There we have combined all our measurements in the directions of galactic continuum sources to obtain estimates for the parameters characterizing them. The properties of the interstellar medium as deduced from the observations presented in this paper and in the other three of this series will be dealt with in a subsequent publication. Some points, however, must be mentioned here, since they play a part in the distance determinations for sources discussed in the notes in the next section.

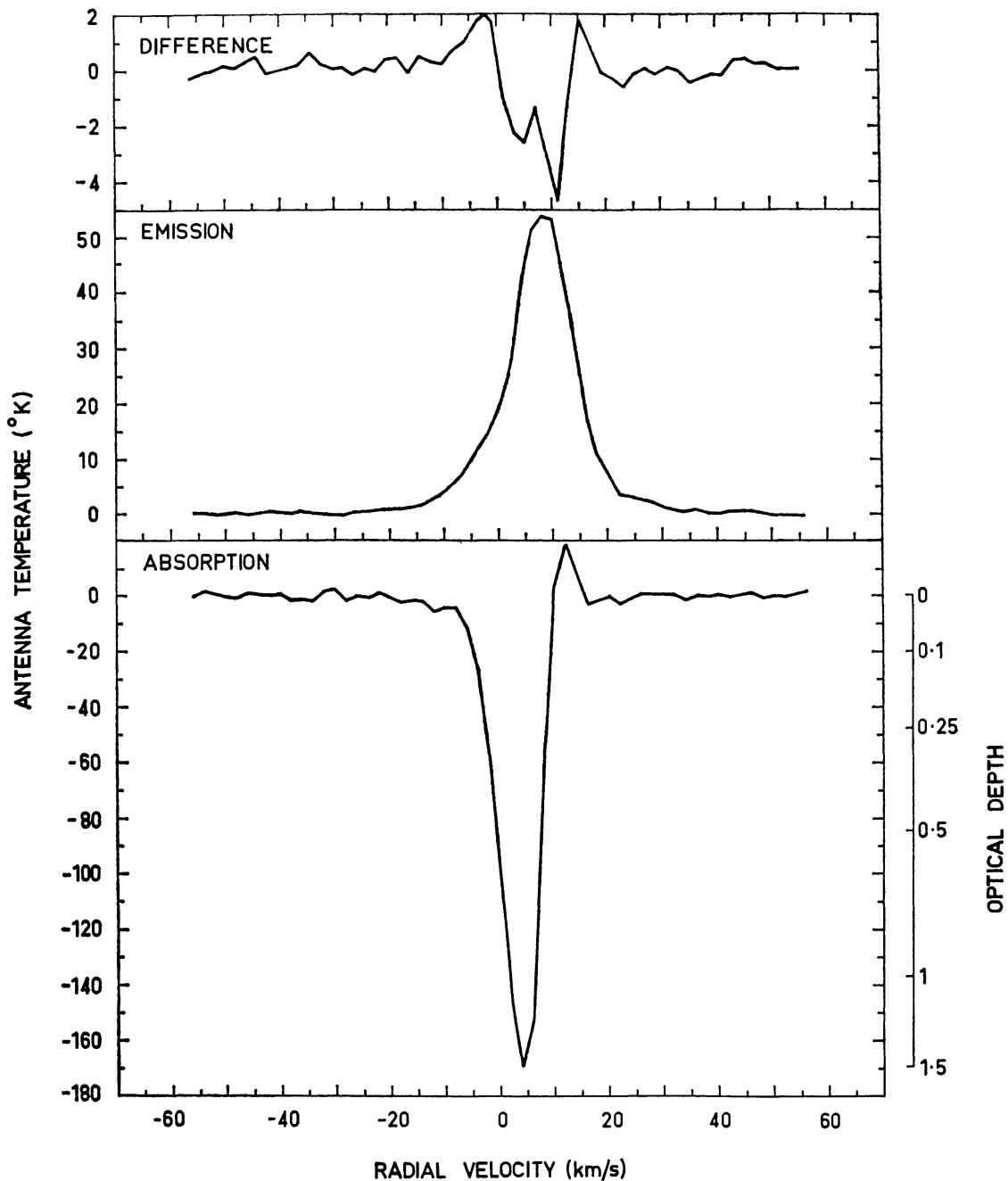


FIG. 4a.—Orion A

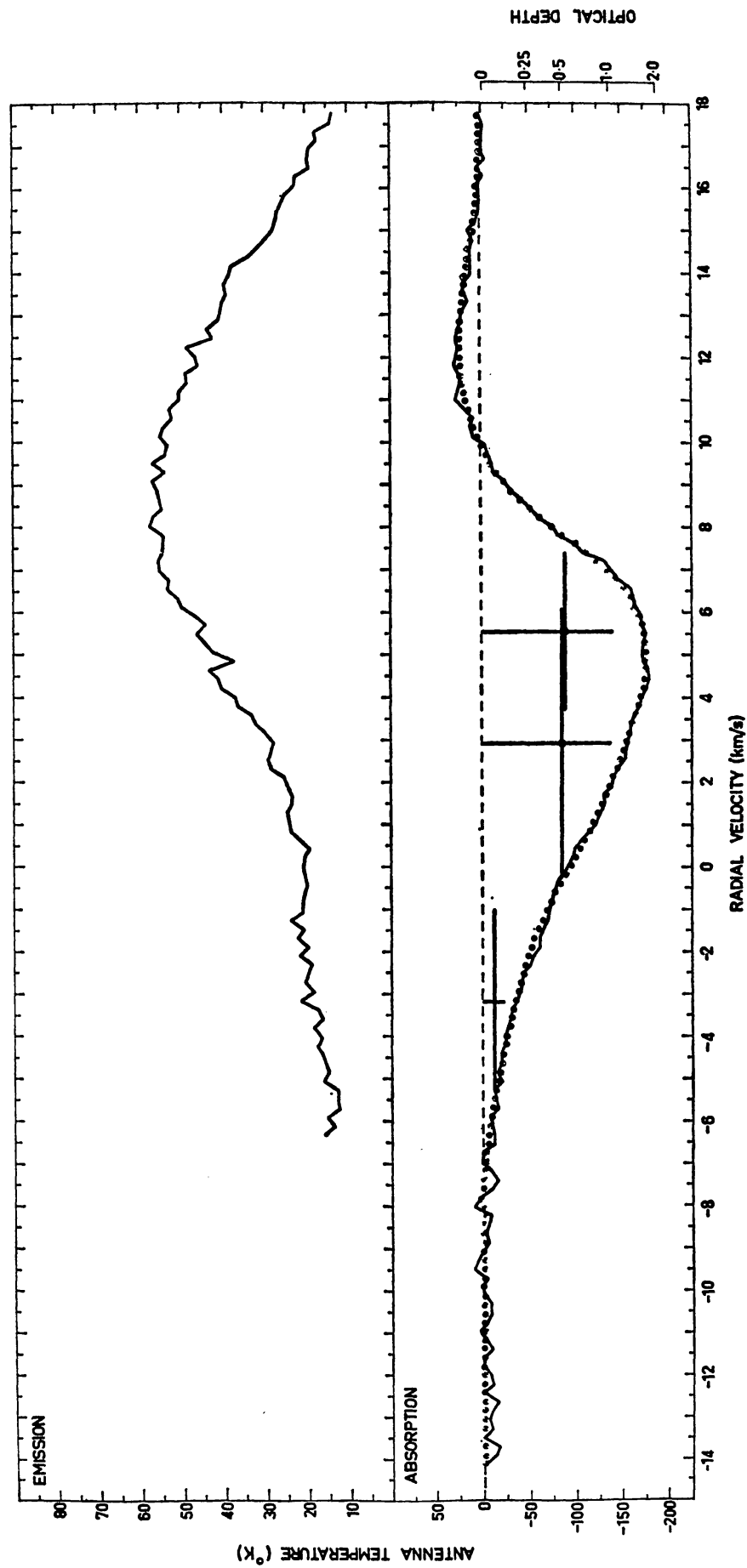


FIG. 4b.—Orion A

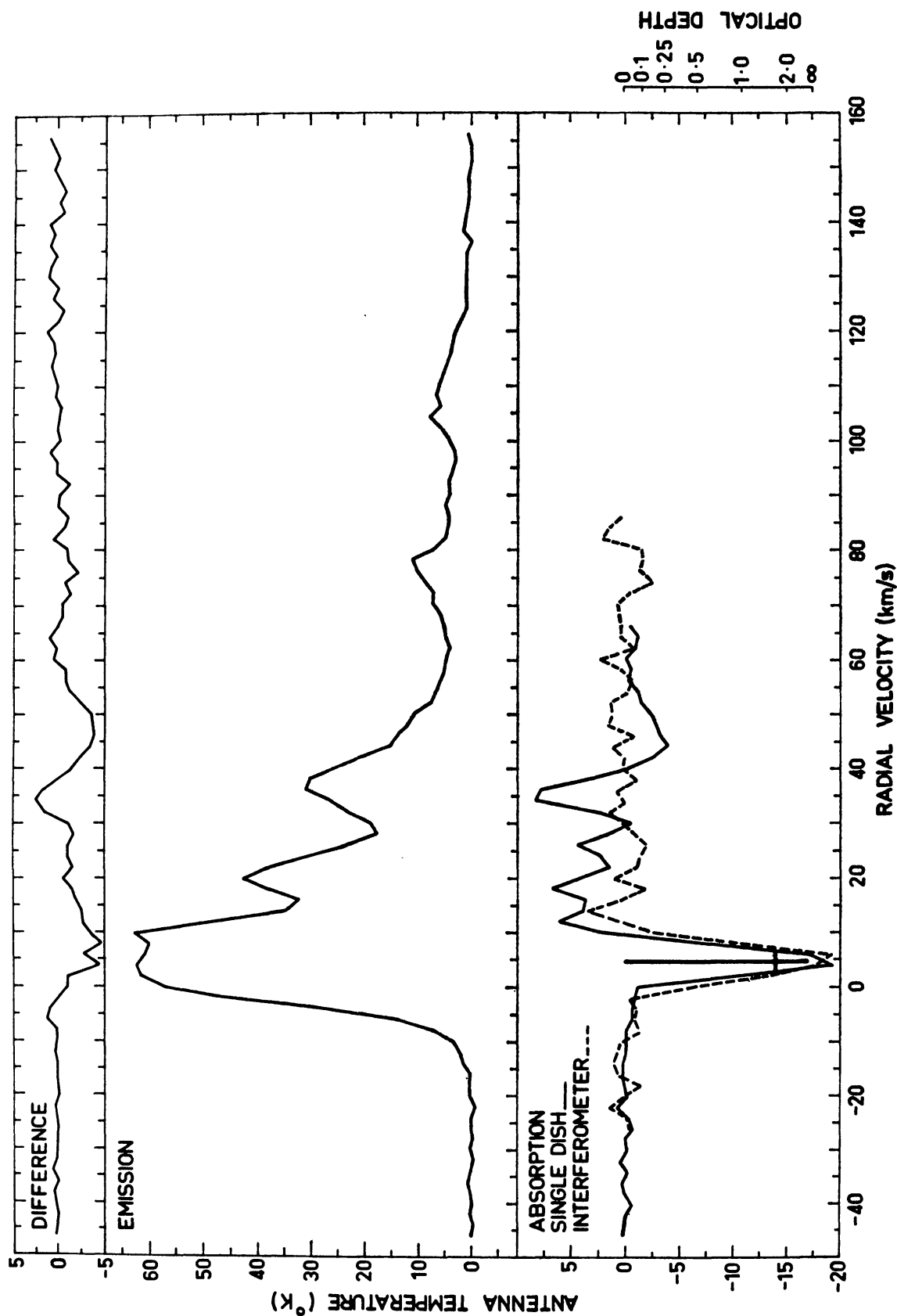


FIG. 5.—RCW 36

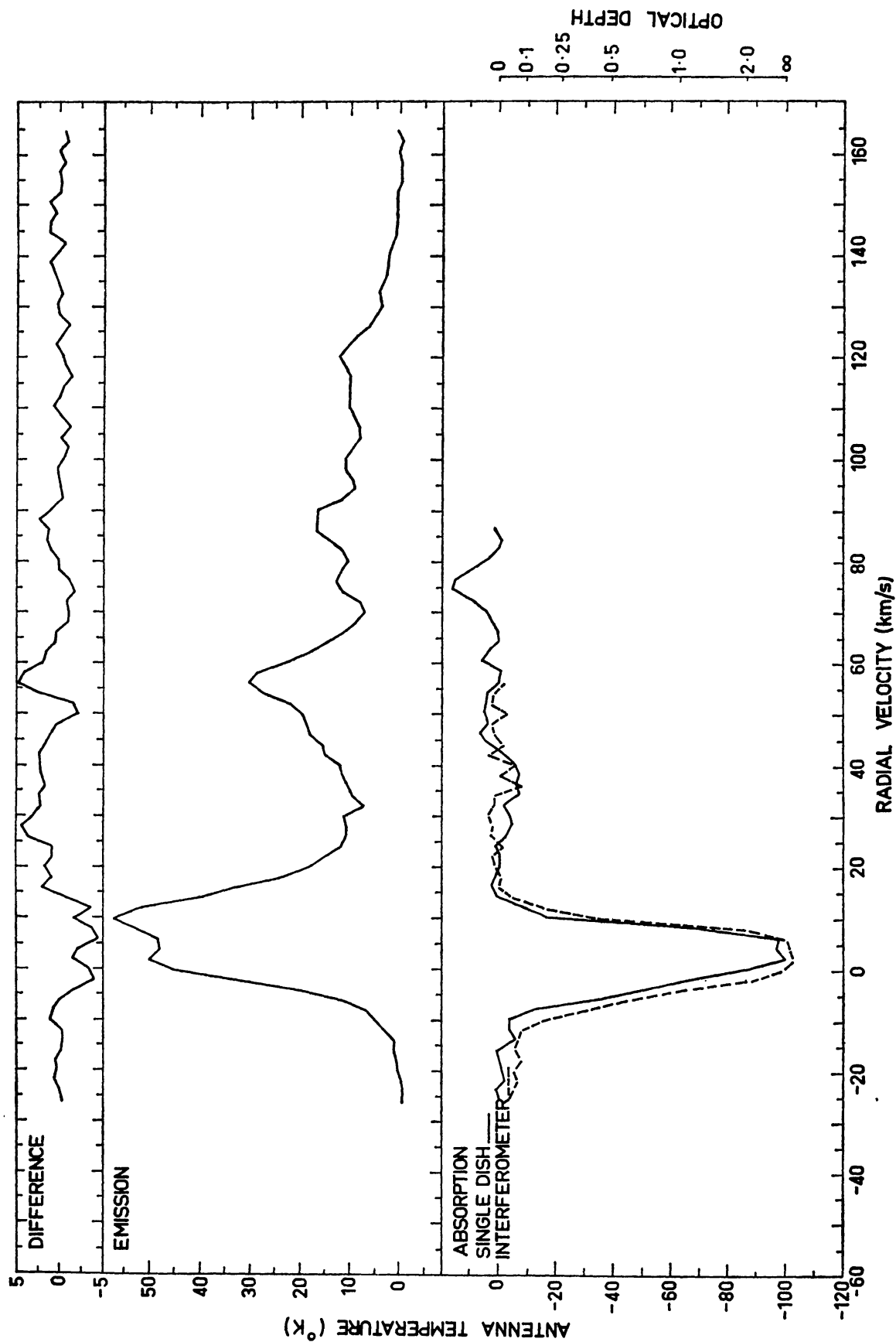


FIG. 6a.—RCW 38

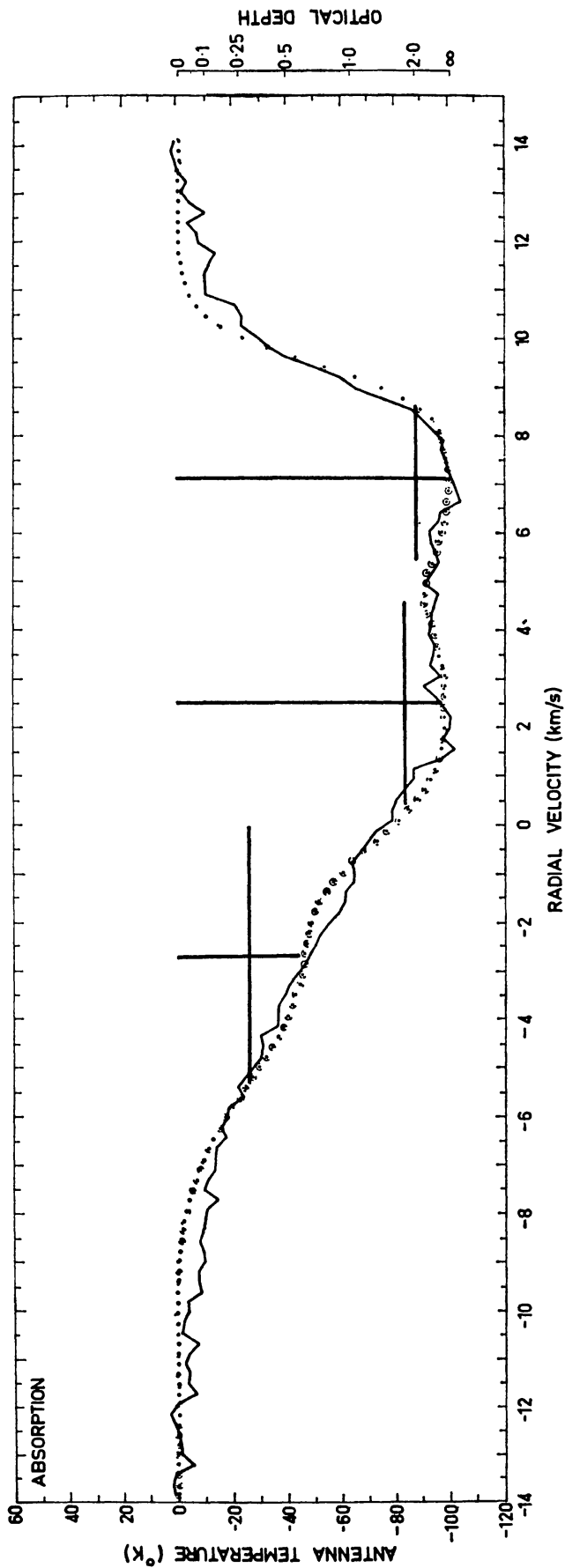


Fig. 6b.—RCW 38

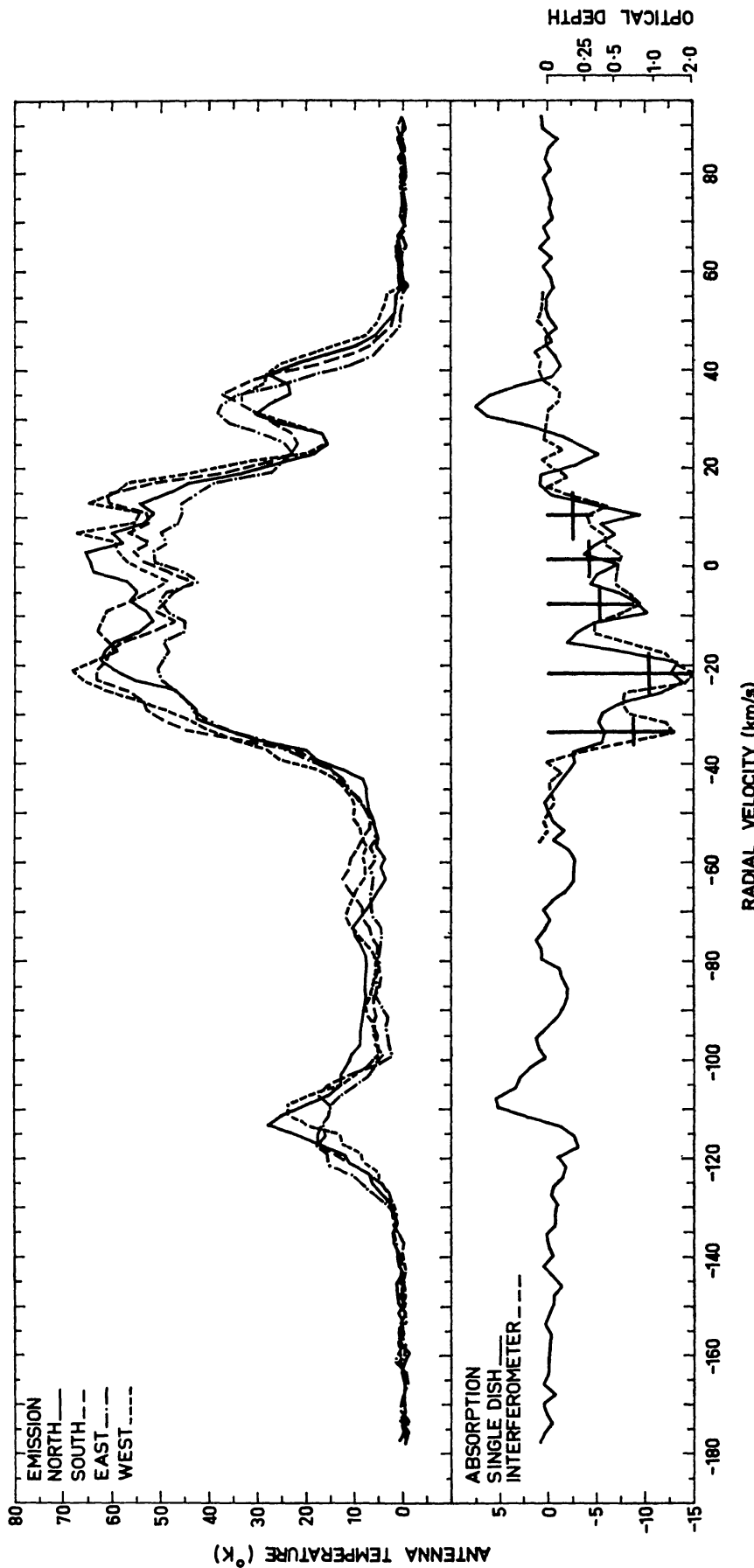


FIG. 7.—RCW 117

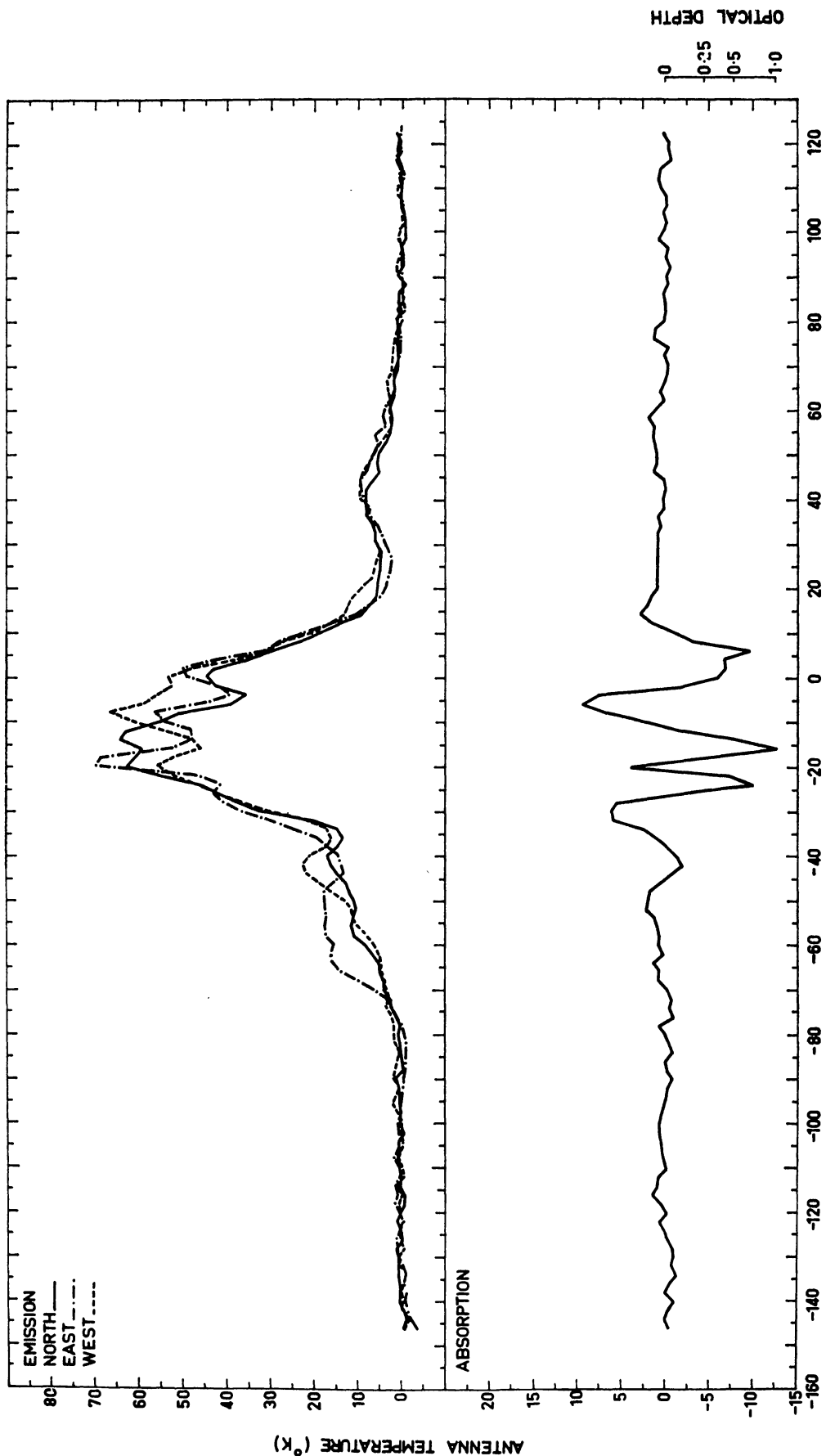


FIG. 8.—CTB 35A

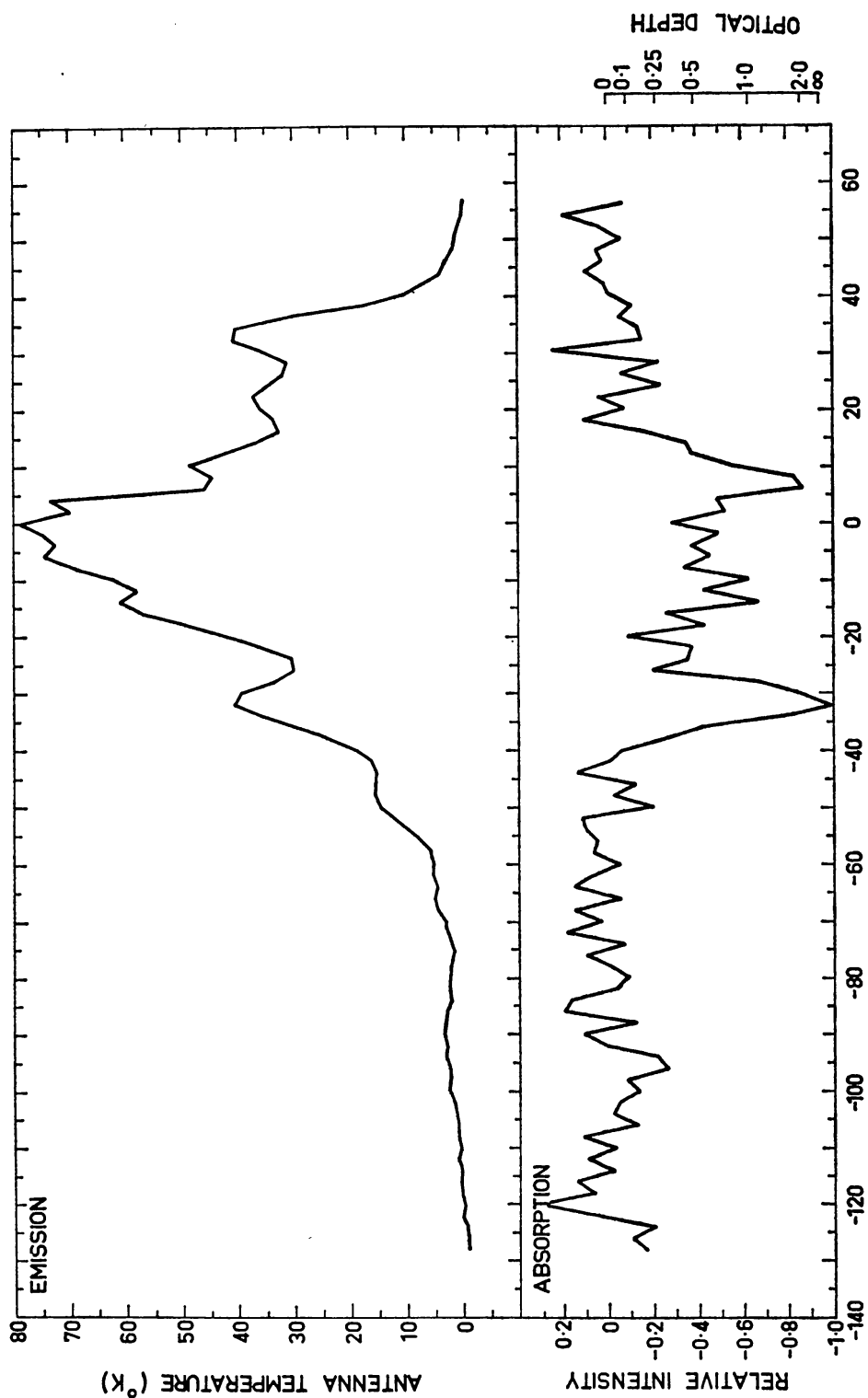
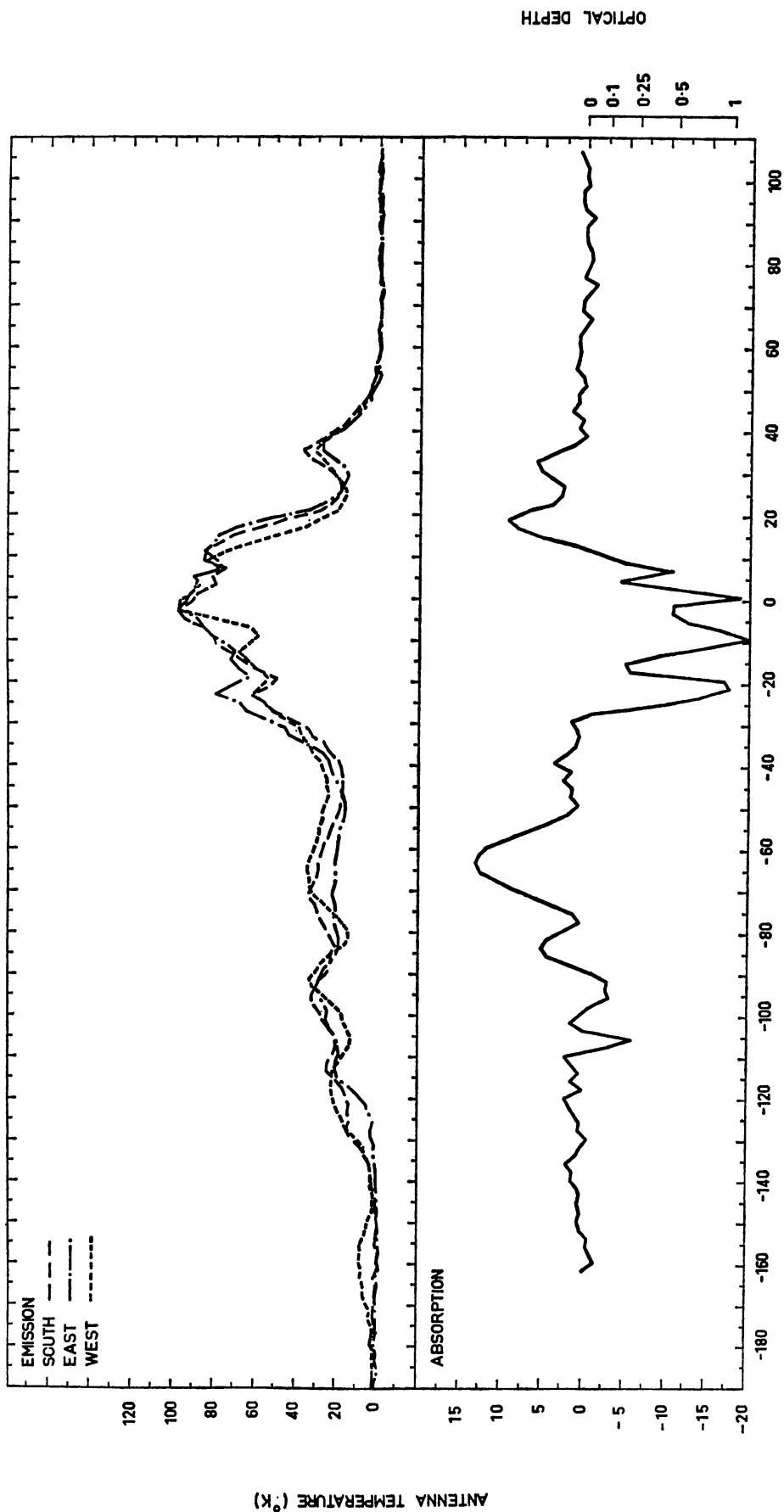


FIG. 9.—RCW 121



RADIAL VELOCITY (km/s)
FIG. 10.—CTB 37A

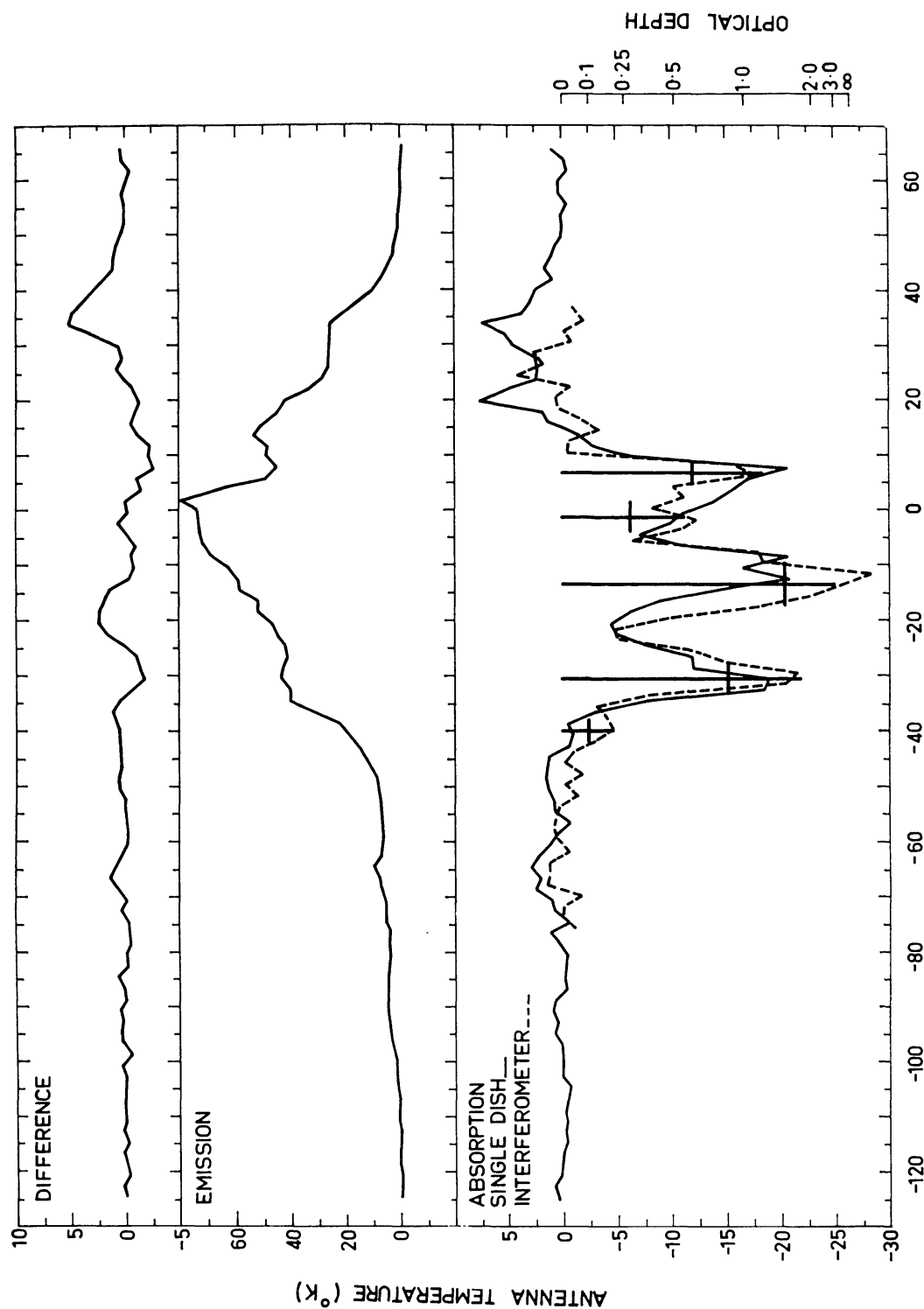


FIG. 11.—G348.7-1.0

It has hitherto been the philosophy in interpretation of 21-cm absorption spectra that they could provide no more than a minimum distance to the source. It was customarily argued that the source could be situated very much beyond the most distant absorbing cloud if the line of sight did not happen to intersect any more hydrogen clouds in the remaining distance. Our observations of galactic sources lead us to believe that this is very unlikely for sources *close* to the plane. If the line of sight occasionally traversed long path lengths without intersecting any clouds, occasional breaks should be observed in absorption spectra between their extreme velocities. Reliable interferometer measurements rarely if ever show this. It is necessary, of course, that the H I emission in this direction is unbroken and reasonably strong over the velocity range in question. If it is, we feel that for all but the weakest sources one can expect to find unbroken

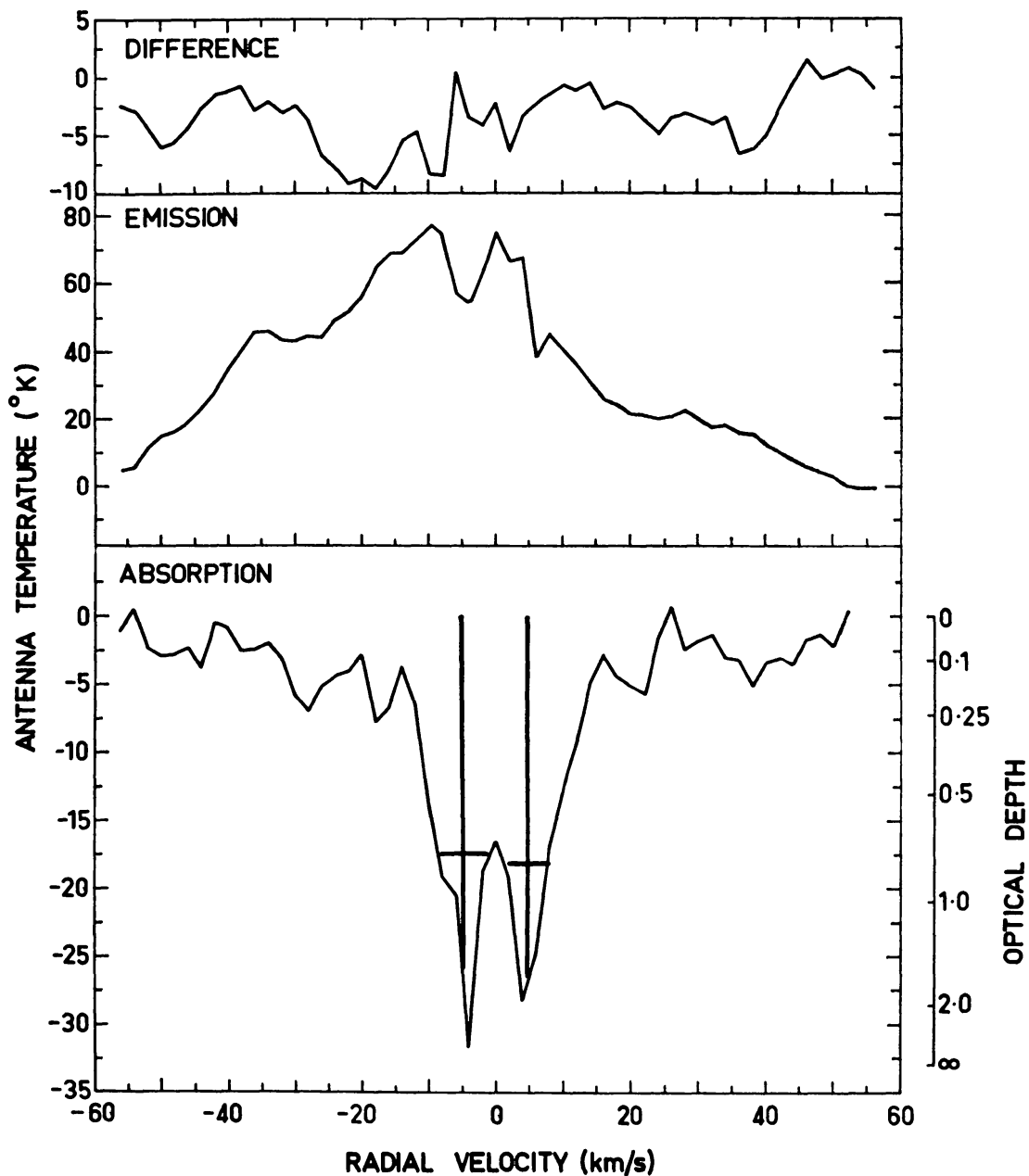


FIG. 12.—G351.1+0.7

measurable absorption to within a kiloparsec of the source. We have therefore very often equated the distance of the farthest absorption feature with that of the source.

A rare example of a good interferometer profile showing a complete break in the absorption at a velocity where the emission is strong can be seen in Figure 33. Between velocities of 30 and 50 km s^{-1} there is no absorption at all; this is almost certainly due to the fact that the emitting hydrogen at these velocities is located beyond the tangential point on the other side of the source.

Radial velocities determined from the $\text{H}109\alpha$ recombination line are often used to derive kinematic distances by assuming circular motion for the H II regions. Whenever possible, we have compared the distances deduced in this way with the kinematic distances deduced from the H I absorption data. In the case of several sources within $\pm 90^\circ$ of the galactic center the H I data helped remove the ambiguity in distance resulting from the recombination-line data alone. In many cases discrepancies between the two

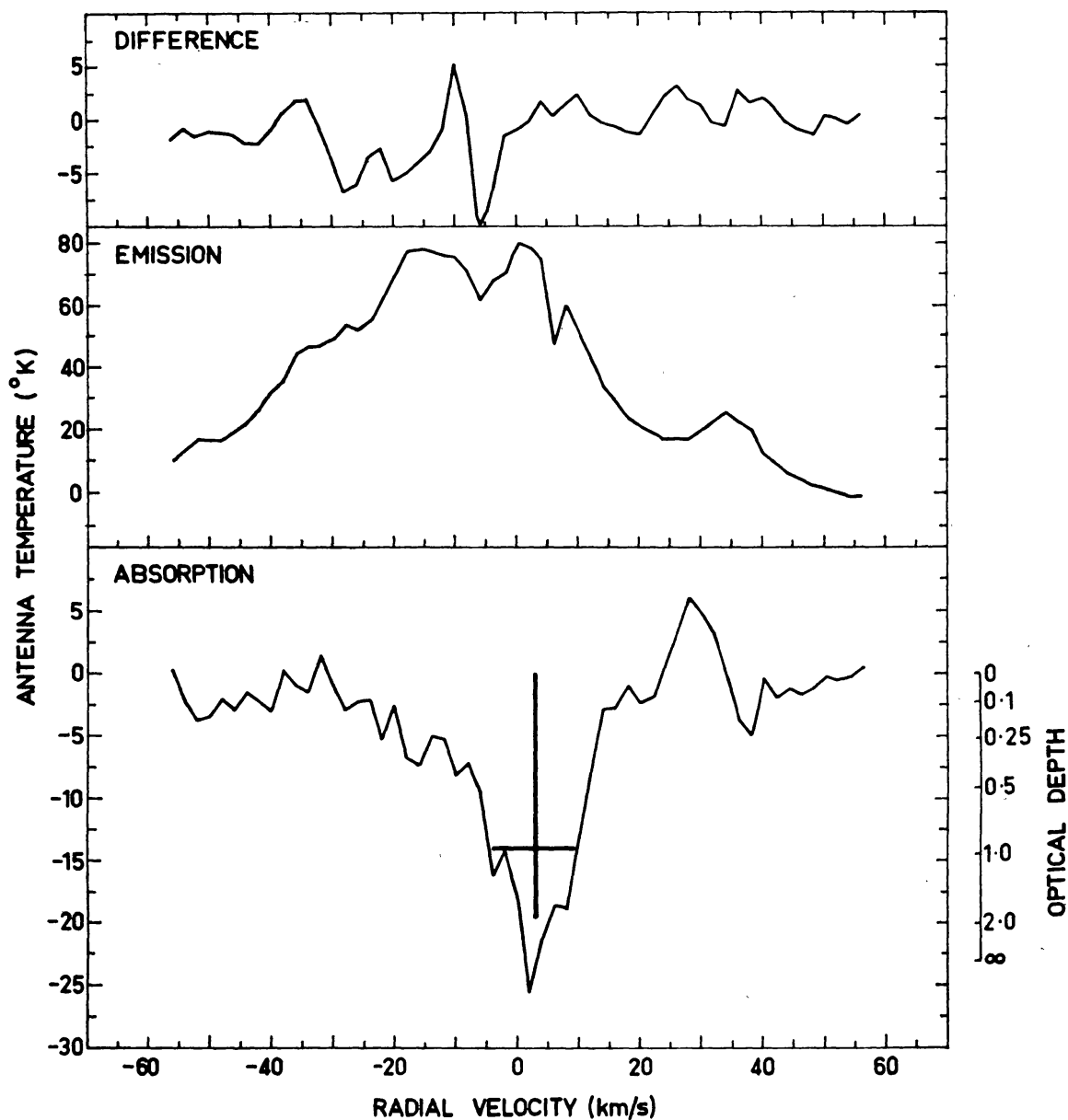


FIG. 13.—G351.2+0.5

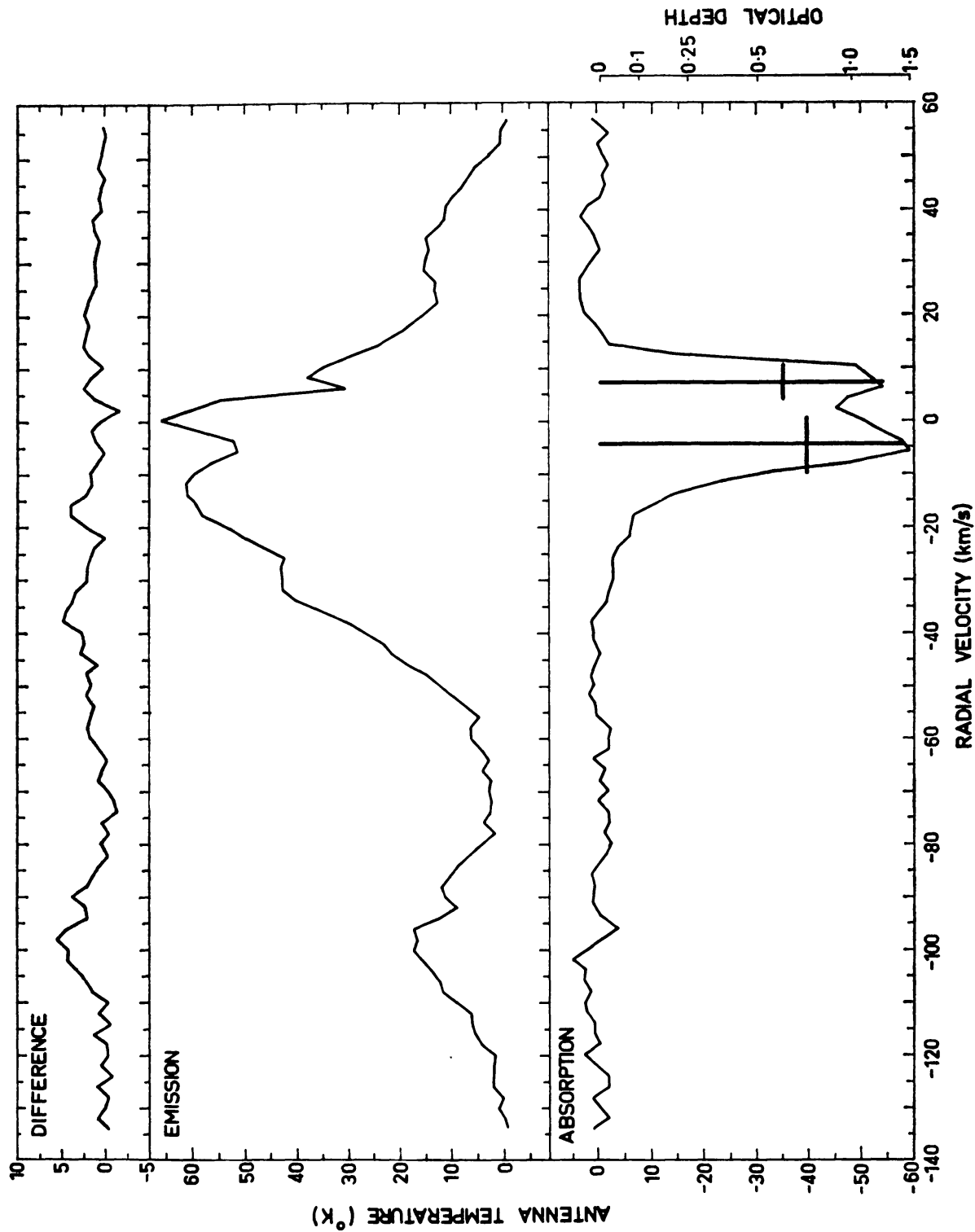


FIG. 14a.—G351.3+0.7

estimates suggest the prevalence of peculiar motions associated with the H I, H II, or both regions. Some extreme examples of this type are discussed in the notes to sources under G351.7-1.2. There we conclude that H II regions can sometimes have peculiar velocities of up to 30 km s^{-1} and that caution should be observed in determining distances from the recombination-line data alone.

VI. NOTES TO SOURCES

The observations presented in Figures 2-41 are discussed in brief in the following notes, where we deal mostly with distance determinations and aspects related to the source under discussion. In these notes we refer frequently to the work of some authors. For convenience, references to their work have been abbreviated as follows: Clark

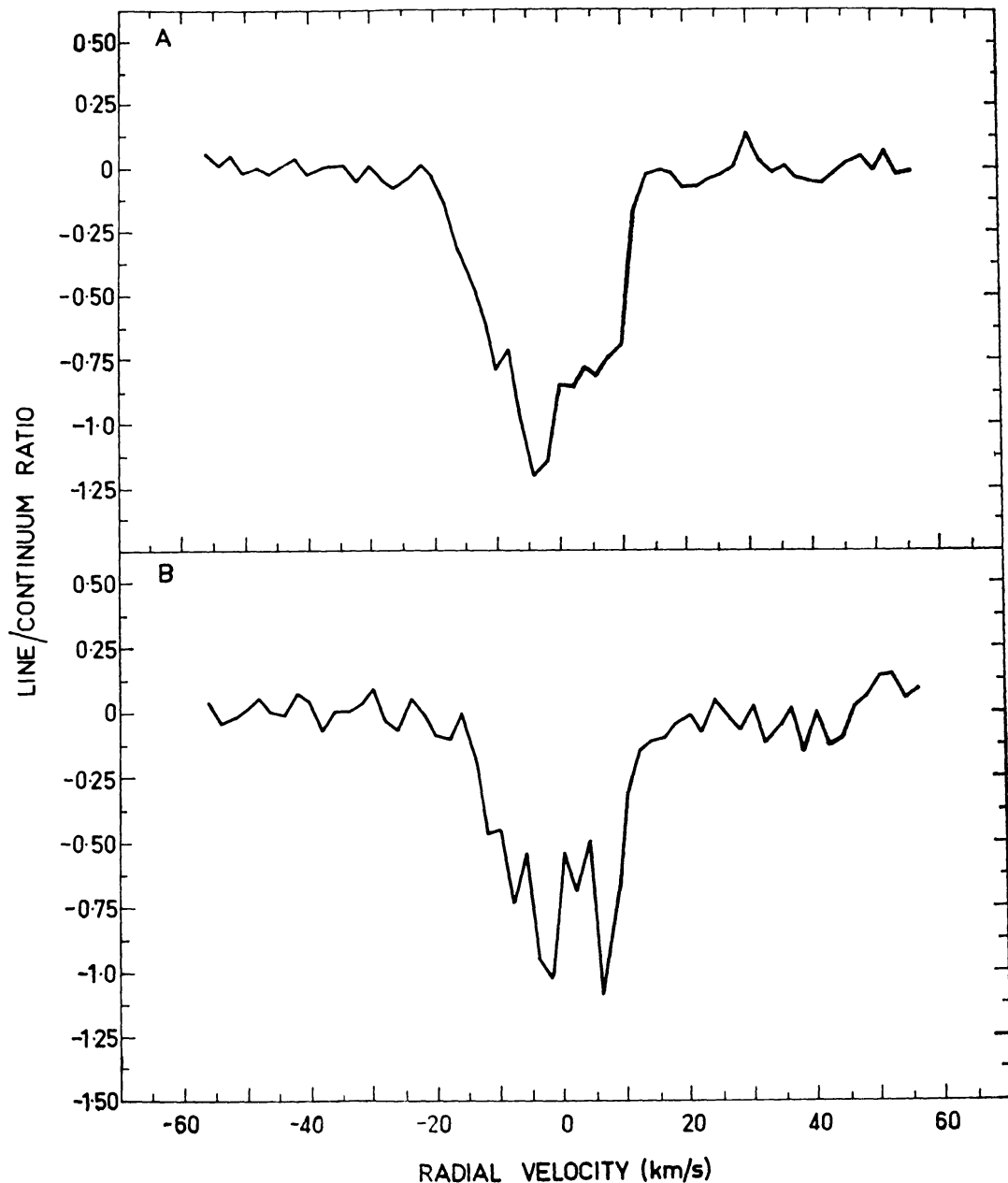


FIG. 14*b*.—Interferometer profiles of NGC 6334 A (*upper*) and NGC 6334 B (*lower*)

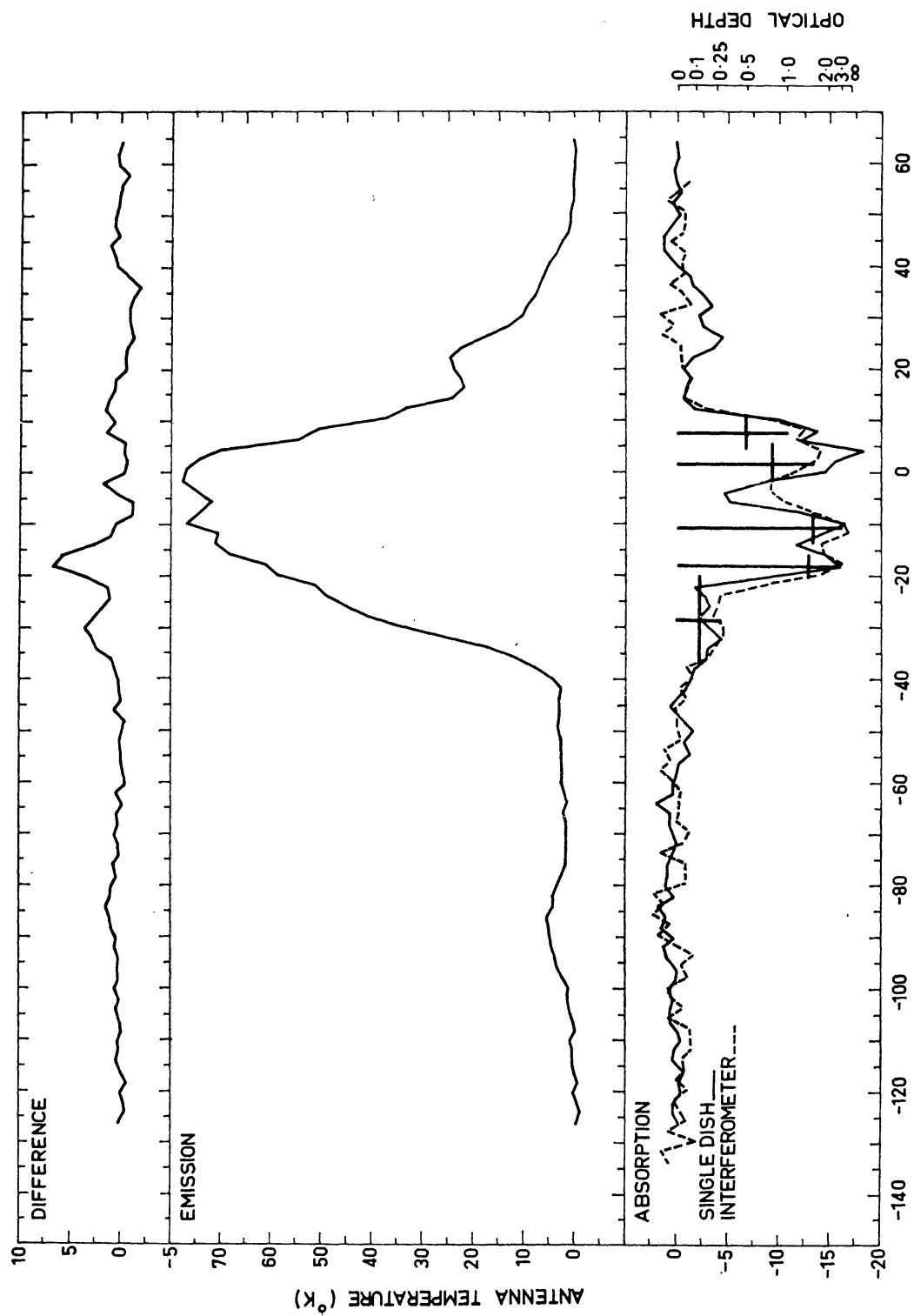
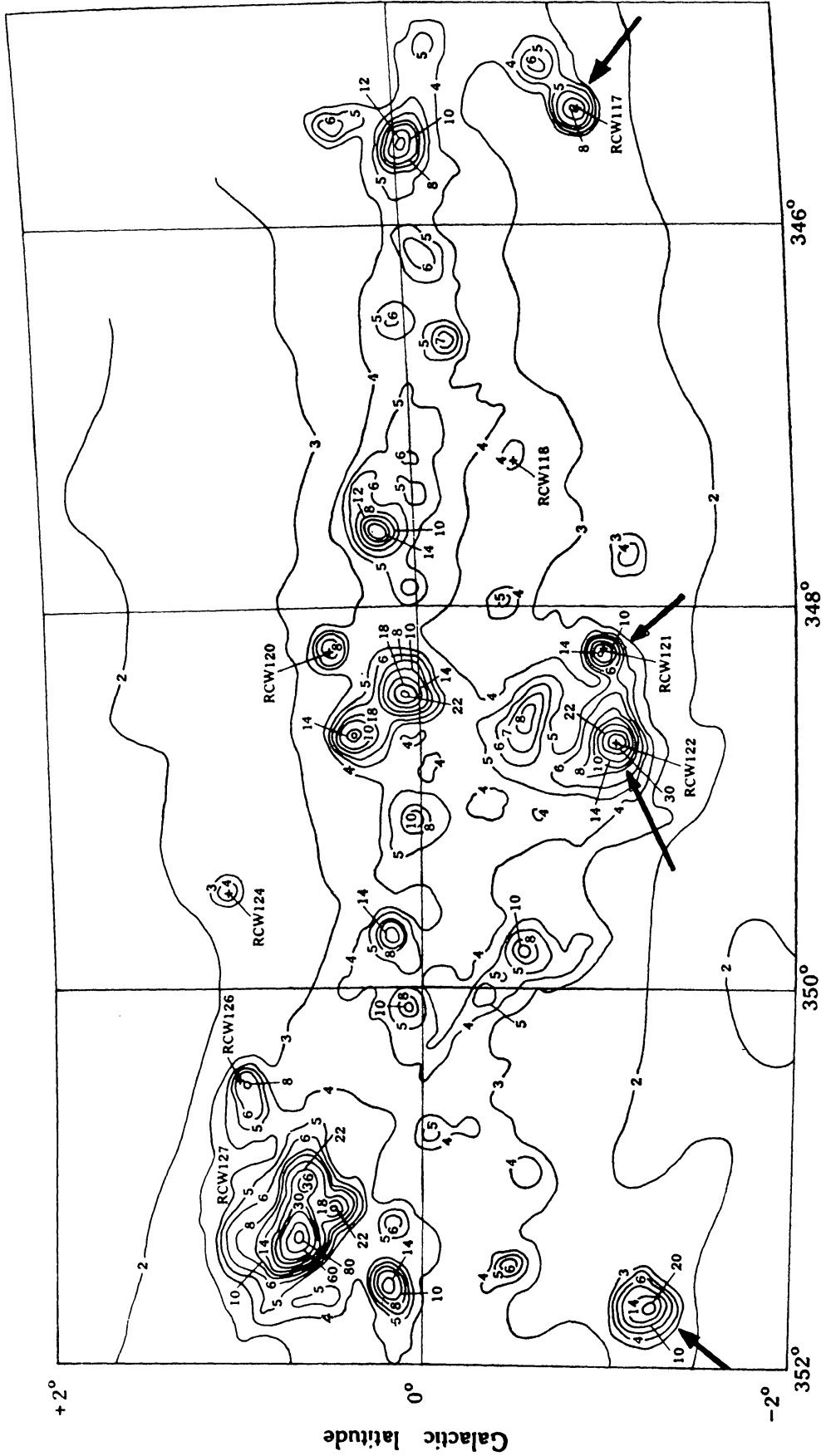


FIG. 15a.—G351.7-1.2



Galactic longitude

FIG. 15b.—The four distant H II regions RCW 117, RCW 121, RCW 122, and G351.7-1.2 are shown by arrows on the 11-cm contour map obtained by Beard *et al.* (1969). The half-power beamwidth is 7'.4, and the contour unit is 1.0° K of brightness temperature.

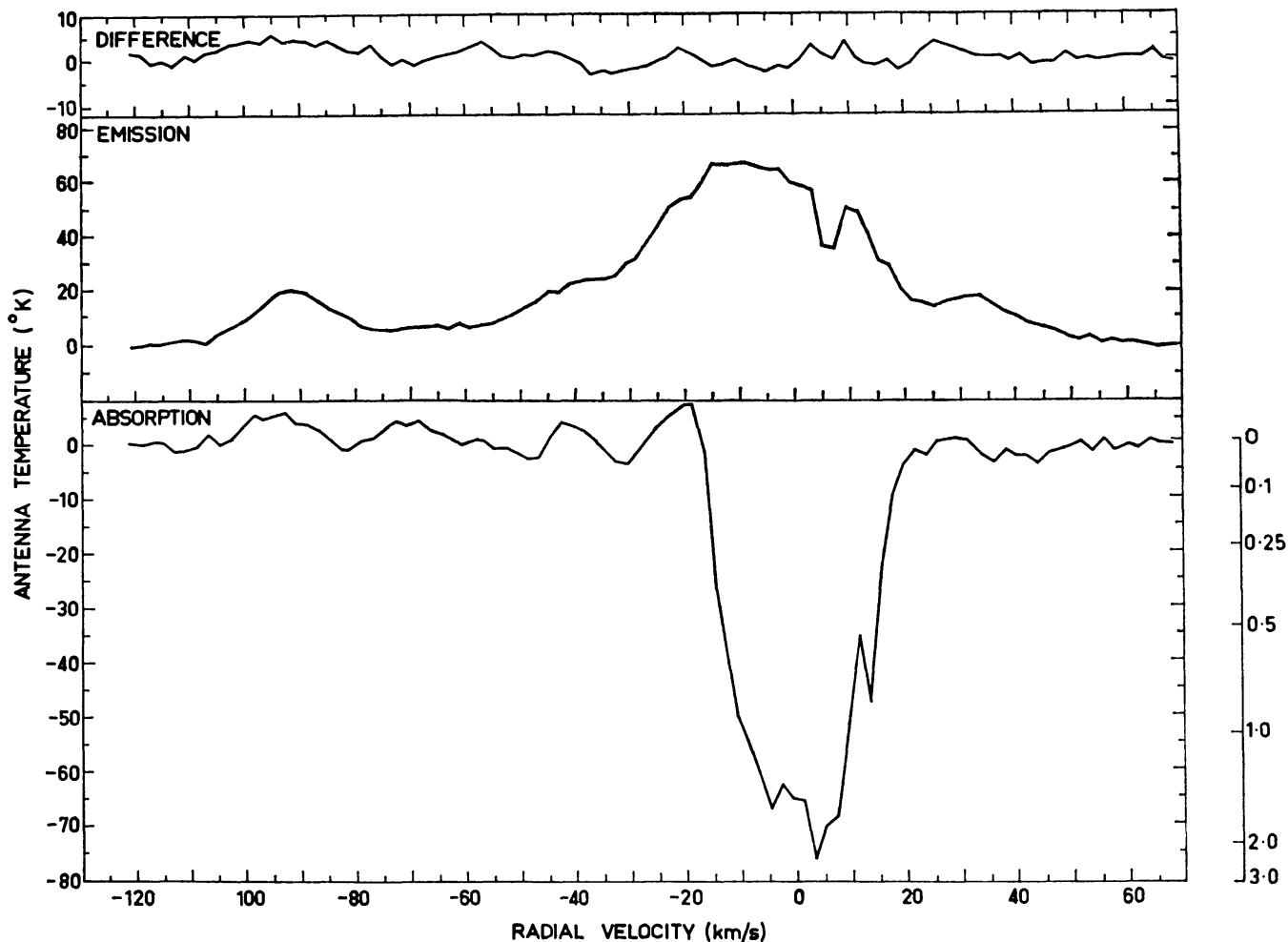


FIG. 16.—G353.2+0.7

(1965); CRW (Clark, Radhakrishnan, and Wilson 1962); Milne (1970); GMR (Goss, Murray, and Radhakrishnan 1970); GS (Goss and Shaver 1970); SG (Shaver and Goss 1970); Goss (1968); WMGM (Wilson *et al.* 1970*a, b*).

a) The Crab Nebula (Figs. 2a and 2b)

The optical measurements of Trimble (1968) place this well-known radio source at a distance of 2 kpc. No comparison with a kinematical determination is possible, however, because of the proximity to the galactic anticenter. A single interferometer measurement at a projected baseline of approximately 300λ north-south is in agreement with the single-dish measurement made with the same velocity resolution (Fig. 2*a*). From measurements at two interferometer spacings Clark also concluded that the absorption profile does not vary significantly with resolution. The implication is that the opacity distribution can be considered relatively uniform over the face of the source.

The various observations of this source referred to in Table 1 have led to different resolutions of the absorption profile into Gaussian components. The most elaborate resolution was by Shuter and Verschuur (1964), who considered nine the minimum number of components necessary for a satisfactory fit. Their observations were made with a frequency resolution of 3 kHz. In Figure 2*b* we show our measurement on this source with 1-kHz filters. The profile has been resolved into five Gaussians, and the sum

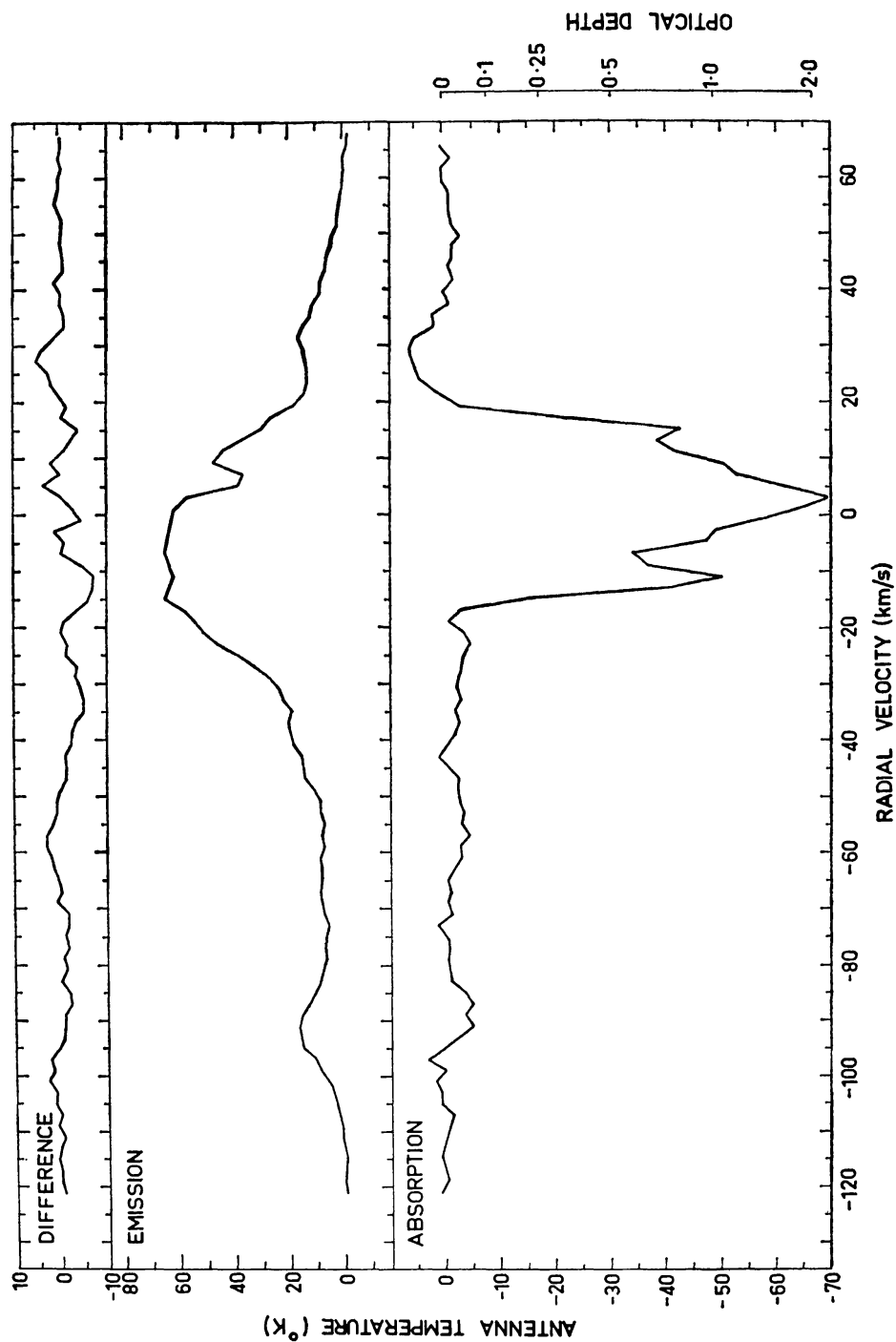


FIG. 17.—G353.2+0.9

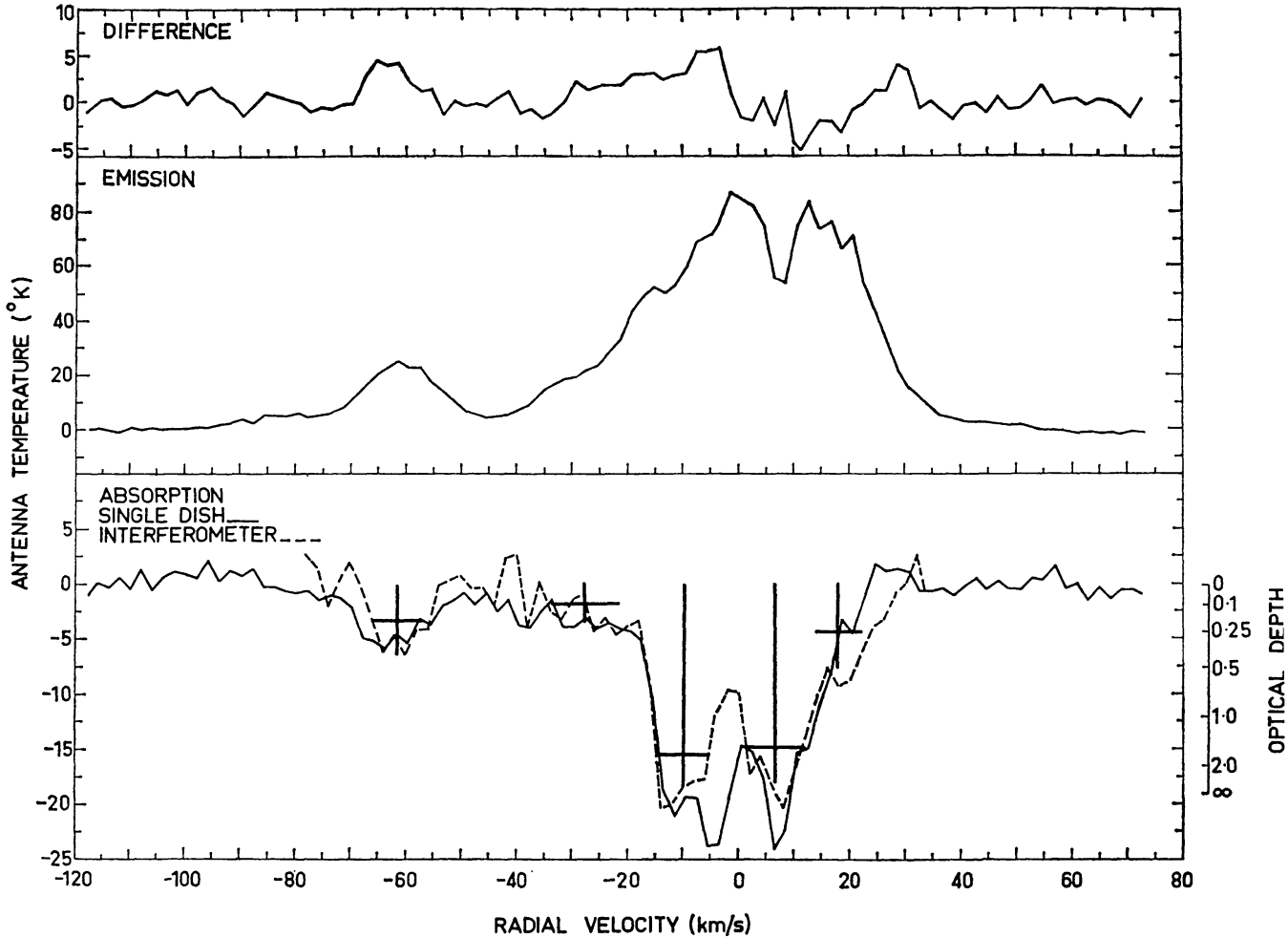


FIG. 18.—G357.7—0.1

of these components is also plotted by the points on the figure. The quality of the fit can be seen at a glance. The narrowest feature at 7.95 km s^{-1} has a width corresponding to pure thermal broadening at $T_s \approx 47^\circ \text{ K}$. The low resolution (10 kHz) OH absorption profile obtained by Goss has roughly the same appearance as the H I profile of corresponding resolution and shows lines at 2.7 and 13.2 km s^{-1} . The 2.7 km s^{-1} line is in good velocity agreement with the second deepest feature in our profile.

b) W12 (NGC 2024) (Figs. 3a and 3b)

The optical depth as measured with the interferometer is definitely higher than the single-dish value. The effect is similar to that observed in Orion (Paper I), but in this case the antenna temperature of the source is only a fraction of that of Orion. Without further interferometer measurements it is not possible to decide whether the single-dish value is erroneous because of emission variations or whether the optical depth varies across the source. The very strong OH absorption line found by Goss at 9.3 km s^{-1} is presumably from the same region responsible for the H I absorption. A line at 12.5 km s^{-1} has been seen both in OH and in H_2CO (see Table 1). All of these absorption features lead to kinematic distances of the order of 1 kpc, twice as great as the H109 α distance of 0.5 kpc. Peculiar motion of either the source or the absorbing clouds is clearly indicated. A photometric distance of 0.4 kpc, based on the assumption that NGC 2024 No. 1

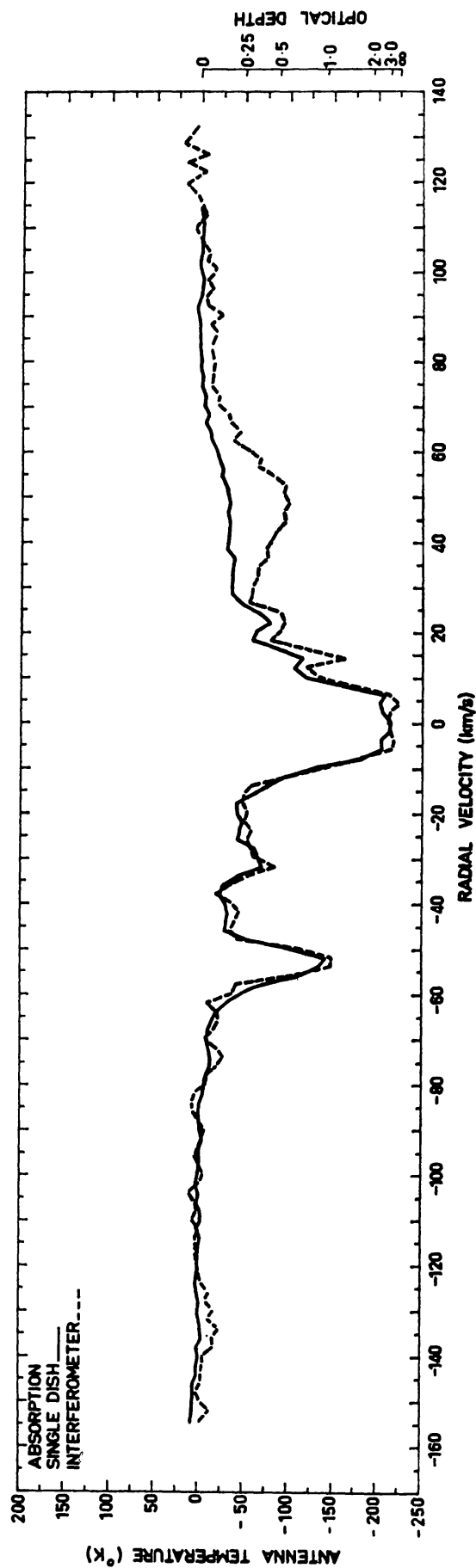


FIG. 19.—Sgr A

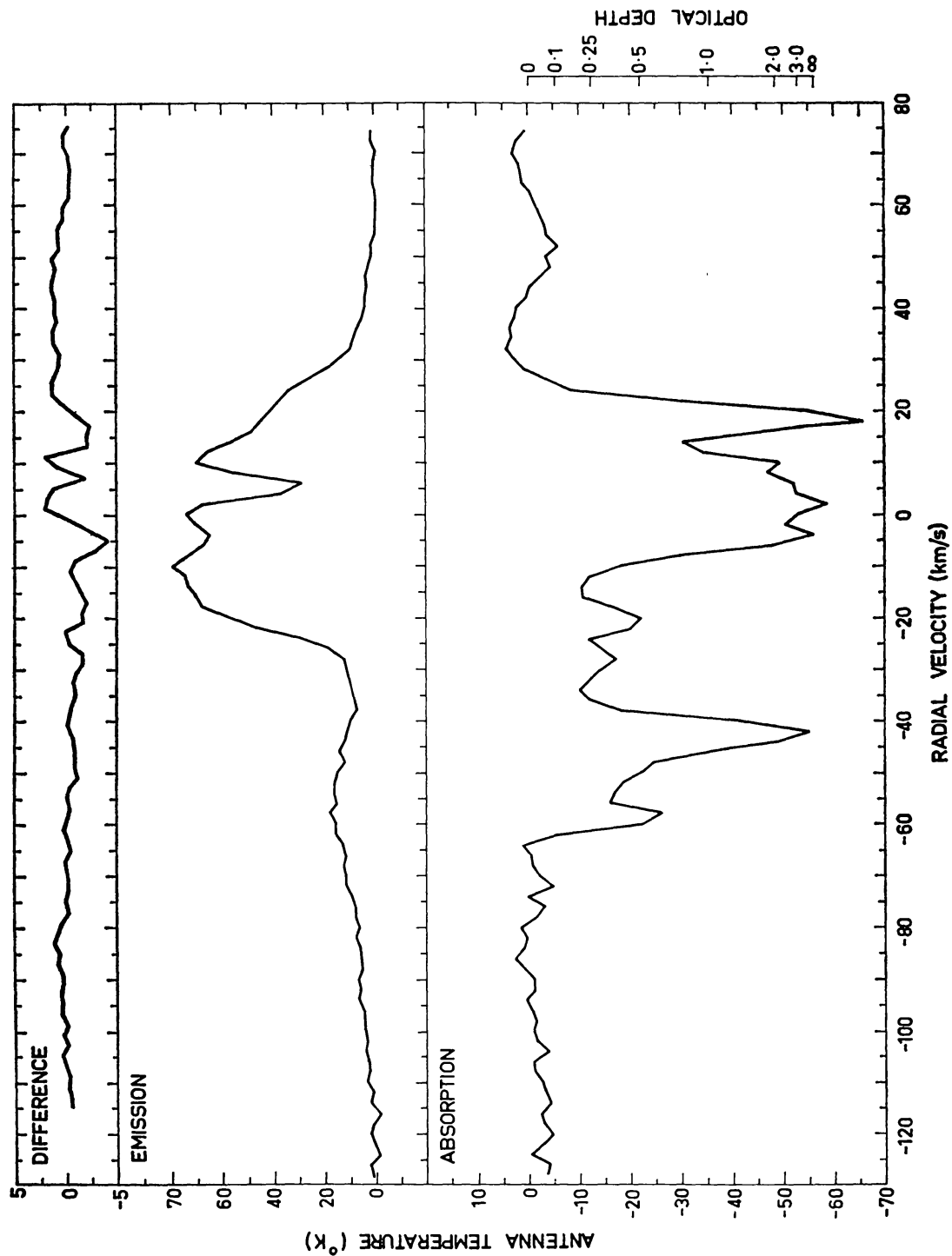


FIG. 20.—Sgr B2

(Johnson and Mendoza V. 1964; Johnson 1967) is the exciting star, lends weight to the H109 α distance determination and suggests that the H I, OH, and H₂CO lines are all affected by considerable peculiar motion. Presumably they arise from the same concentration of interstellar gas.

c) Orion A (Figs. 4a and 4b)

The absorption spectrum of this source has been discussed at length in Paper I. The single-dish profile of Figure 4b obtained with the bank of 1-kHz filters has been resolved into Gaussians in the manner shown. The profile obtained in the direction of this source has a significantly higher emission temperature on the high-velocity side than does the mean of the north, south, east, and west profiles. This excess appears on the "absorption" profile and undoubtedly introduces errors in the determination of the shape of the profile on that side. We have attempted to reduce these errors somewhat by including an

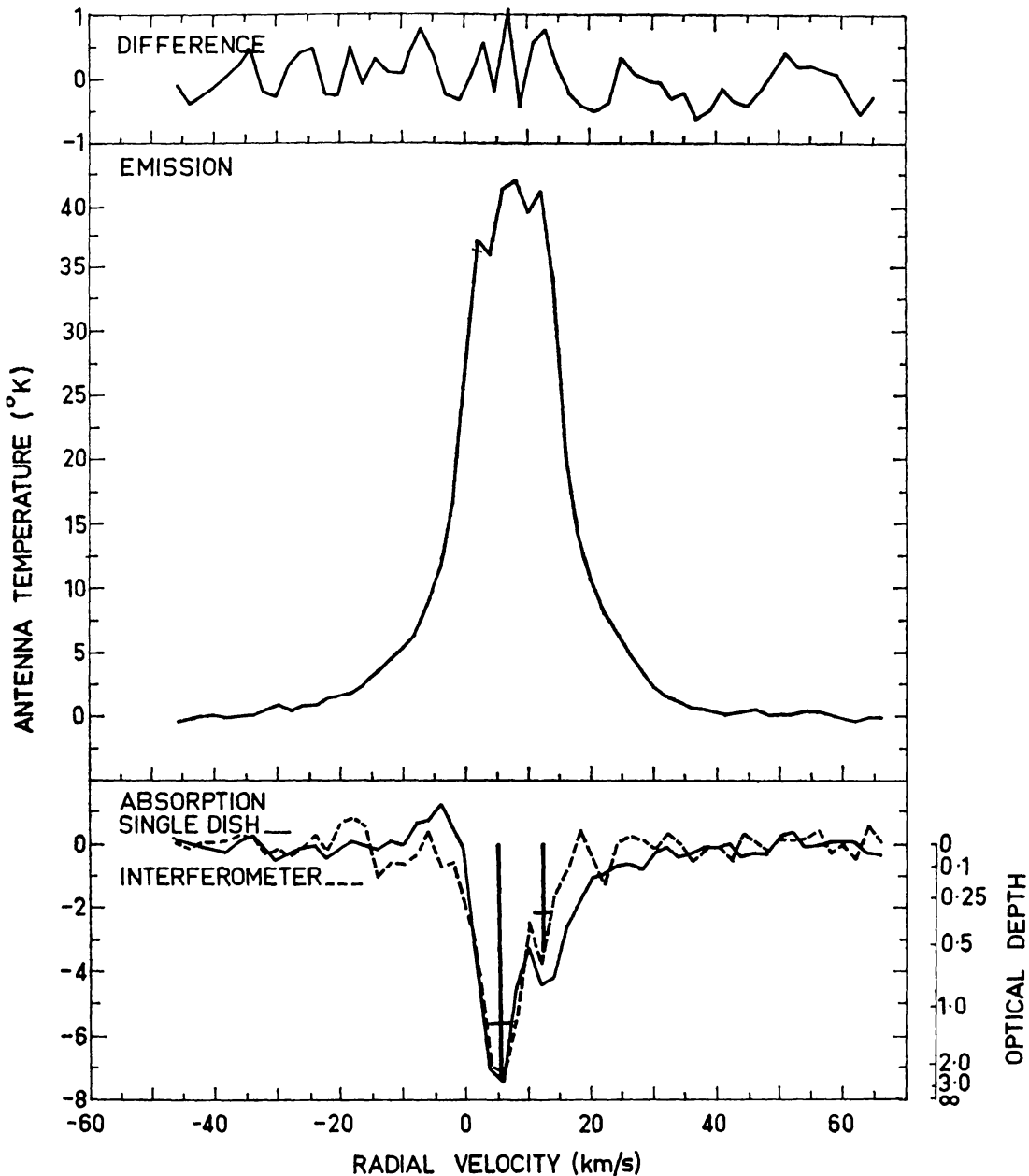


FIG. 21.—3C 358

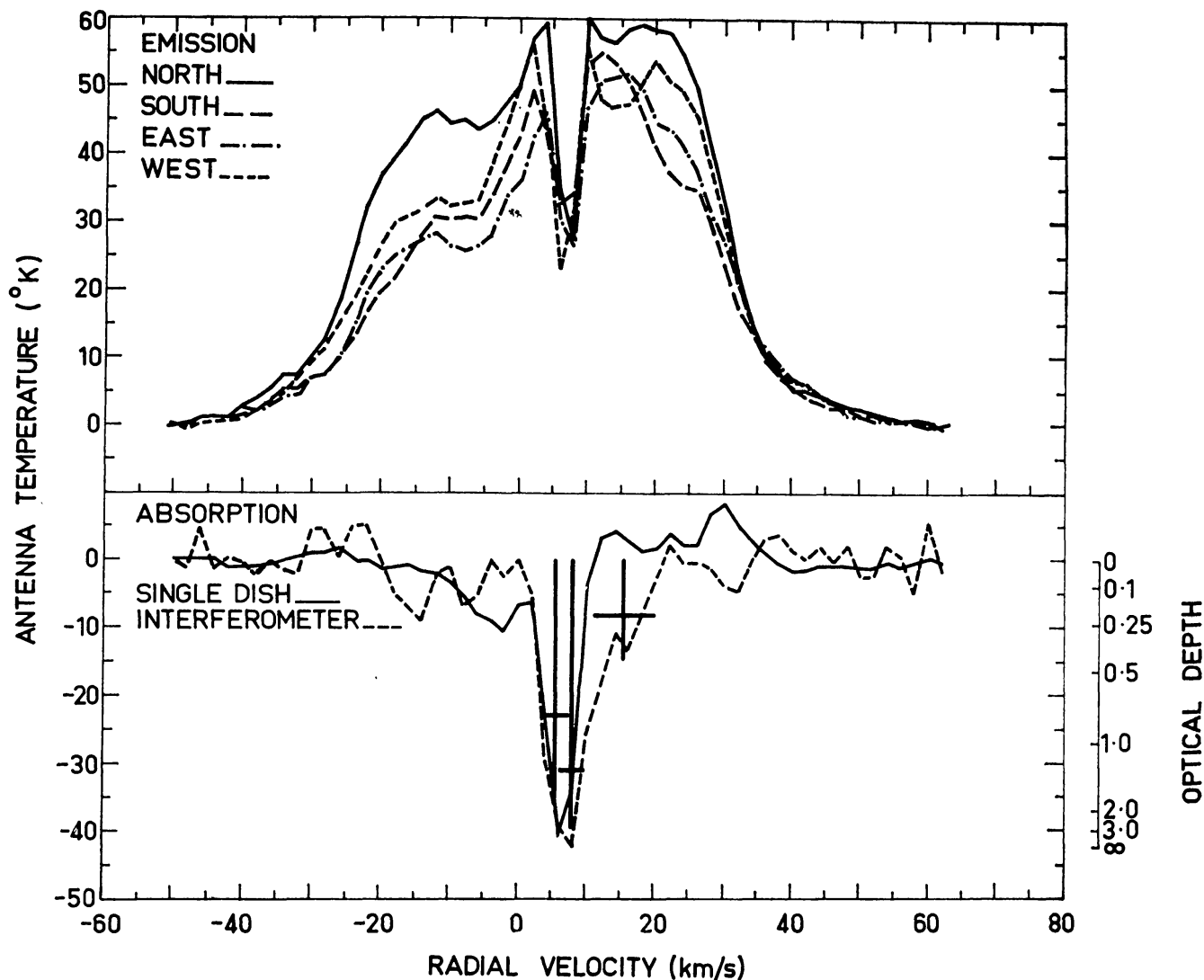


FIG. 22a.—M8

emission feature in the Gaussian-fitting computation for this profile. The procedure is questionable on a number of grounds and is justifiable only with a number of assumptions. The fit on the low-velocity side of the profile is unaffected by this, however, and the need for a component at ~ -3 km s⁻¹ is apparent from the shape on that side. As discussed in Paper I, this feature is presumably caused by the H I concentration, which is displaced with respect to the centroid of the continuum source.

Menon (1970) has discussed the emission feature at +12 km s⁻¹ based on observations with the NRAO 43-m and 92-m telescopes. He has concluded that the excess emission is caused by a cloud of less than 10' in size situated about 5' from the center of the emission nebula and to the east of it. Our observations with the 64-m telescope are in partial agreement with his. Restricting ourselves to the signal measured in a 2 km s⁻¹ wide channel centered at +12 km s⁻¹, we obtain temperatures of the order of 60° K in the direction of the source, and 45°, 29°, 43°, and 49°, respectively, when the telescope is pointed one beamwidth away (15') in the north, south, east, and west directions. There is certainly an excess in the general direction of the source, but the most drastic variation in the neighborhood is a deficiency toward the south.

d) RCW 36 (Fig. 5)

This is a prominent H II region in Vela. WMGM adopt a distance of 0.6 kpc from H109 α and other measurements. The H I absorption feature at 4.8 km s⁻¹ implies a distance of 1.3 kpc or more for the source. The single-dish profile shows severe variations in the emission in the range 10–40 km s⁻¹ but is in good agreement with the interferometer profile over the velocity range of the absorption. A single Gaussian has been fitted to this profile, although higher-resolution observations are certain to show structure in it. Manchester, Robinson, and Goss (1970) have observed an OH line at 5.75 km s⁻¹.

e) RCW 38 (CTB 31) (Figs. 6a and 6b)

This source is the other prominent H II region in Vela and is more intense than RCW 36. Neither of these two sources has optical distance determinations. Here again WMGM

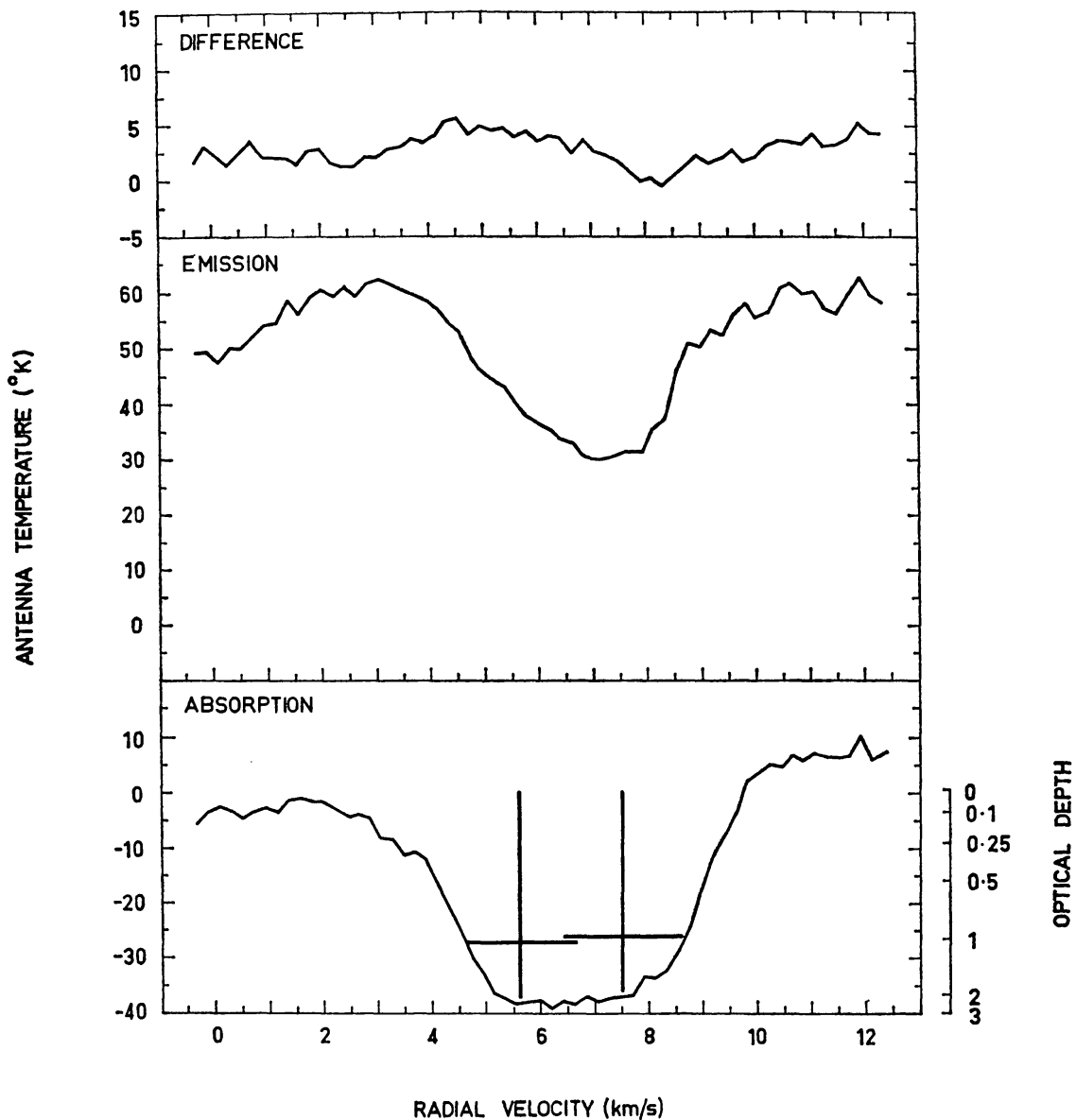


FIG. 22b.—M8

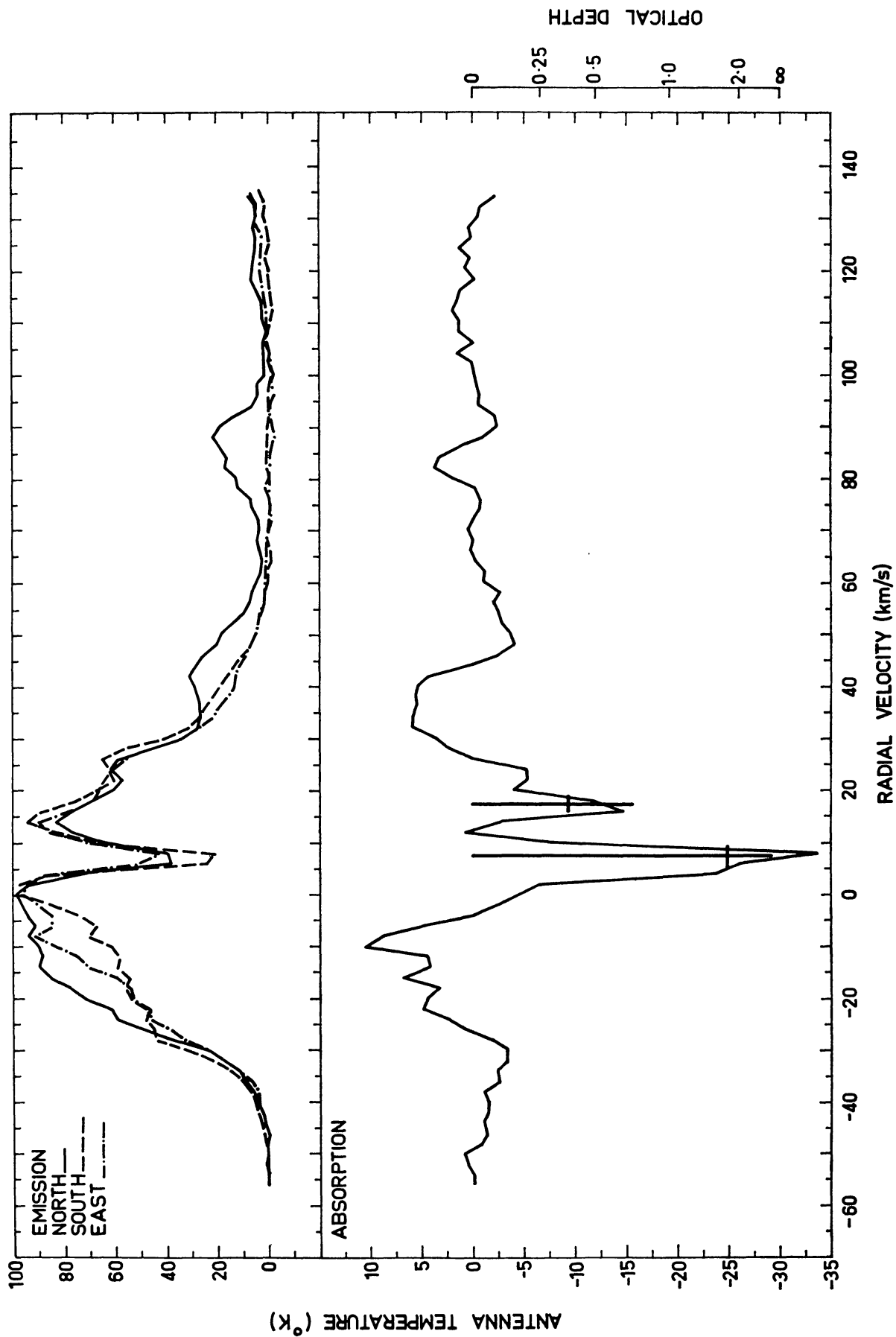


FIG. 23.—W28

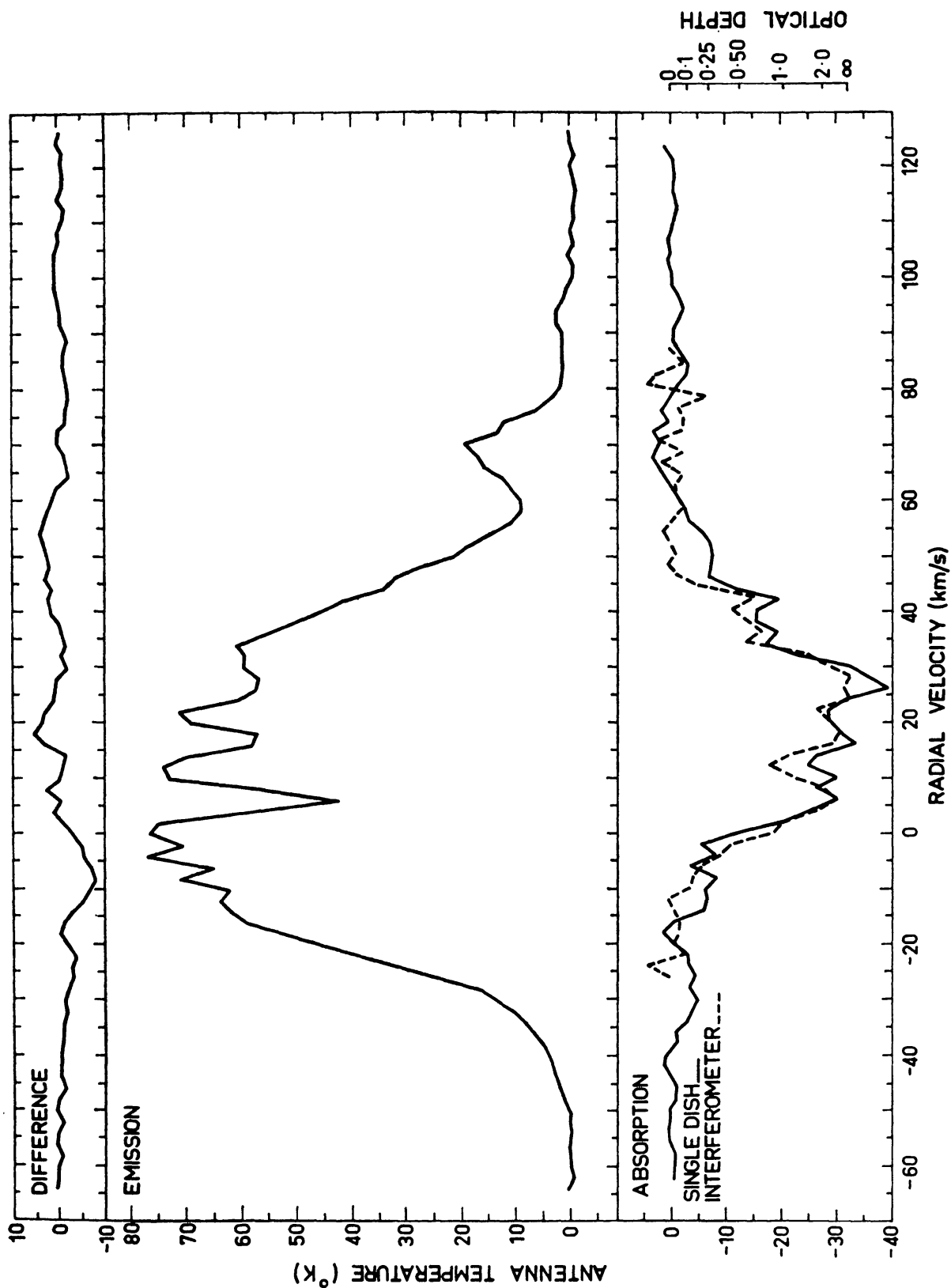


FIG. 24.—W31

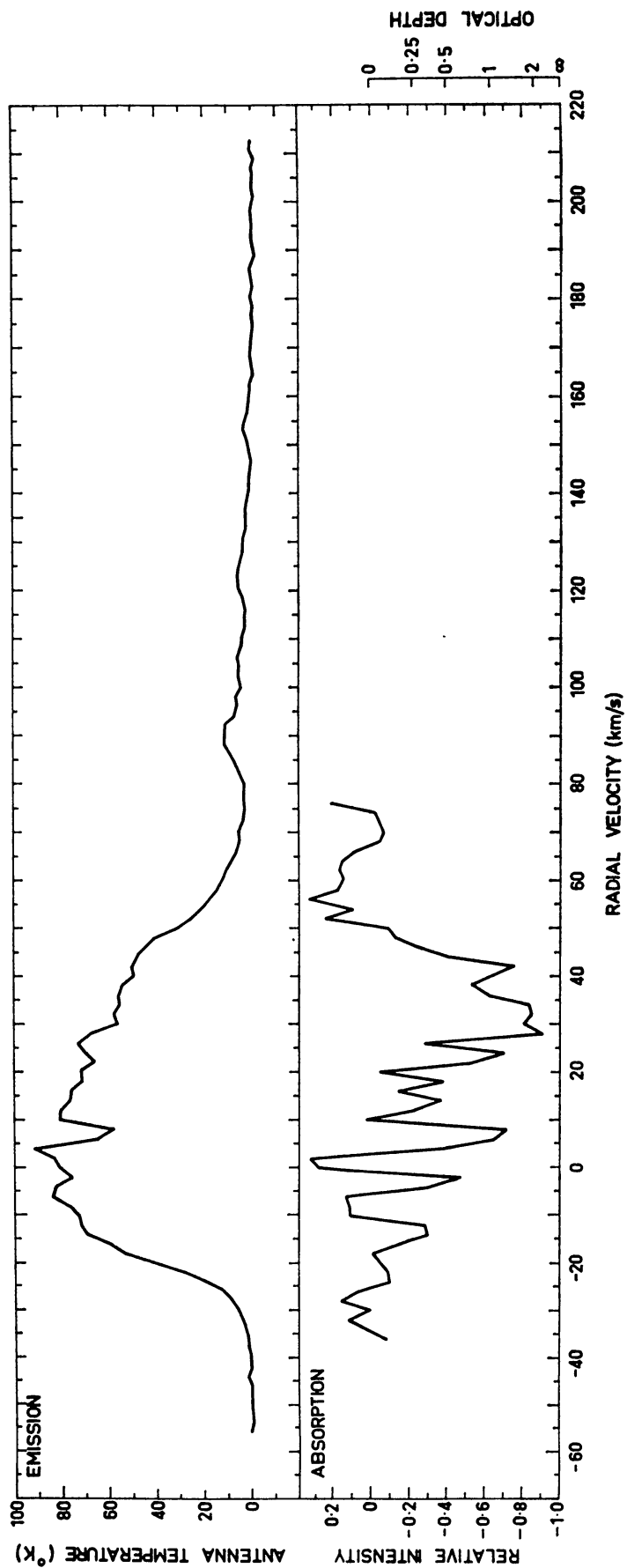


FIG. 25a.—G11.2-0.3

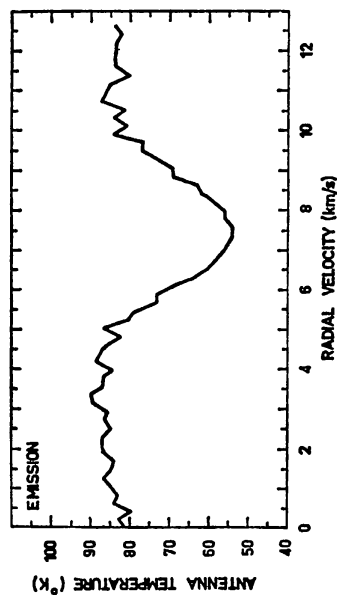


FIG. 25b.—G11.2-0.3

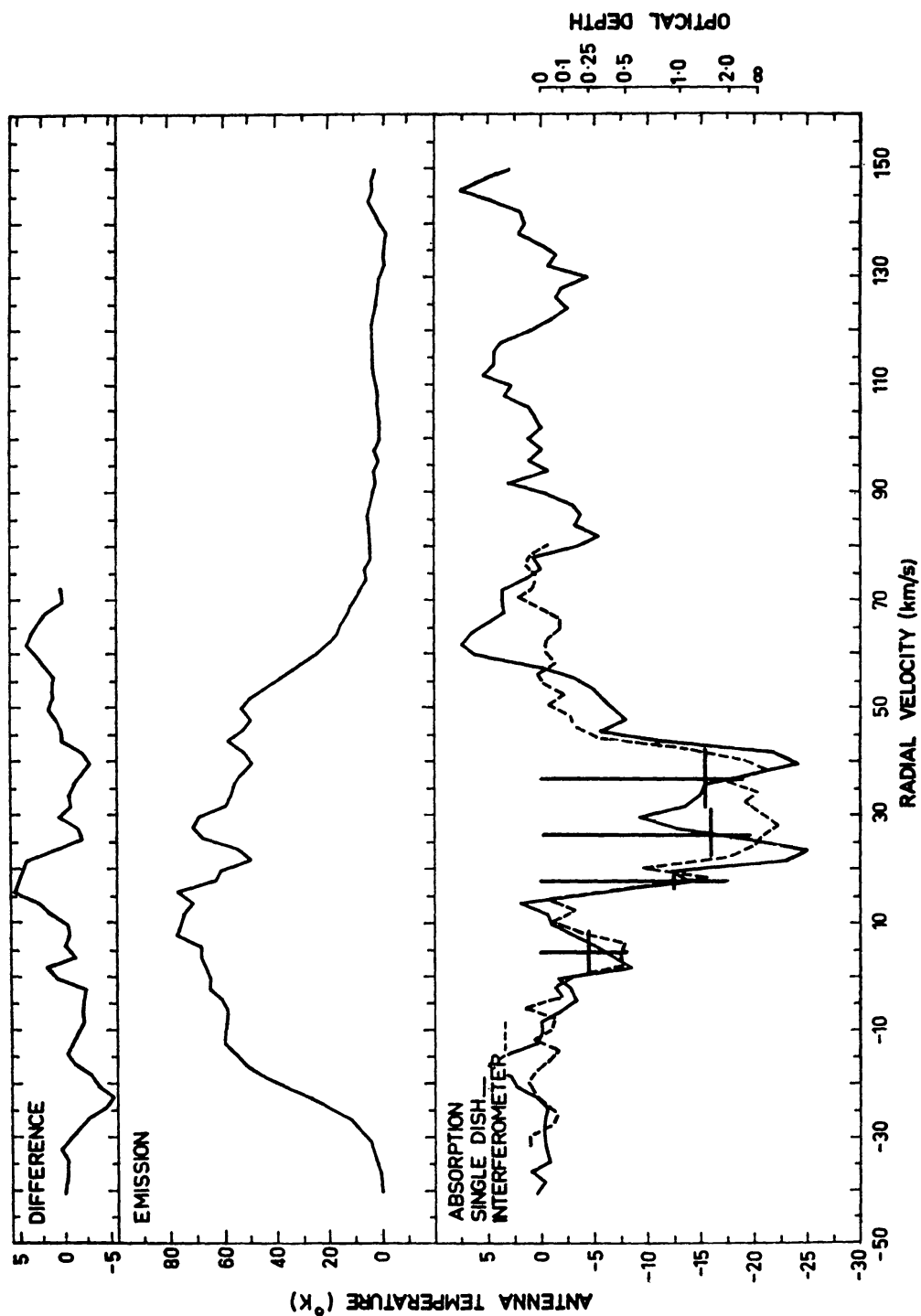


FIG. 26.—W33

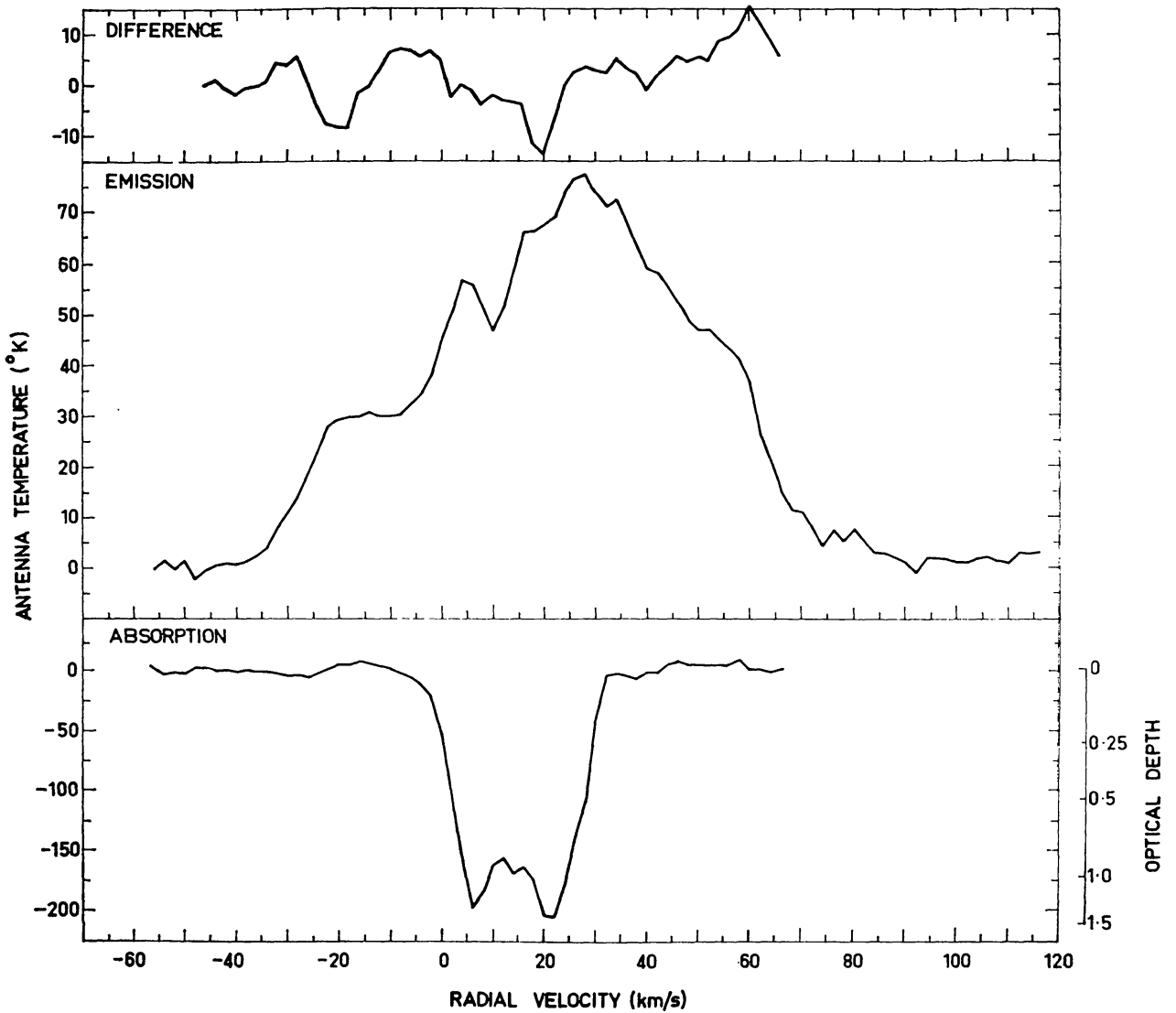


FIG. 27a.—M17

have suggested 0.6 kpc for the distance from H109 α measurements, and the H I velocities suggest a greater distance. We estimate 1–2 kpc as a probable distance. The single-dish and interferometer profiles are in reasonable agreement, with a suggestion of greater width as measured by the interferometer. As seen in Figure 6b, the absorption line is saturated in the range 1–8 km s⁻¹. The Gaussian fitting is therefore very approximate and indicates only the absolute minimum number of features in the profile. Manchester *et al.* (1970) find a strong OH line at a velocity of 1.8 km s⁻¹.

f) RCW 117 (Fig. 7)

See under G351.7–1.2.

g) CTB 35A (Fig. 8)

This H II region has been studied by SG and has been optically identified. At 6 cm the complex breaks up into four sources. The H109 α measurements of WMGM suggest a near distance of ~ 2 kpc; the far distance alternative (~ 17 kpc) would imply a Z

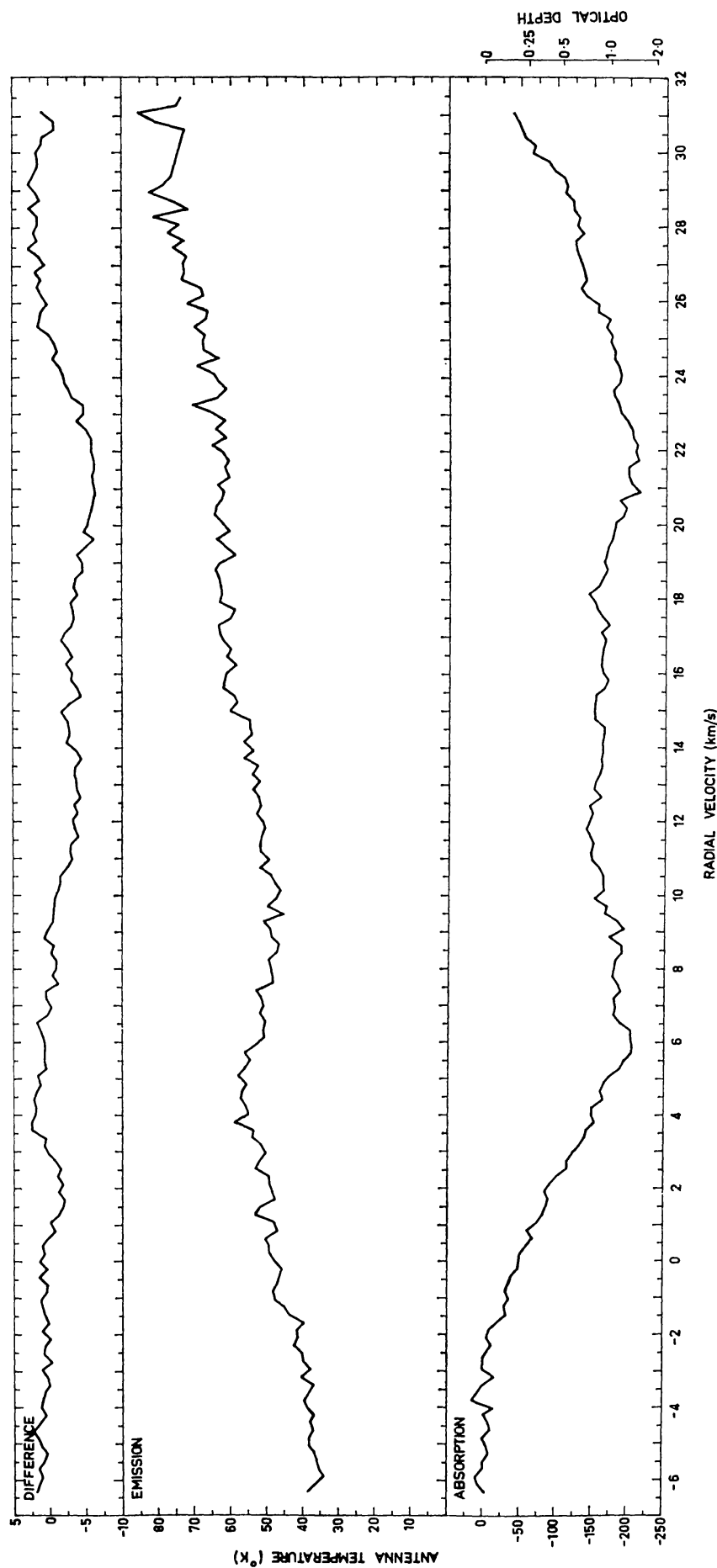


FIG. 27*b*—M17

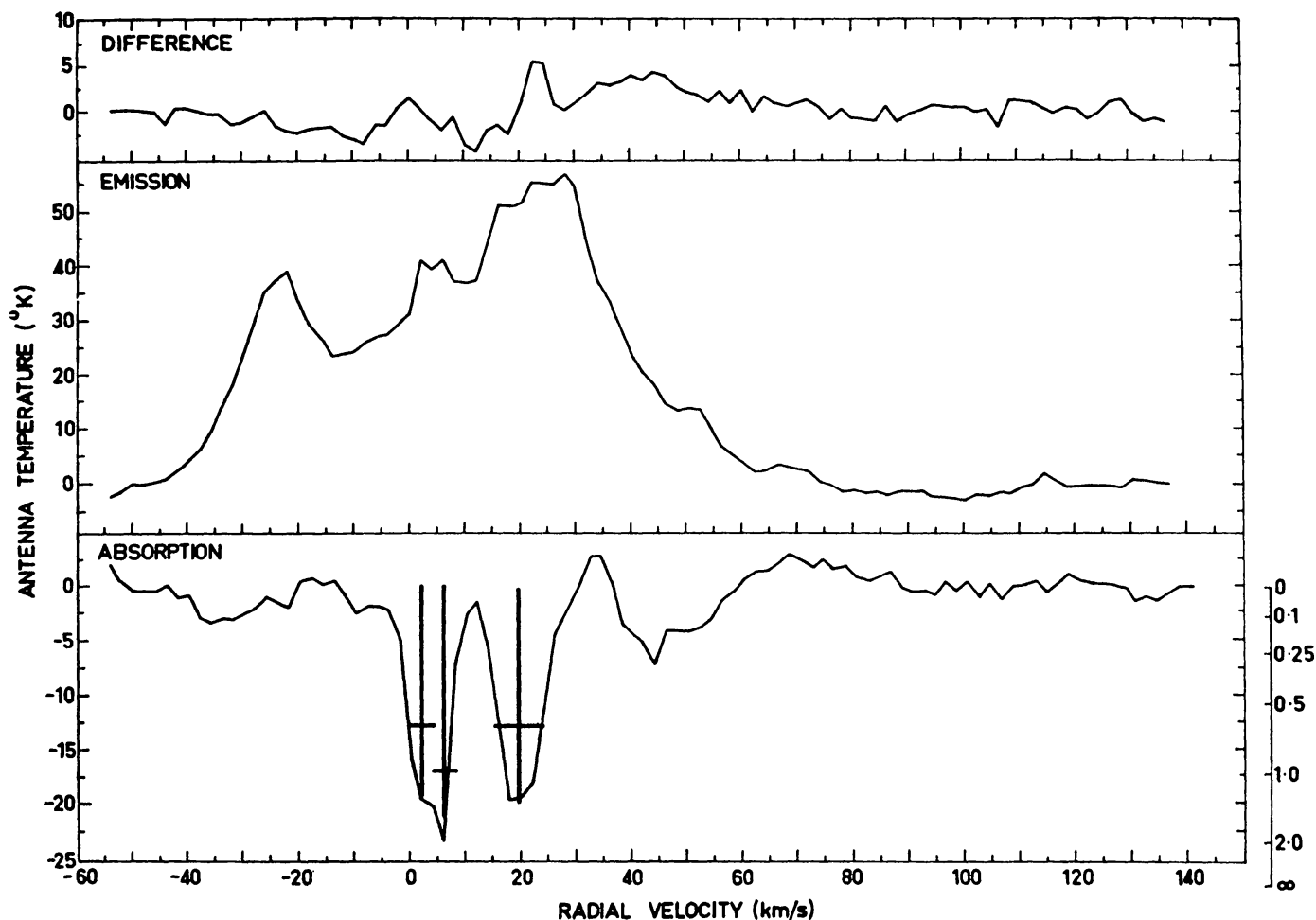


FIG. 28.—M16

distance greater than 400 pc. The H I absorption profile is of marginal quality, having suffered both from the weakness of the source and the difficulty of getting reference emission profiles free of the other sources in the complex.

The whole complex of sources is presumably associated and at a distance of the order of 2 kpc.

h) RCW 121 (Fig. 9)

See under G351.7—1.2.

i) CTB 37A (Fig. 10)

The extended nature of this source makes it difficult to obtain satisfactory emission references. This is seen in the large positive excursions of the baseline in the absorption profile. There is a suggestion, however, that the absorption cuts off short of the emission on the negative-velocity side. If this can be construed as evidence, the approximate distance of the source is 3 kpc. The continuum source is nonthermal. Milne has suggested that if it is a supernova remnant, its surface brightness indicates a distance of 4.5 kpc. The uncertainties in both these estimates are large enough to make them consistent.

j) G348.7—1.0 (RCW 122) (Fig. 11)

See under G351.7—1.2.

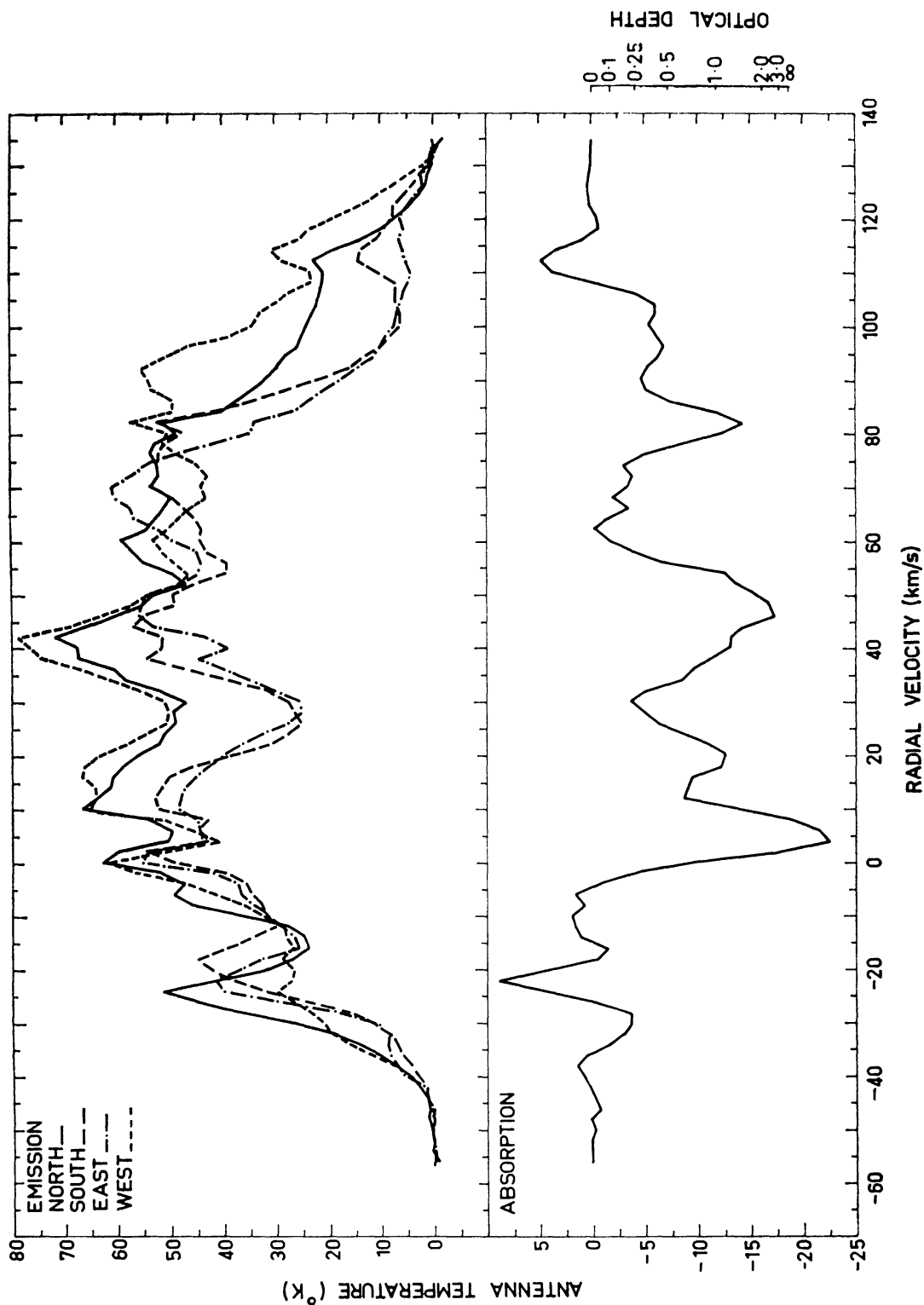


FIG. 29.—G21.8—0.6

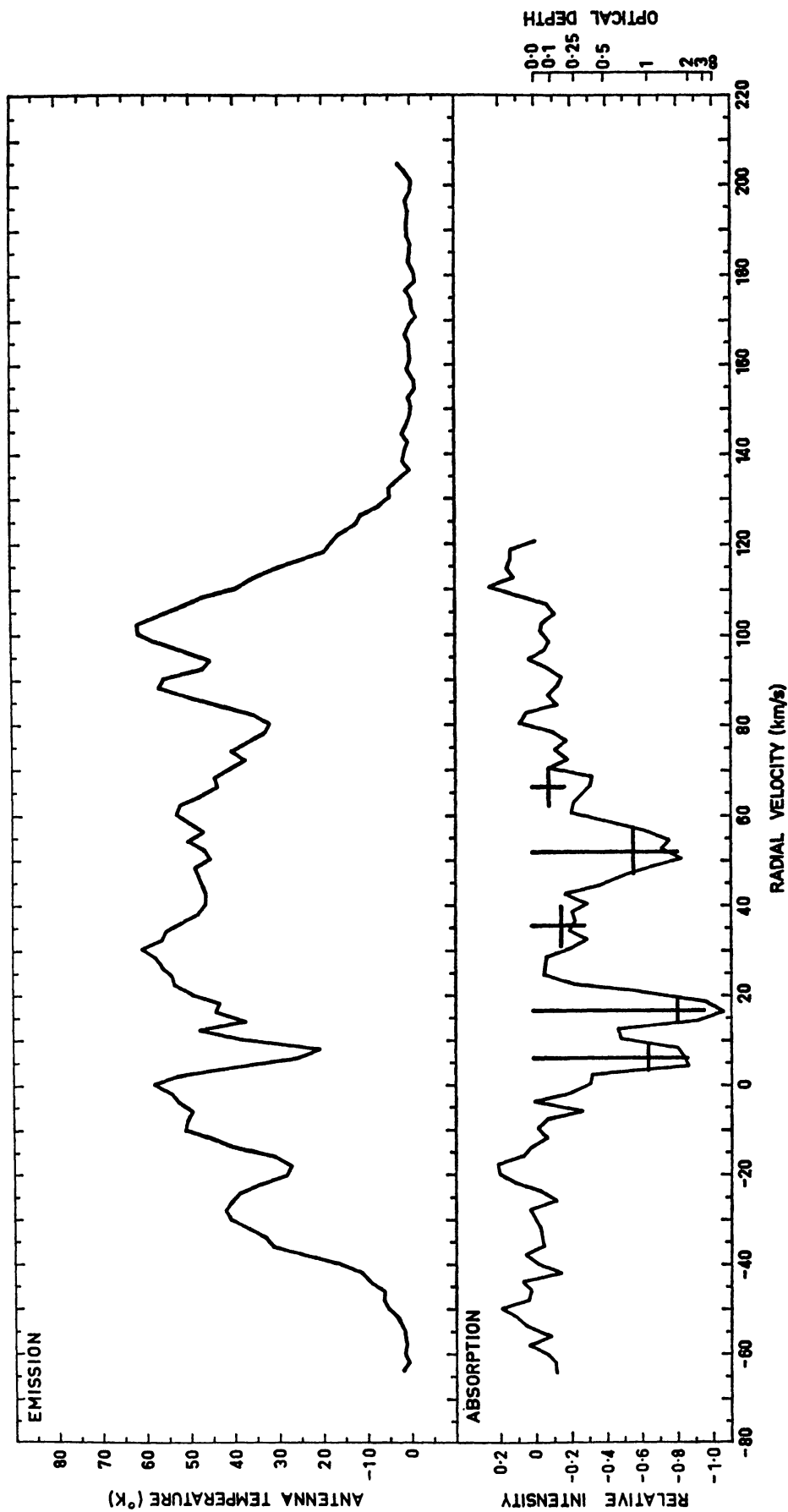


FIG. 30. — G25.4—0.2

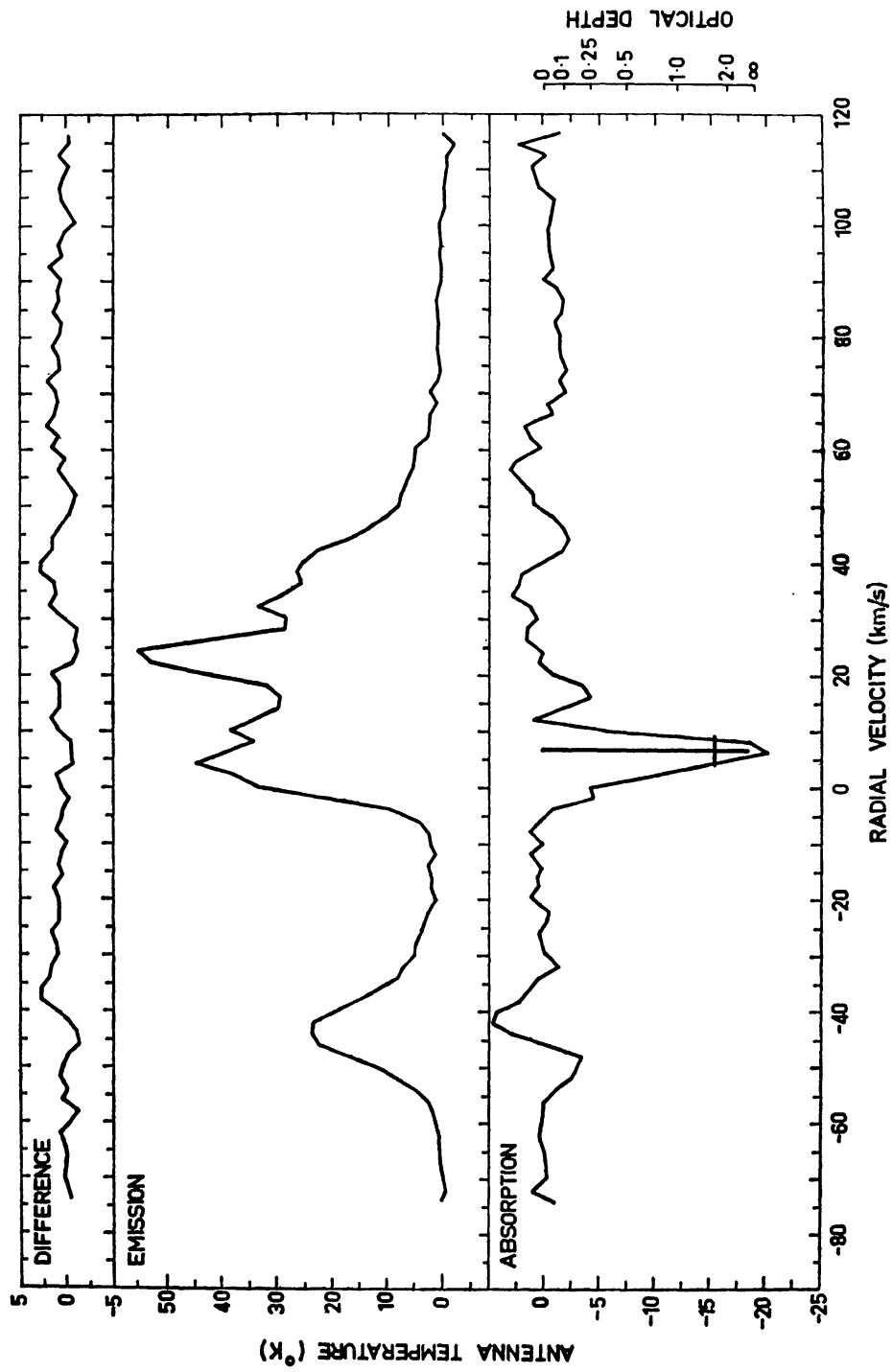


FIG. 31a.—W40

k) NGC 6334 (Figs. 12, 13, 14a, and 14b)

The three components of this well-known emission nebula G351.3+0.7, G351.1+0.7, and G351.2+0.5 will be referred to in the following as A, B, and C, respectively. An optical distance of 1 kpc has been obtained by Roslund (1966). The OH lines from this source have been studied by a number of authors. The H I absorption profile was first observed by CRW, whose antenna beam treated the whole complex as one source. The separation and size of the three components are such that profiles obtained by pointing the 64-m telescope in the direction of each of these three sources are relatively free of contamination by absorption effects due to the other sources. It was naturally impossible to find reference regions all around each source and close to them. We have used two reference regions for each source spaced symmetrically on either side along a line which provided the closest approach to that source. It is half the difference between

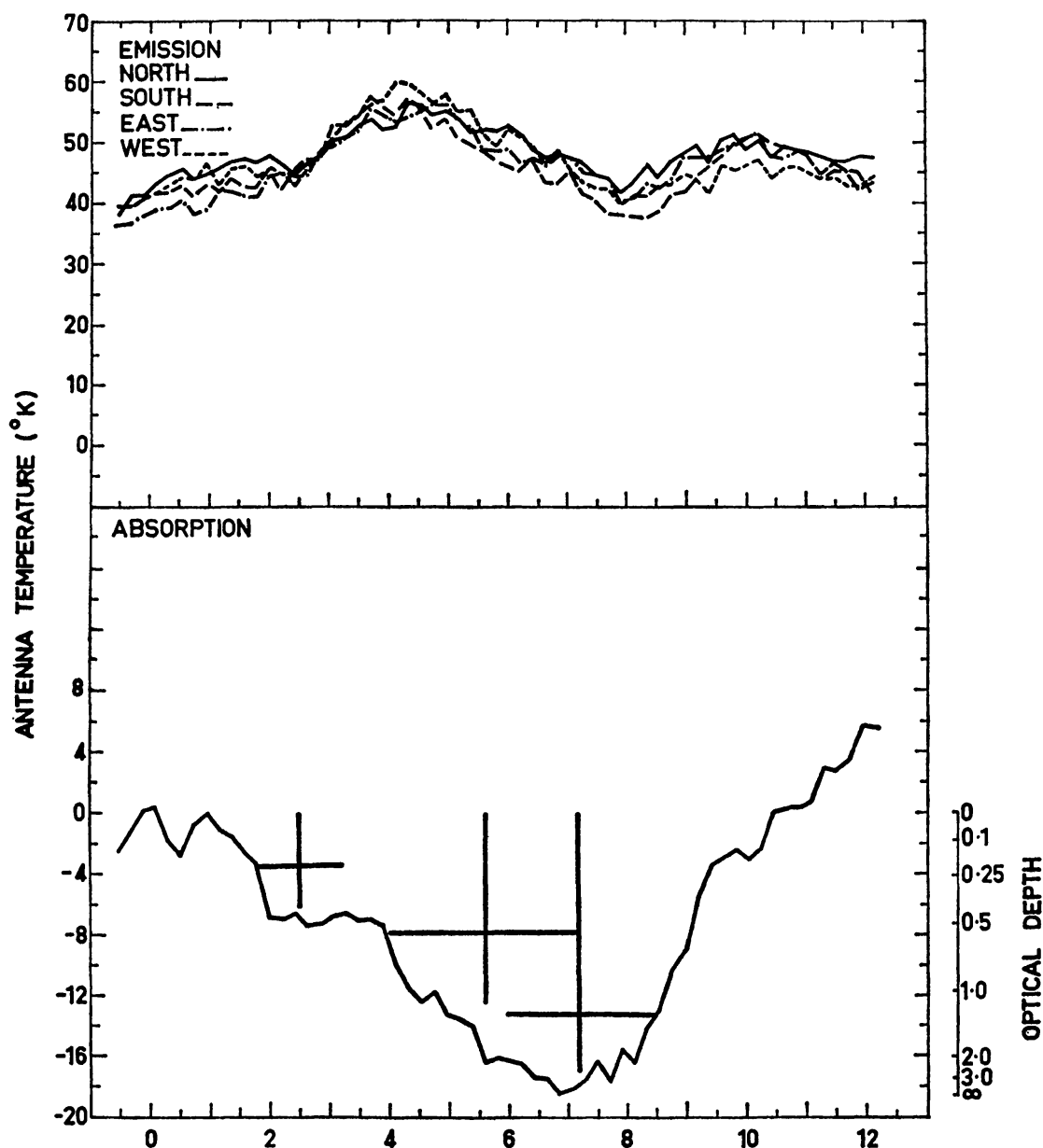


FIG. 31b.—W40

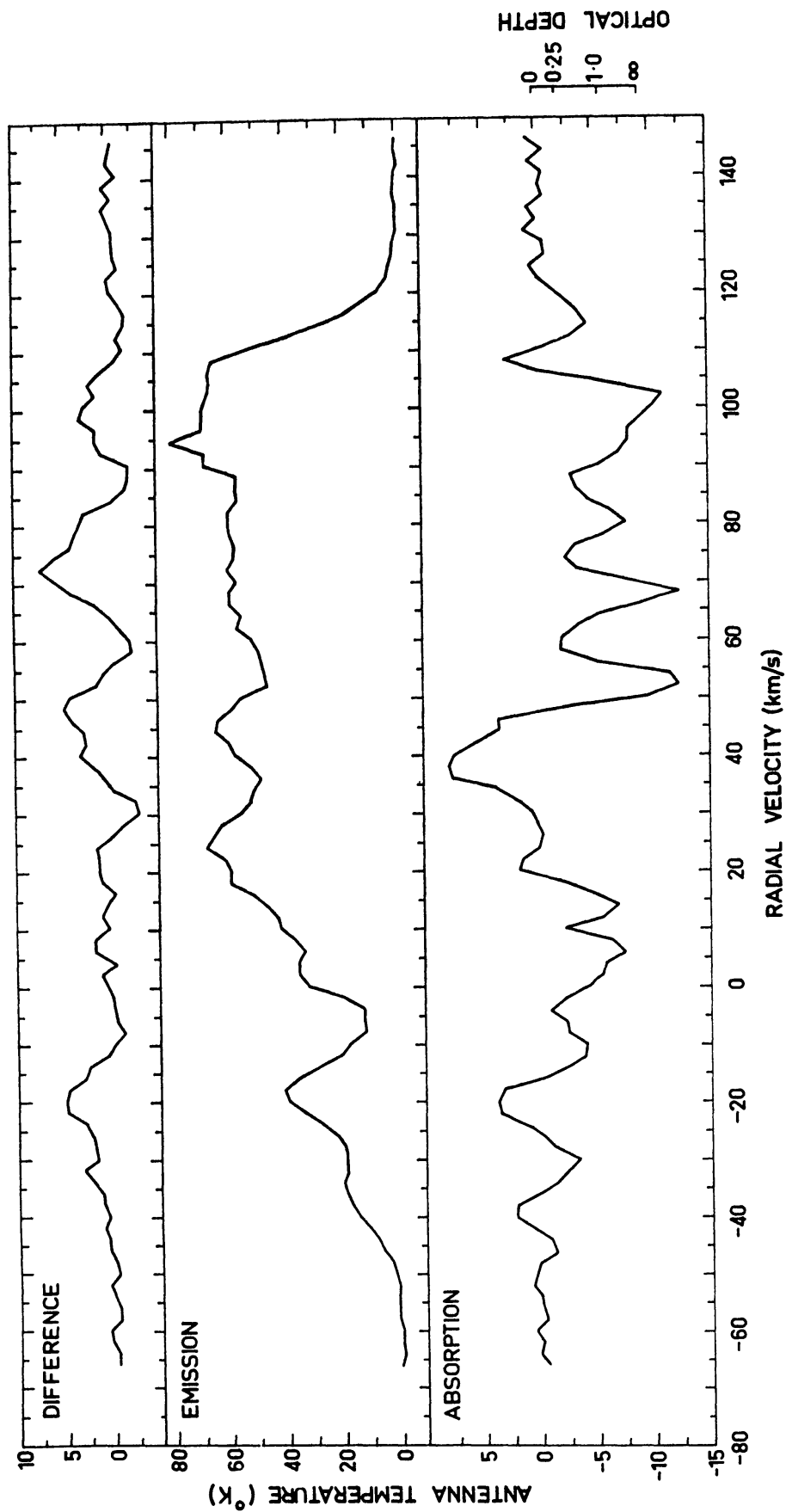


FIG. 32.—G29.9—0.1

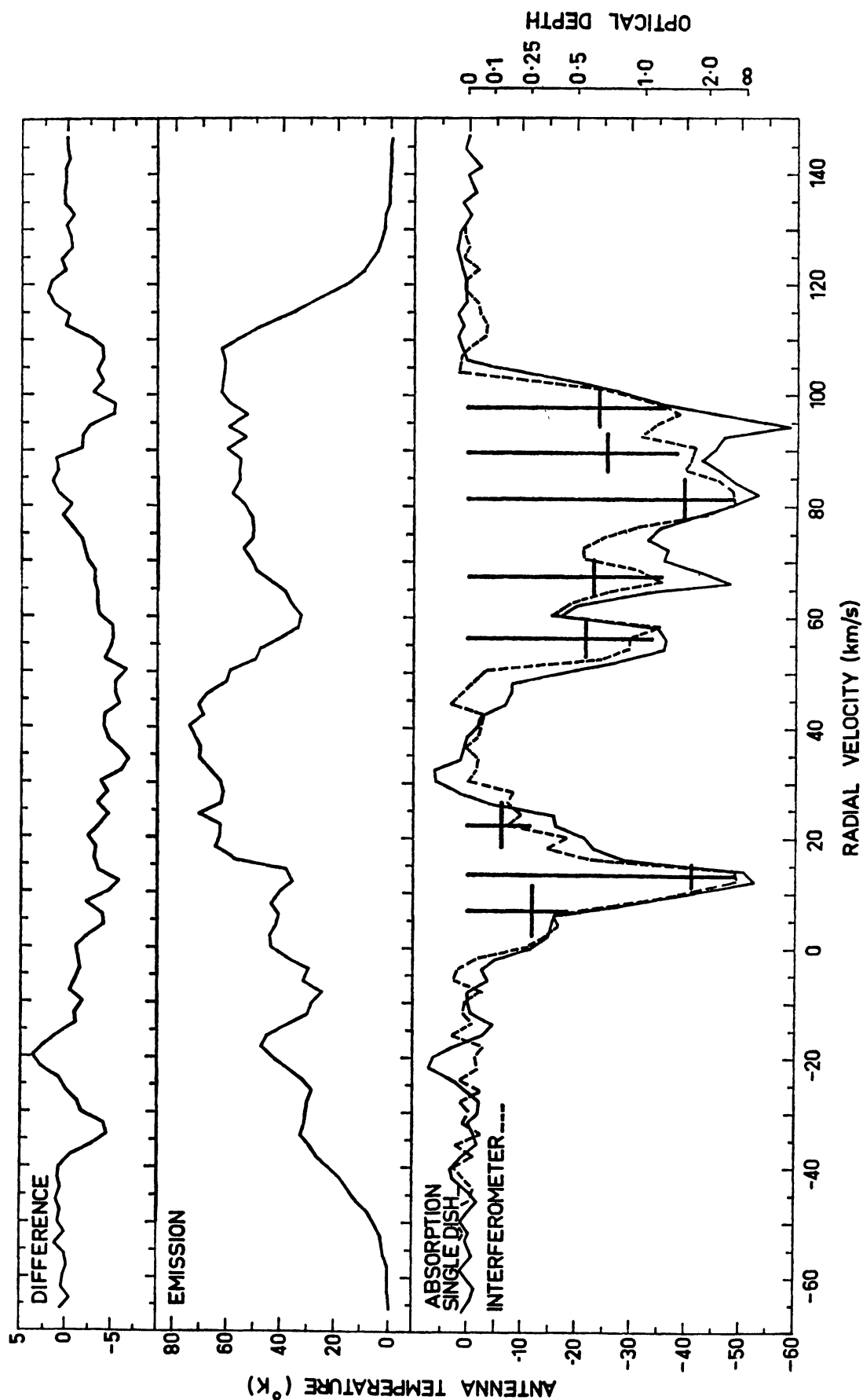


FIG. 33.—G30.8—0.0

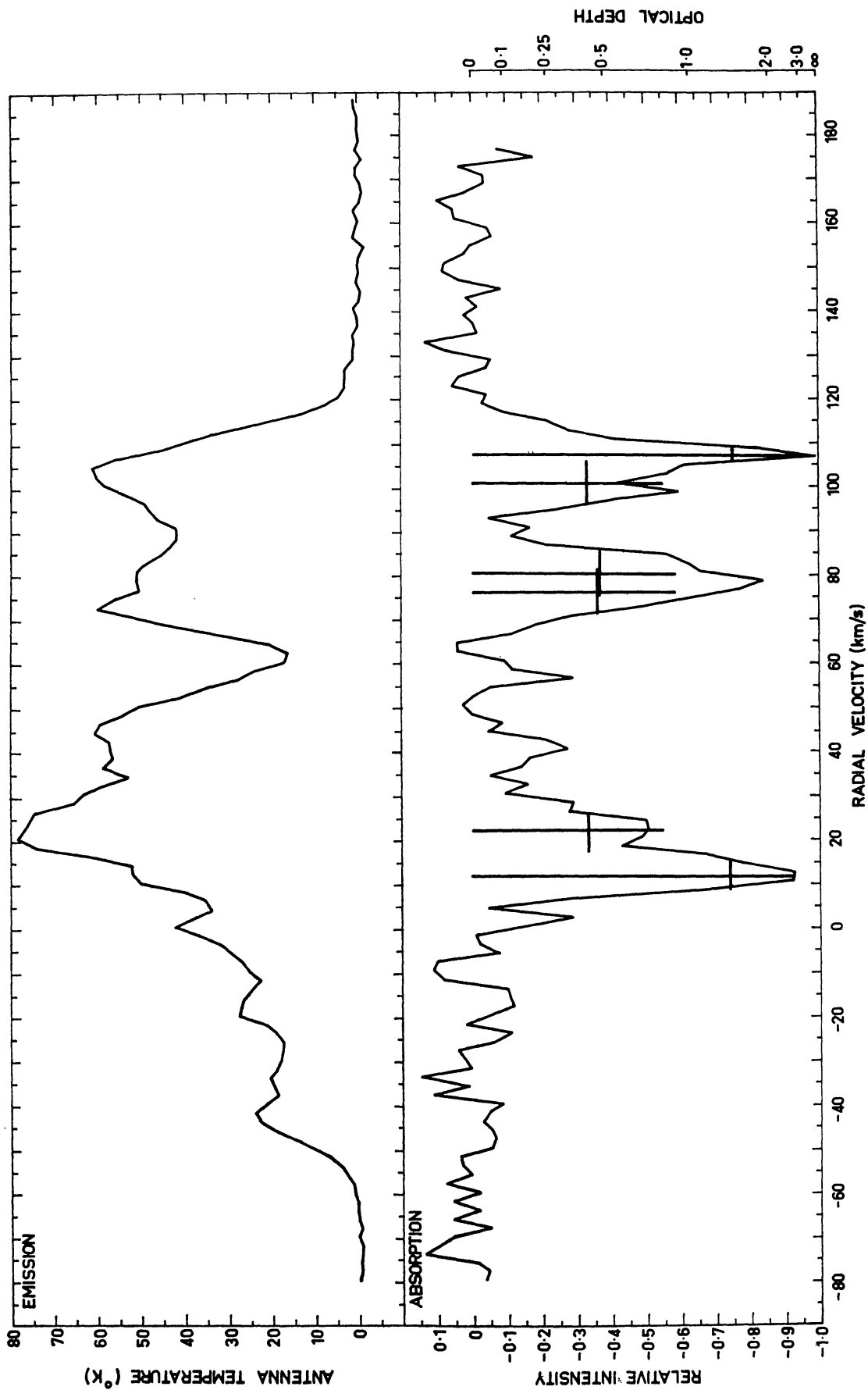


FIG. 34.—3C 391

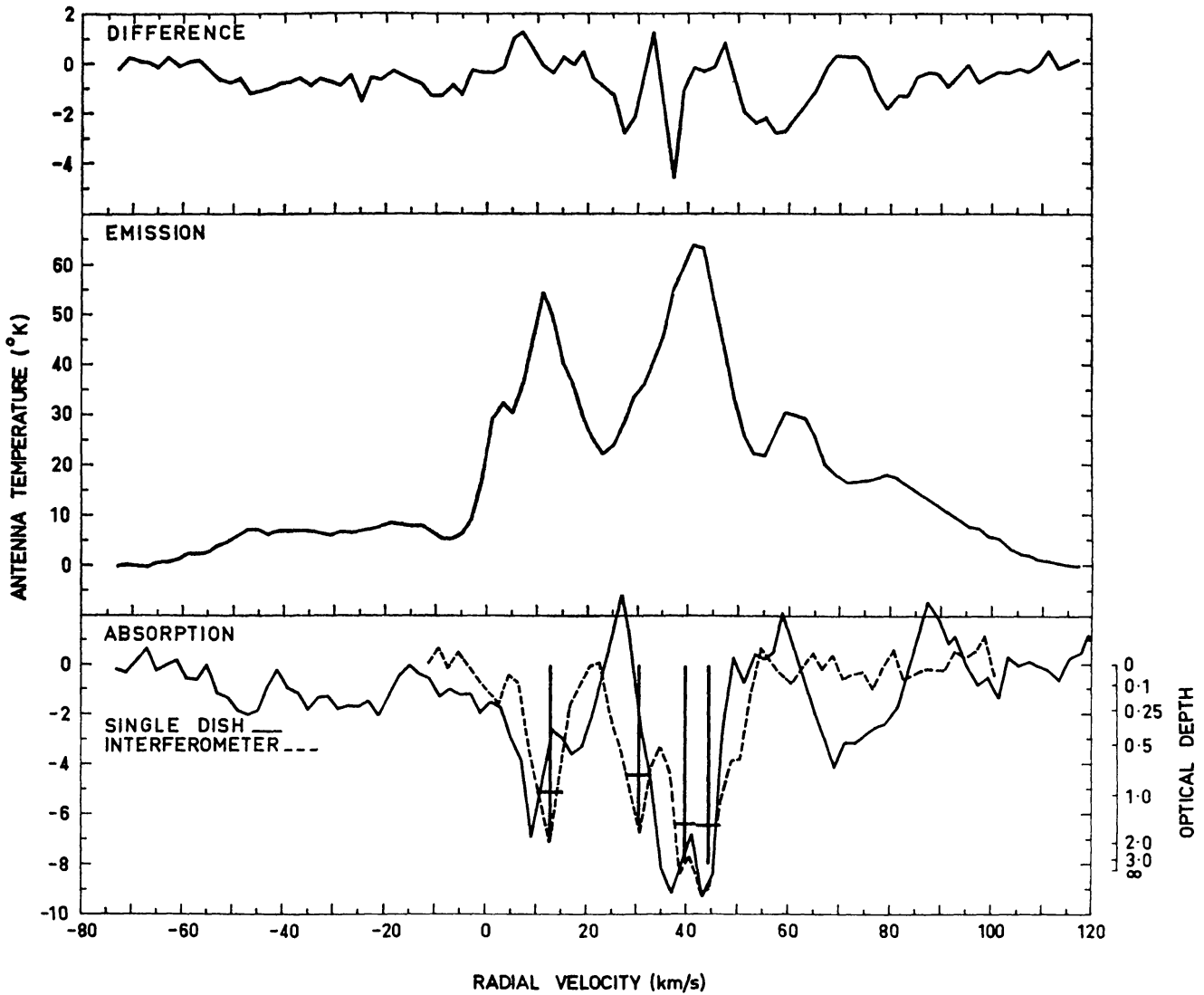


FIG. 35.—W48

these two emission profiles which is plotted as the “difference” in the case of these three sources. Whatever the errors introduced by this method, it is clear from a comparison of the three absorption profiles that the optical depth varies over the region occupied by these sources. The CRW profile is a weighted combination of our three profiles and is in good qualitative agreement. Source A is by far the strongest and the most separated of the three sources. For these reasons the interferometer profile of source A (Fig. 14*b*, *upper*) is almost free of the effects of B and C. We note that this profile indicates an apparent fractional absorption greater than unity (line-to-continuum ratio < -1) and is different in shape from the corresponding single-dish profile. As shown in Paper I for the case of Orion, this indicates an opacity variation across the source and could imply a dense concentration at -5 km s^{-1} partially covering the source. The interferometer profile for source B (Fig. 14*b*, *lower*) is not significantly different from the single-dish profile of Figure 12.

Note the negative kink in the emission profiles for all three sources at a velocity of $+6 \text{ km s}^{-1}$. This is a depression of the background brightness temperature by a dense cold cloud in the foreground. Its presence was first discovered by Heeschen (1955) in the

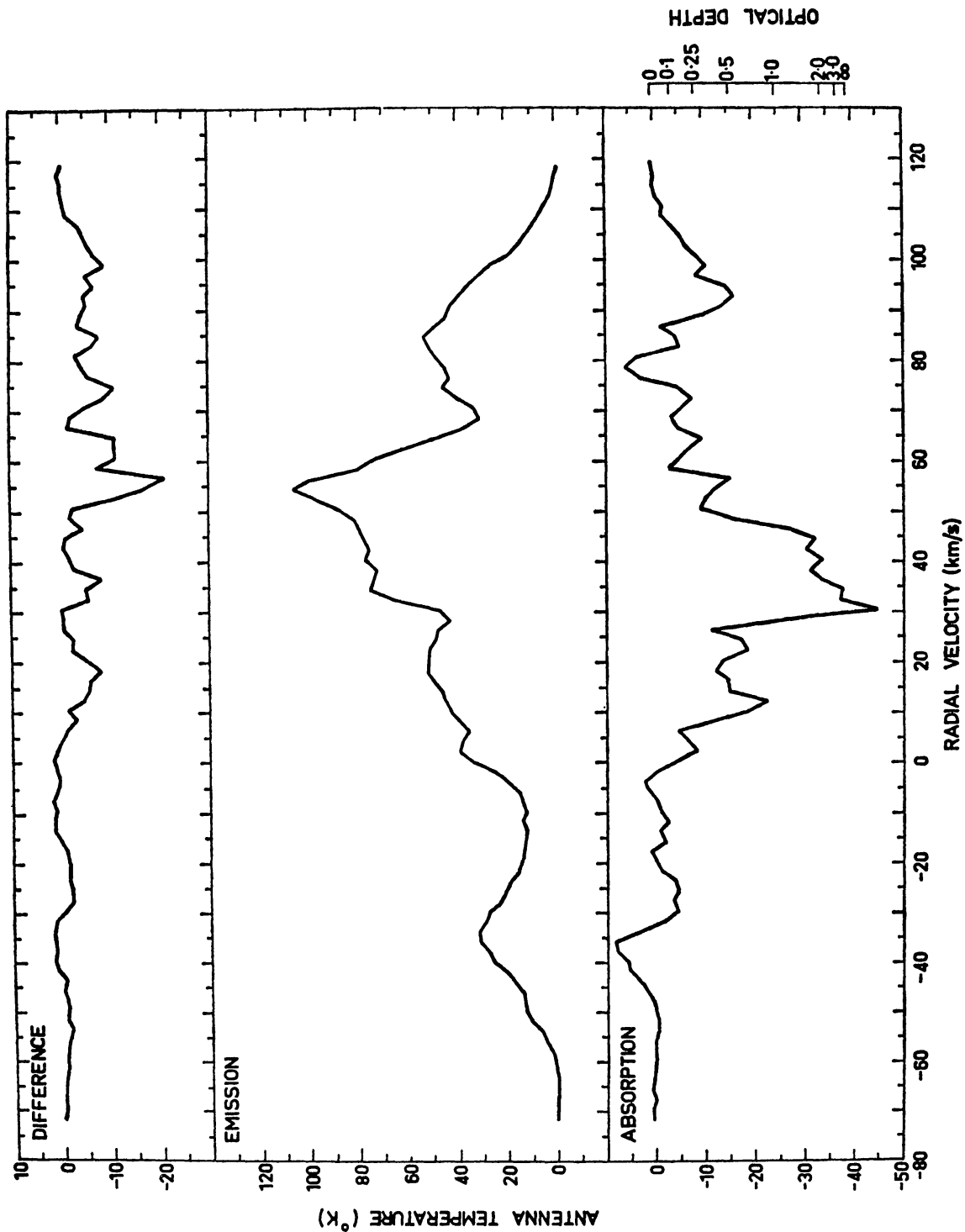


FIG. 36.—W44

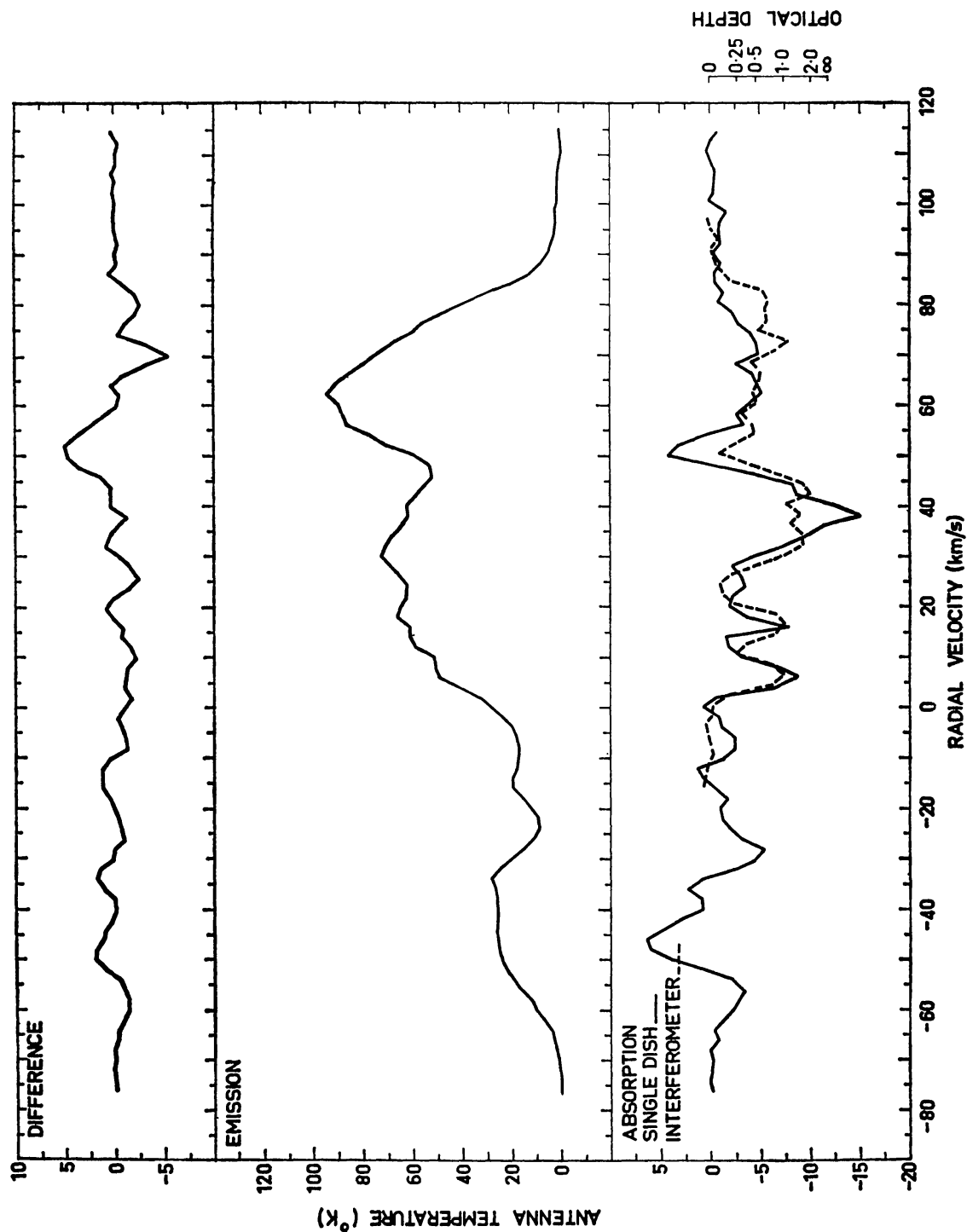


FIG. 37.—G41.1-0.3

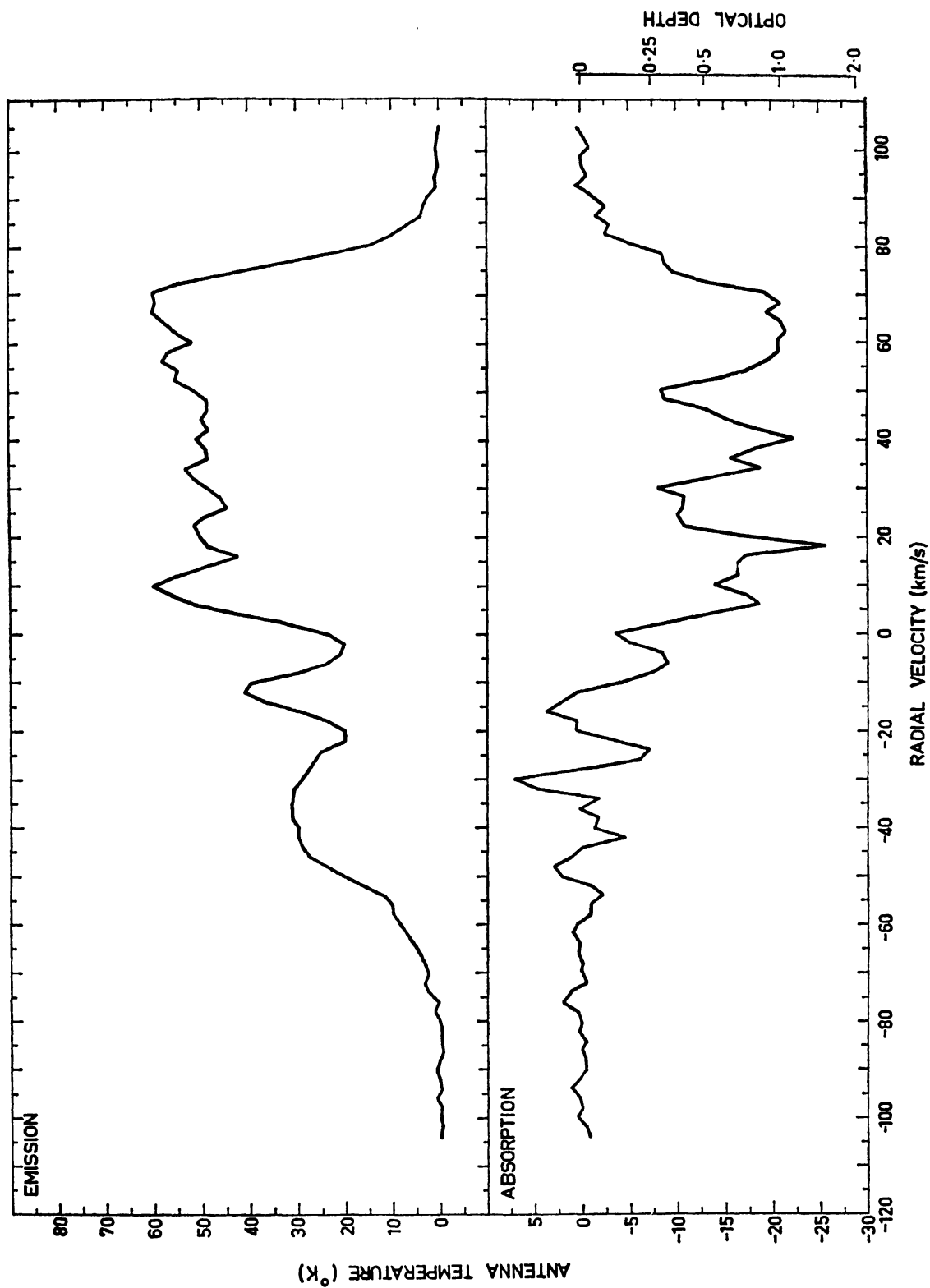


FIG. 38a—W49 A

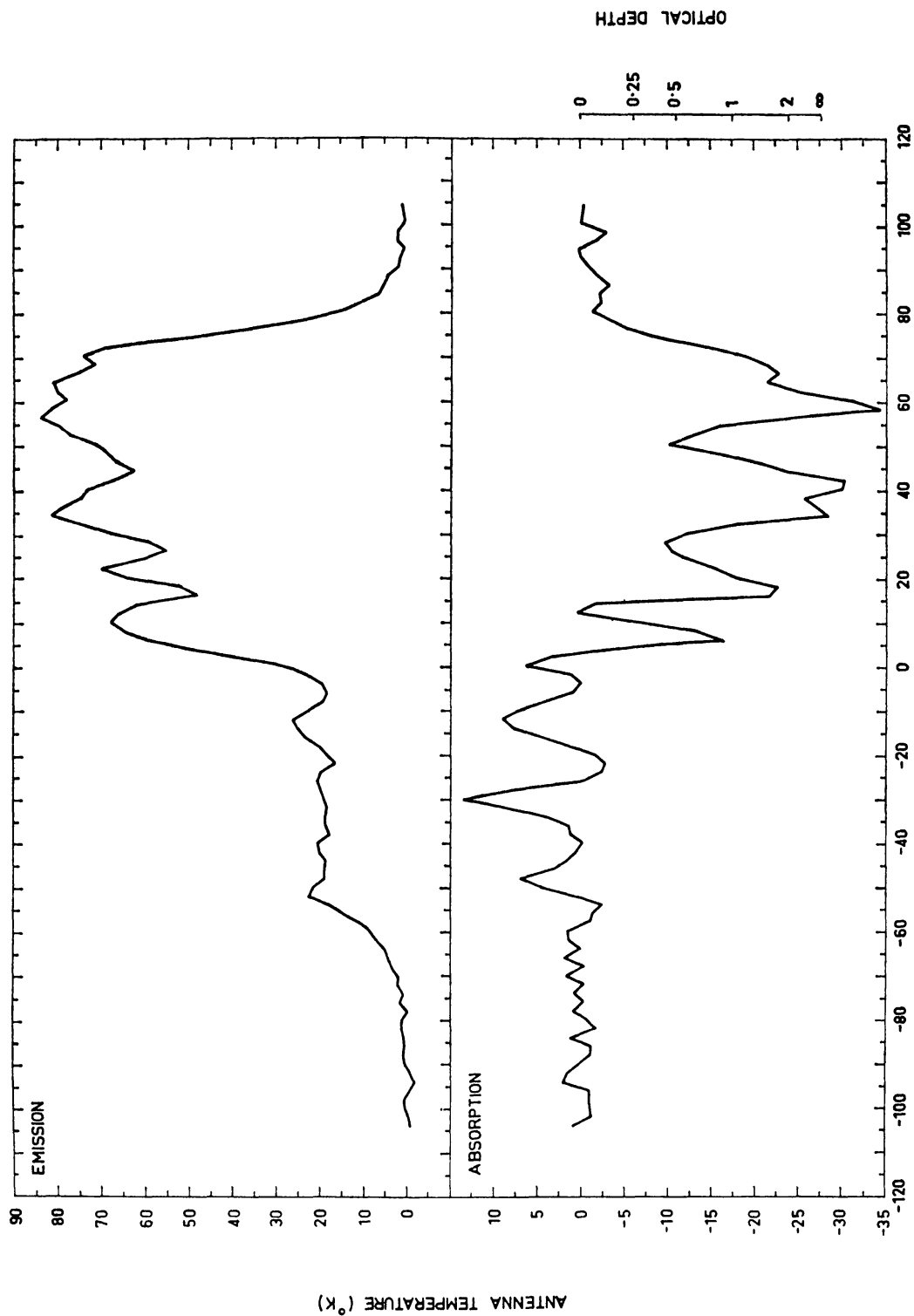


FIG. 38*b*.—W49 B

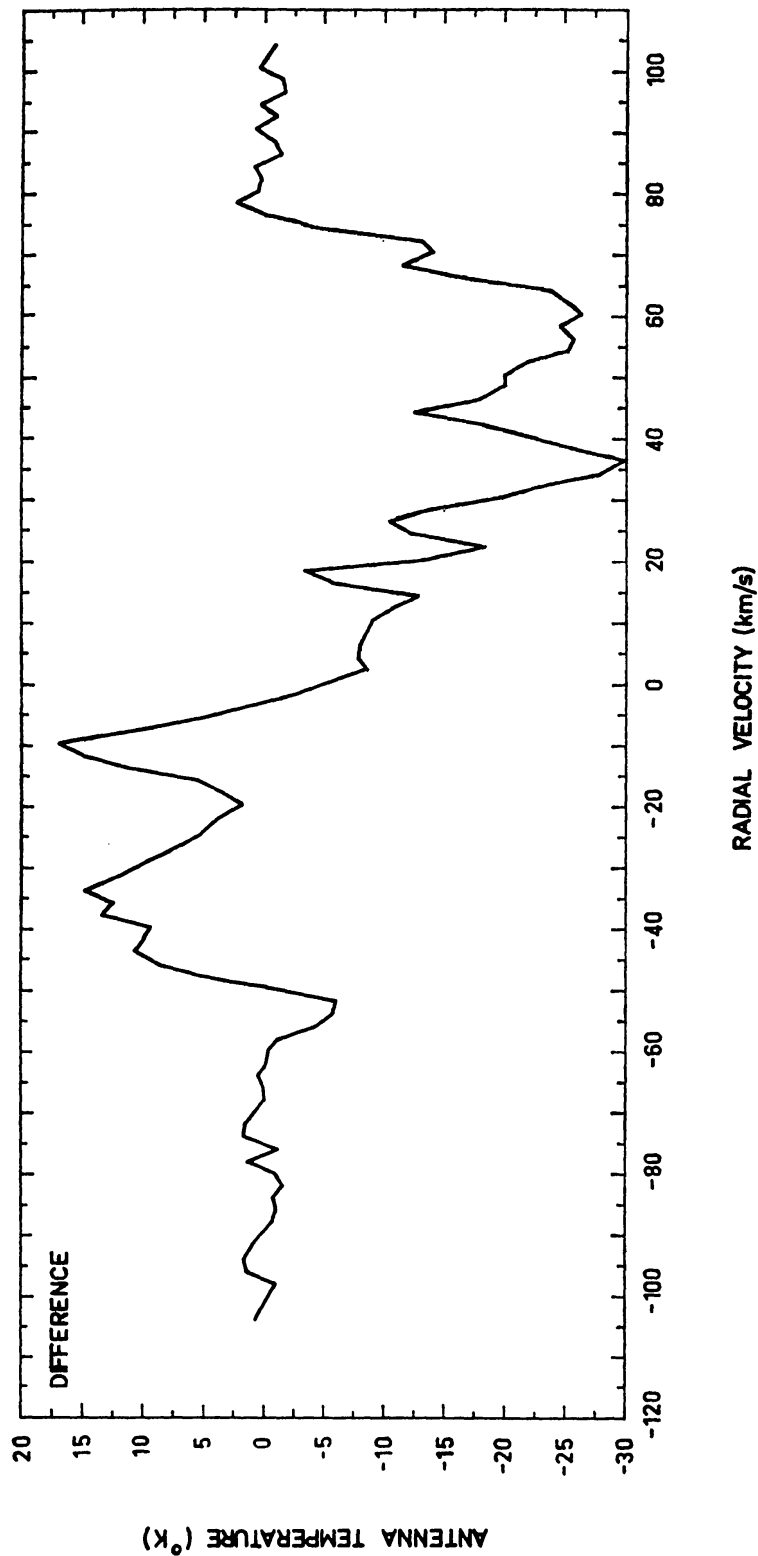


FIG. 38c.—Difference between the mean emission profiles for W49 A and W49 B

direction of the galactic center. The cloud covers an area of many square degrees, and this is the first appearance in this catalog. We shall see it again in the directions of at least a dozen sources situated closer to and beyond the direction of the galactic center.

l) G351.7–1.2 (Fig. 15a); G345.4–0.9 (RCW 117) (Fig. 7); G348.2–1.0 (RCW 121) (Fig. 9); G348.7–1.0 (RCW 122) (Fig. 11)

We have chosen to discuss these sources together because of certain similarities between them. An 11-cm map of the area from $l = 344^\circ$ to $l = 355^\circ$ (Beard, Thomas, and Day 1969) is shown in Figure 15*b*, where these four H II regions are indicated by arrows. All of these sources have latitudes of approximately -1° , and all of them show absorption to the cutoff in the emission from H I. The absorption profiles were not all of comparable quality, RCW 121 in particular having a very noisy interferometer profile due to the weakness of the source. The 4-kpc arm shows up prominently in emission only in the direction of RCW 117, but unfortunately the interferometer absorption profile

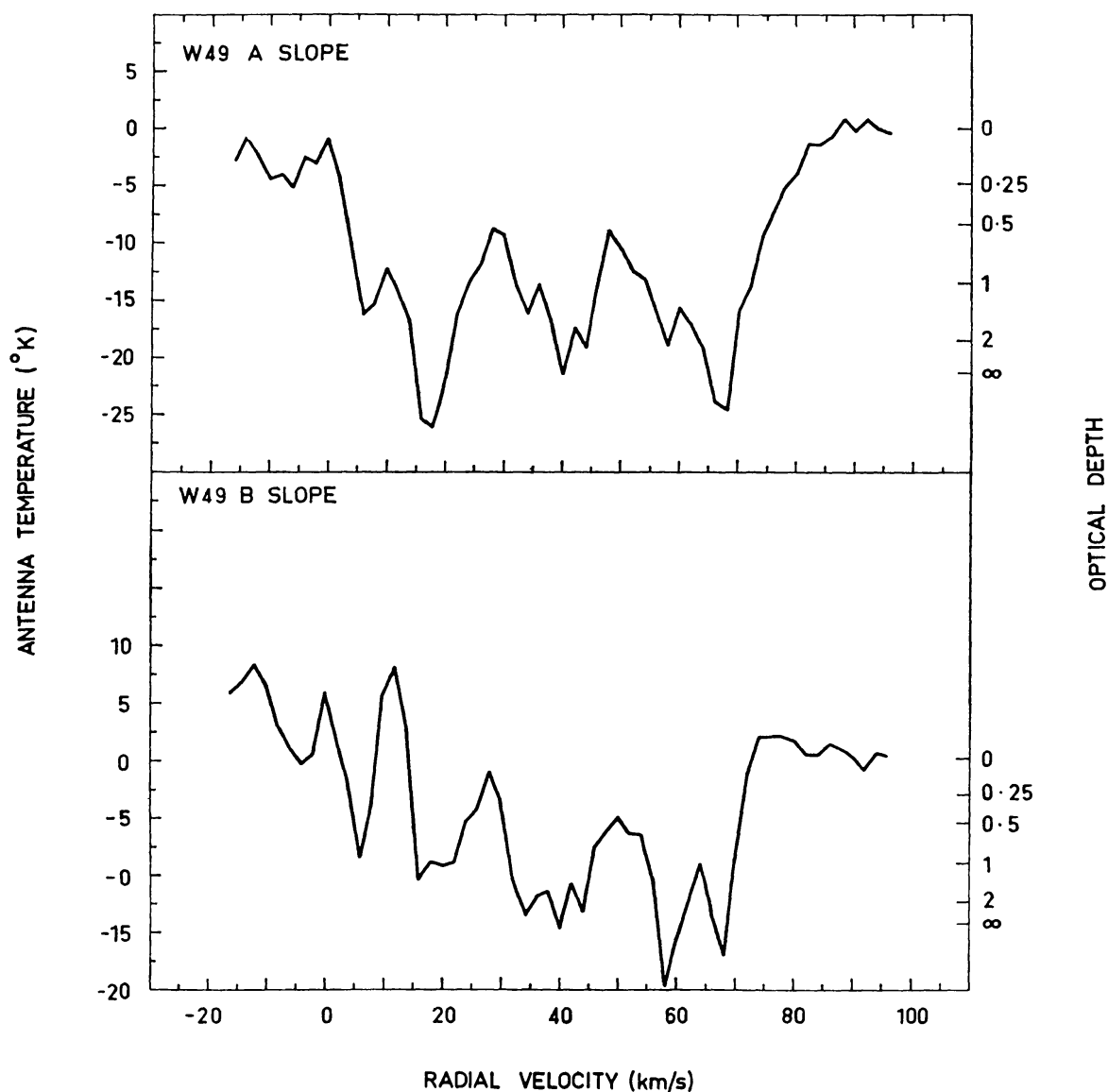


FIG. 38*d*.—Absorption profiles for W49 A and W49 B obtained with the single dish by using the “slope” method.

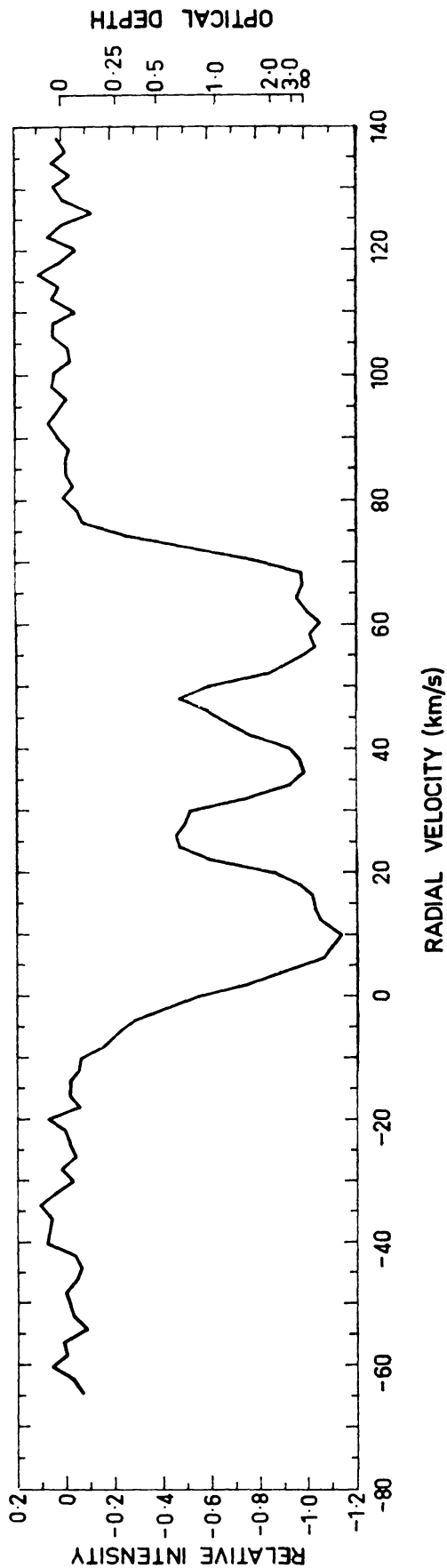


Fig. 38e.—An interferometer absorption profile for W49 A

for this source did not cover the appropriate velocity. The single-dish profile is very unreliable, and as a result we have no information as to whether absorption is present in the 4-kpc arm in the spectrum of RCW 117. In spite of these deficiencies in the observations, it is still quite clear that all four spectra show evidence of absorption up to the cutoff velocity in the emission. On this basis one would conclude that all four sources

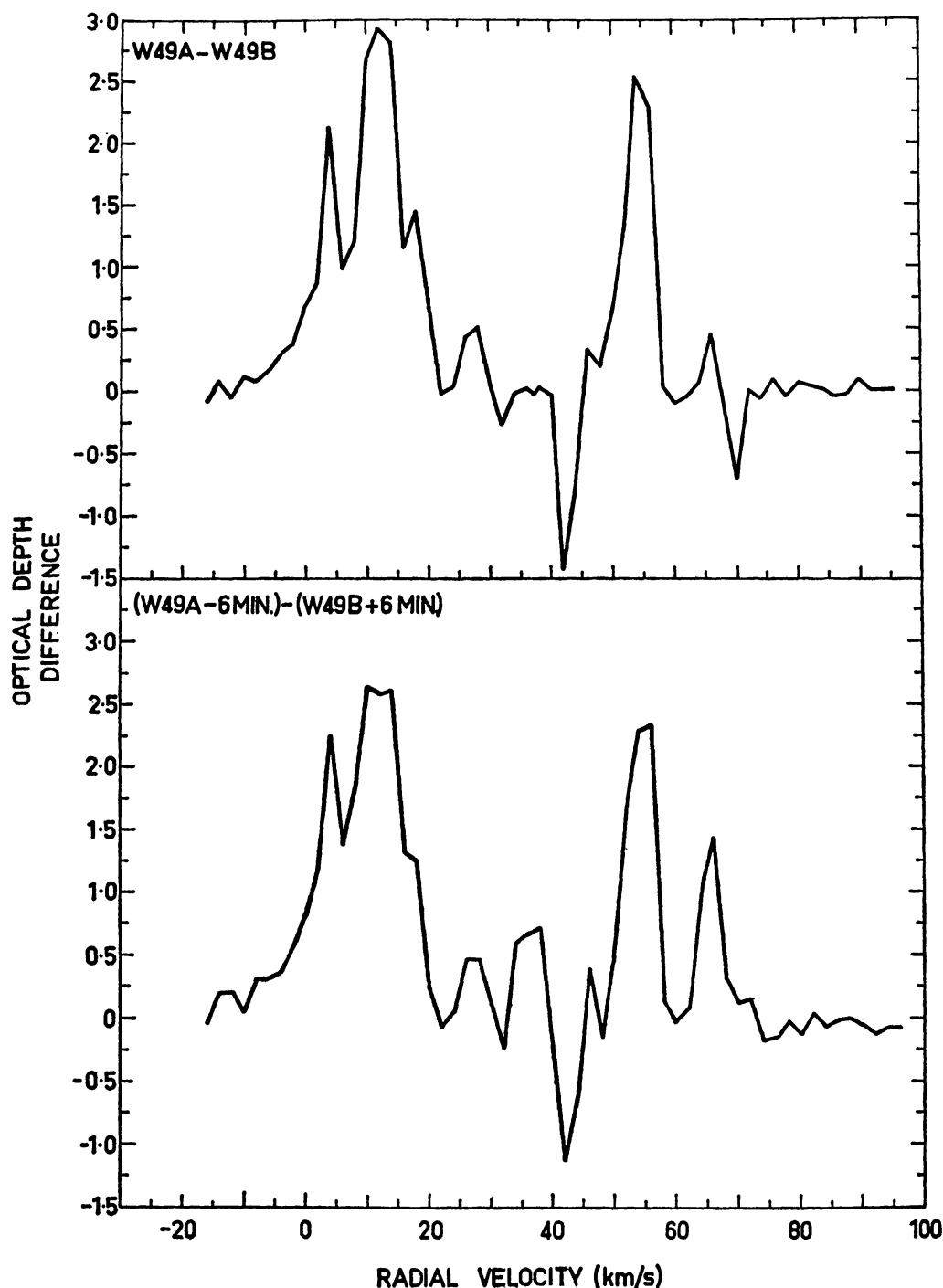


FIG. 38f.—Approximate differences in optical depths in the directions of the two components of W49 obtained by interferometer measurements in the directions of the two components (*upper*), and in directions $6'$ away from the two components (*lower*). See notes to sources for detailed explanation.

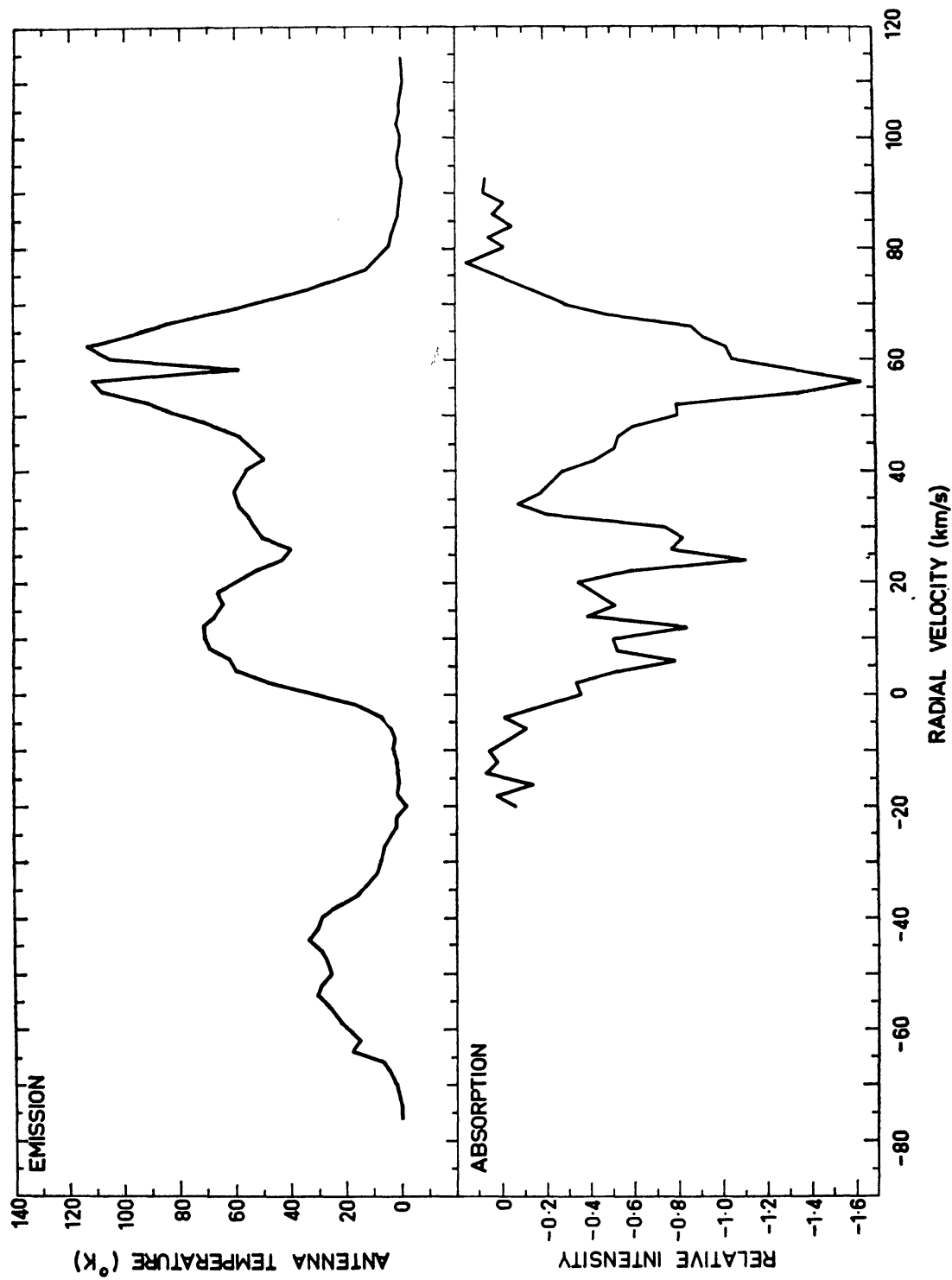


FIG. 39.—G45.5+0.1

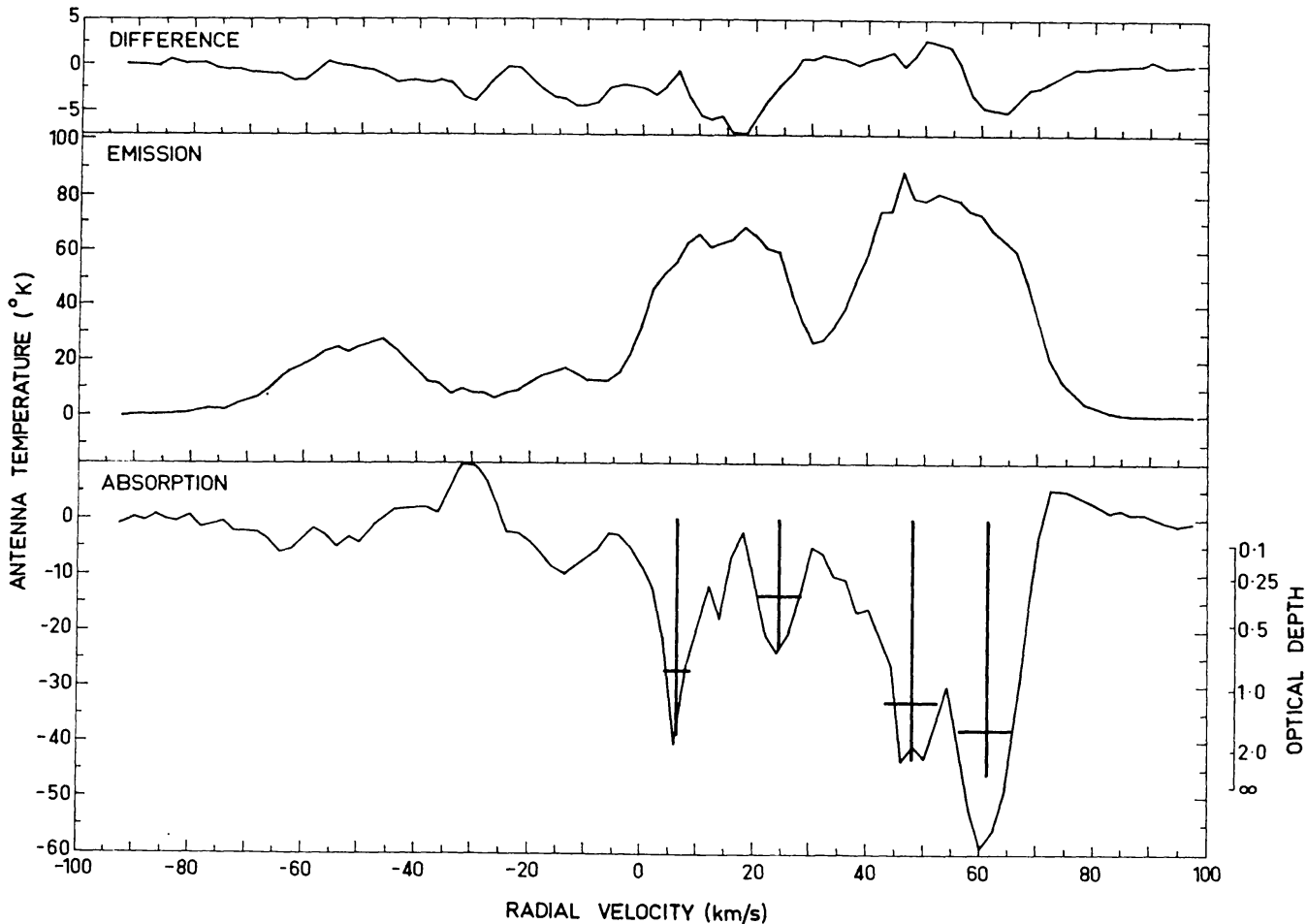


FIG. 40.—G49.1-0.4

were situated at a distance of 5 kpc or more. The difficulty with this simple interpretation is that it conflicts with other evidence on these sources. The last two have H109 α data showing velocities of -12.2 km s^{-1} . The corresponding distance alternatives are 2 and 17 kpc. If the H I absorption is used to reject the near distance, then the galactic latitude implies the improbably large Z displacement of $\sim 300 \text{ pc}$ at the alternative far distance of 17 kpc. The fact that RCW 122 is an optical object also throws doubt on the possibility of its being at a distance of 17 kpc from the Sun and yet unobscured.

The sources RCW 117, RCW 121, and RCW 122 are all optically visible; but, as mentioned above, they have H I absorption spectra indicating distances in excess of 5 kpc. One must conclude that the extinction in their general direction is low, or that they are near but have a bar of absorbing hydrogen with a large peculiar velocity in front of them. At a distance of 2 kpc, where its peculiar motion would be $\sim 30 \text{ km s}^{-1}$, such a bar would have to be $\sim 130 \text{ pc}$ in extent. A smaller linear dimension could be obtained by postulating a cloud very much closer to the Sun, but then its peculiar motion would have to be even greater than 30 km s^{-1} . On the other hand, if these sources are located at a distance of $\sim 5 \text{ kpc}$, then at least two of them have large peculiar motions as shown by their H109 α velocities.

Considering all these factors, it seems to us that the most reasonable hypothesis is that all four objects are situated on the edge of the Sagittarius arm, about 90 pc below the plane in a region where considerable star formation is taking place. The distance

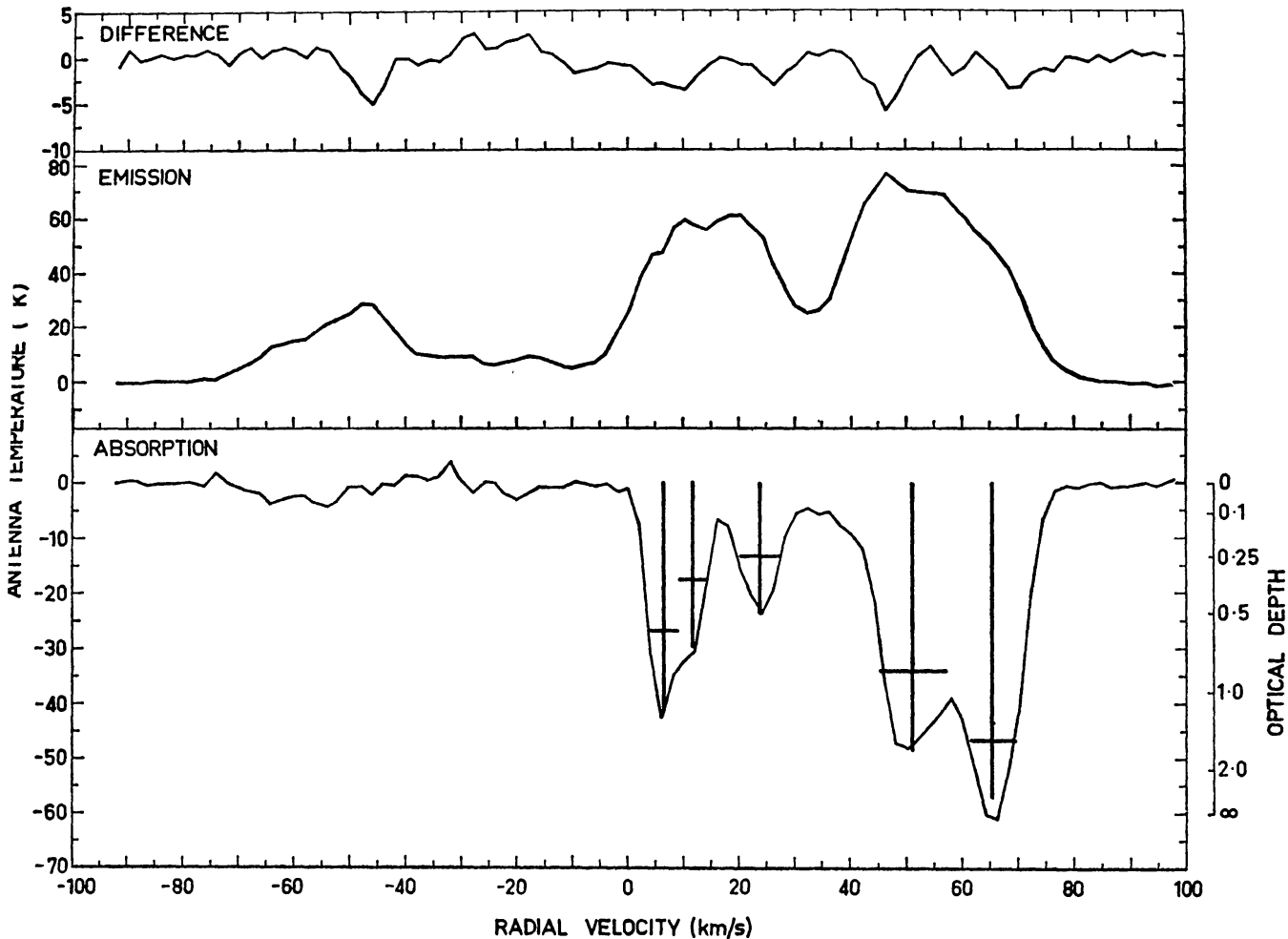


FIG. 41.—G49.5—0.4

must be of the order of 5 kpc, and the interstellar extinction low enough for three of these four objects to be optically visible. In Figures 15*c* and 15*d* (Plates 1 and 2) we show plates taken from the Whiteoak extension to the Palomar Sky Atlas (effective wavelength 6000 Å). Figure 15*c* shows the area near RCW 117. The nebulosity (west of center) is crossed by a major dust lane to the north. The area near RCW 121 and RCW 122 is shown in Figure 15*d*. In the southwest corner, RCW 121 can be seen as a bright and symmetrical nebulosity with a dust lane in the northeast corner. The source RCW 122 (east of center) can be seen in the same figure, heavily obscured and appearing as separated areas of nebulosity. The angular diameters of RCW 117, RCW 121, and RCW 122 are all of the order of 2'; these sizes are to be compared with the 35' extent of the nearby object NGC 6334 at $l = 351^\circ.4$ and $b = 0^\circ.7$.

GMR, who considered only the cases of RCW 122 and G351.7—1.2, arrived at the same conclusion as to the probable distance to these sources. If this conclusion is correct, the implication is that H II regions can sometimes have peculiar velocities of up to 30 km s⁻¹, which may lead to serious errors in distance determinations based *only* on their recombination line velocities.

(We have recently learned that H109α data have also been obtained on the first two of these four sources [Turner, private communication].) The velocities obtained (−23.3 km s⁻¹ for RCW 117, −18.9 km s⁻¹ for RCW 121) do not affect our discussion of these sources and in fact reinforce our conclusions about the prevalence of peculiar velocities.

PLATE 1

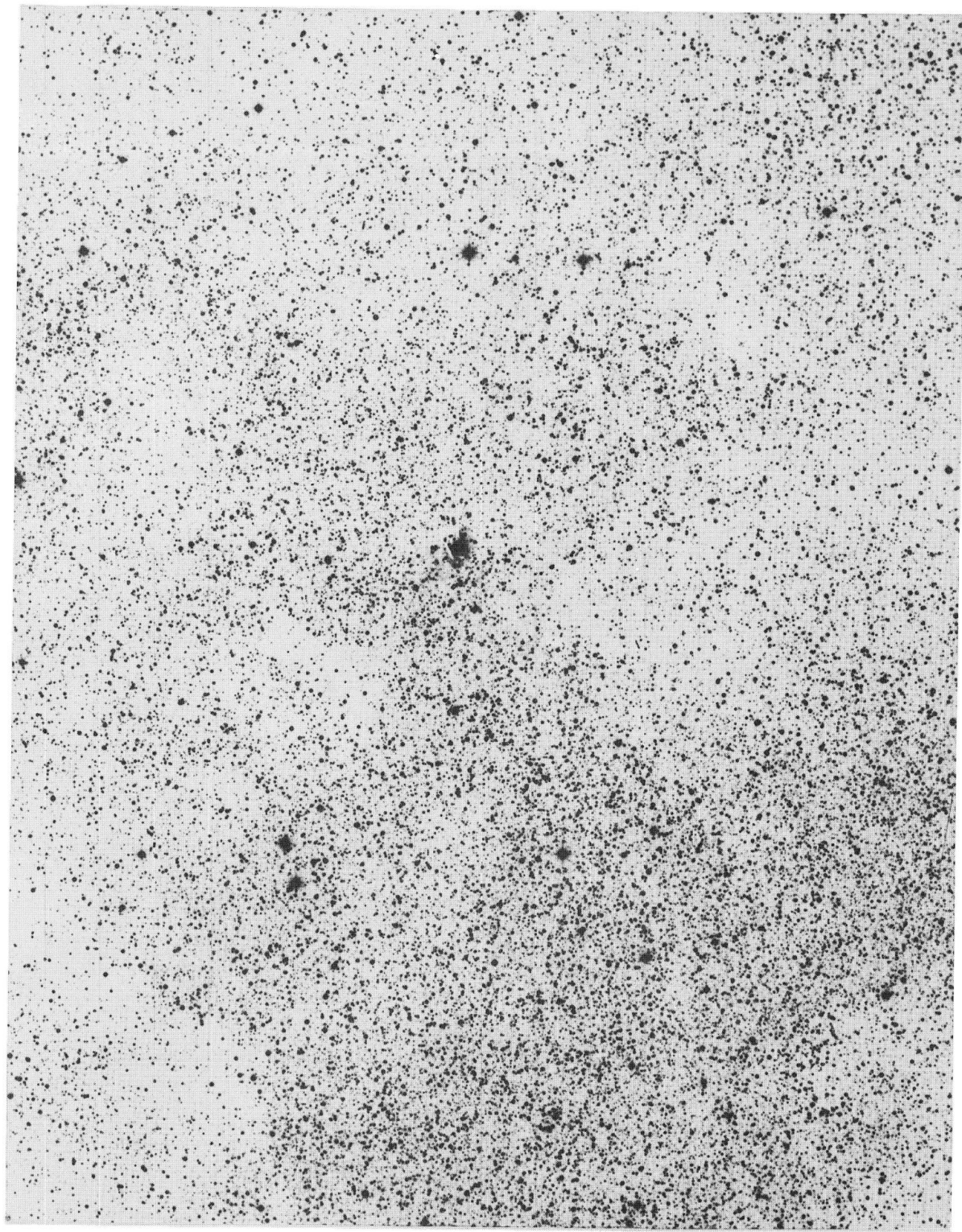


FIG. 15c.—RCW 117 is the $2' \times 2'$ nebula seen here on a portion of the 17^h , -42° plate of the Whiteoak extension to the Palomar Sky Atlas (effective wavelength $6000 \text{ \AA}$). The nebula is to the right of the center. North is at the top and east to the left. The east-west dimension is approximately 1° .

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PLATE 2

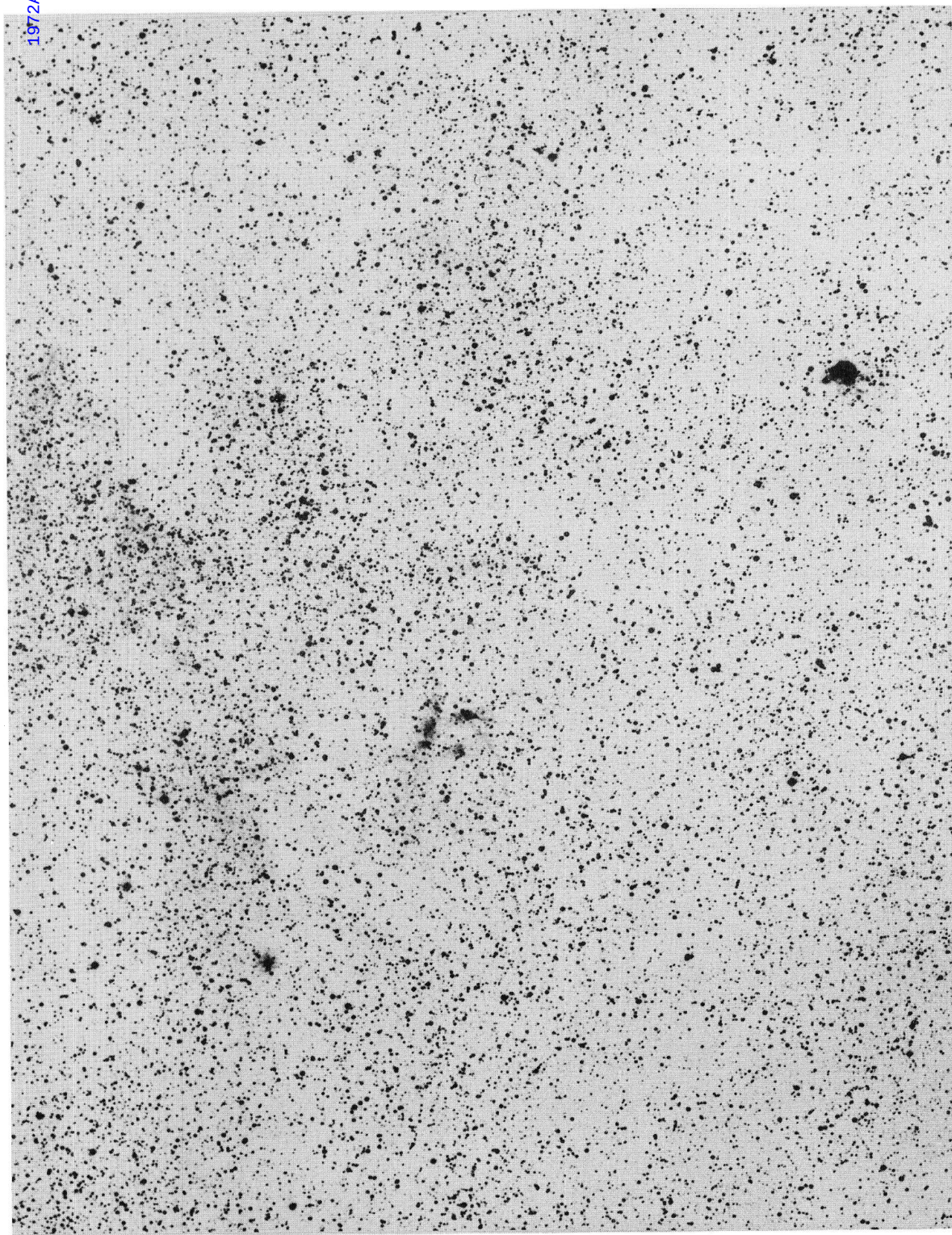


FIG. 15*d*.—RCW 121 is the bright $3' \times 2'$ nebulosity seen in the right-hand lower corner. RCW 122 is the faint nebulosity ($2' \times 2'$) to the left of the center. This picture was taken from the $17^{\text{h}} 16^{\text{m}}, -36^{\circ}$ plate of the Whiteoak extension to the Palomar Sky Atlas. The orientation and east-west extent are the same as for Fig. 15*c*.

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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)	Ref. (7)	Distance (kpc) (8)	Ref. (9)	T _A (° K) (10)	Other Absorption Line Data (11)	Ref. (12)	Absorption Measurement (13)	Figure Number (14)
G184.6-5.8....	Crab	05 ^h 31 ^m 31 ^s	+21° 59'	SNR	...	...	2	1	530	{H OH}	2, 3, 4 5	SD, I	2a, b
G206.5-16.4....	W12, NGC 2024	05 39 11	-01 56	H II	6.0	6	0.5	6	36	{H OH H ₂ CO}	27 5, 7 8, 21	SD, I	3a, b
G208.9-19.3....	Orion	05 32 50	-05 26	H II	- 2.8	6	0.5	6	217	{H OH}	2, 4, 9 5	SD, I	4a, b
G265.1+1.5....	RCW 36, CTB 32	08 57 38	-43 34	H II	2.8	6	1-2	This work	17.5	{H OH H ₂ CO}	13, 27 7 8	SD, I	5
G267.9-1.0....	RCW 38, CTB 31	08 58 05	-47 20	H II	1.8	6	1-2	This work	100	{H OH H ₂ CO}	13, 27 7 8	SD, I	6a, b
G345.4-0.9....	RCW 117	17 06 00	-41 33	H II?	...	...	~ 5	This work	17.5	...	...	SD, I	7; 15b, c
G345.4+1.4....	CTB 35	16 56 10	-40 07	H II	-14.6	6	2	6, this work	20*	H	16	SD	8
G348.2-1.0....	RCW 121	17 14 59	-39 16	H II?	...	...	~ 5	This work	6	...	...	I	9; 15b, d
G348.5+0.1....	CTB 37	17 11 12	-38 27	SNR	...	...	~ 3	This work	28*	{H OH}	16 10	SD	10
G348.7-1.0....	RCW 122	17 16 39	-38 55	H II	-12.8	6	~ 5	This work	26.5	{OH H ₂ CO}	10 8	SD, I	11; 15b, d
G351.1+0.7....	NGC 6334	17 16 26	-36 02	H II	...	...	1	12	33*	...	...	SD	12; 14b
G351.2+0.5....	NGC 6334	17 17 33	-36 01	H II	...	...	1	12	23*	...	...	SD	13
G351.3+0.7....	NGC 6334	17 17 16	-35 47	H II	- 3.2	6	1	12	76*	{H H ₂ CO OH}	13, 16 8 14	SD, I	14a, b
G351.7-1.2....	...	17 25 59	-36 35	H II	-12.2	11	~ 5	This work	17	OH	10	SD, I	15a, b

*Reference regions for the expected emission profile contain a small amount of continuum emission.

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)	Ref. (7)	Distance (kpc) (8)	Ref. (9)	T_A (° K) (10)	Other Absorption Line Data (11)	Ref. (12)	Absorption Measurement (13)	Figure Number (14)
G353.2+0.7....	W22	17 ^h 22 ^m 18 ^s	-34° 20'	H II	- 2.9	11	1	15	85*	{H OH H ₂ CO H	{13, 16 5 8 16	SD	16
G353.2+0.9....	W22	17 21 30	-34 08	H II	- 3.3	11	1		77*	{H ₂ CO H	{8 16	SD	17
G357.7-0.1....	MSH 17-39	17 37 09	-30 56	SNR	...	...	> 6	This work	19	...	...	SD, I	18
G0.0-0.0.....	Sgr A	17 42 30	-28 59	NT	...	...	10	...	225†	{H OH H ₂ CO	{2, 4, 17 18 19	SD, I	19
G0.7-0.0.....	Sgr B2	17 44 07	-28 22	H II	61.6	11	10	17	56*	{H OH H ₂ CO	{17 20 19	SD	20
G4.5+6.8.....	3C 358 (Kepler's SN)	17 27 43	-21 26	SNR	...	...	11.4?†	1	8	...	...	SD, I	21
G6.0-1.2.....	M8	18 00 38	-24 24	H II	3.0	11	1.4	15	42.5*	{H OH H ₂ CO	{4, 16, 27 5 21	SD, I	22a, b
G6.6-0.2.....	W28	17 58 20	-23 25	SNR	...	...	1.5?†	1	30*	{H OH	{16, 27 5, 20	SD	23
G10.2-0.3.....	W31	18 06 23	-20 20	H II	13.9	11	9?†	This work	32*	{OH H ₂ CO	{5 21	SD, I	24
G11.2-0.3.....	...	18 08 32	-19 27	SNR	...	...	> 4.5	This work	12	...	...	I	25a, b
G12.8-0.2.....	W33	18 11 13	-17 58	H II	36.3	11	4.6	This work	20.4	{OH H ₂ CO	{5, 20 21	SD, I	26
G15.0-0.6.....	M17	18 17 36	-16 13	H II	17.2	11	2.4	15	274*	{H OH H ₂ CO	{4, 16, 27 5 8, 21	SD	27a, b
G16.9+0.8.....	M16	18 15 54	-13 48	H II	24.5	11	2.2	15	27	{H OH H ₂ CO	{4, 27 5 21	SD	28
G21.8-0.6.....	MSH 18-113	18 30 20	-10 14	SNR	...	...	~ 4	This work	18.7	...	...	SD	29

† For Sgr A the expected emission profile was obtained at symmetrical positions where the continuum antenna temperature was 22.5° below that at the peak of Sgr A.

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)	Ref. (7)	Distance (kpc) (8)	Ref. (9)	T ₄ (°K) (10)	Other Absorption Line Data (11)	Ref. (12)	Absorp- tion Measure- ment (13)	Figure Number (14)
G25.4-0.2.....	NRAO 572	18 ^h 35 ^m 30 ^s *	-06° 50'	H II	60.4	11	~ 5	This work	14.5	...	...	I	30
G28.8+3.5.....	W40	18 28 53	-02 08	H II	0.7	11	0.6±0.3	This work	18.5	OH	22	SD	31a, b
G29.9-0.1.....	...	18 43 31	-02 45	H II	96.4	11	7-10	11 & this work	9.3	...	...	SD	32
G30.8-0.0.....	W43	18 45 01	-02 00	H II	92.3	11	7	This work	51*	{ H OH H ₂ CO H }	{ 4, 16 5, 20 8, 21 16 }	SD, I	33
G31.9+0.0.....	3C 391	18 46 47	-00 59	SNR?	...	...	<13.4	This work	10	H	16	I	34
G35.2-1.8.....	W48	18 59 15	+01 08	H II	46.5	11	3.4	This work & 11	8.2	OH	5	SD, I	35
G34.6-0.5.....	W44	18 53 48	+01 18	SNR	...	...	~ 3.0	This work & 5	39*	{ H OH H ₂ CO }	{ 16 5, 20 21 }	SD	36
G41.1-0.3.....	3C 397	19 05 01	+07 03	SNR	...	...	> 7.5	This work	11.8	...	...	SD, I	37
G43.2-0.0.....	W49 A	19 07 55	+09 01	H II	8.6	11	14	11	33	{ H H ₂ CO }	{ 23, 24, 26 8, 21 }	SD, I	38a, d, e
G43.3-0.2.....	W49 B	19 08 44	+09 01	SNR	...	...	10	24 & this work	22	{ H H ₂ CO }	{ 23, 24, 26 8 }	SD, I	38b, d
G45.5+0.1.....	NRAO 601	19 12 00	+11 04	H II?	...	...	6-7	22 & this work	8.8	...	...	I	39
G49.1-0.4.....	W51	19 20 32	+14 03	H II	~67	25	6.5	25 & this work	48*	{ H OH H ₂ CO }	{ 13, 16 14 8, 21 }	SD	40
G49.5-0.4.....	W51	19 21 25	+14 25	H II	~59	25	8.0	25 & this work	60*	{ H OH H ₂ CO }	{ 13, 16 14 8, 21 }	SD	41

REFERENCES TO TABLE 1

- | | |
|--------------------------------------|--|
| 1. Milne (1970) | 15. Shaver and Goss (1970) |
| 2. Muller (1959) | 16. Kerr and Knapp (1970) |
| 3. Shuter and Verschuur (1964) | 17. Kerr and Vallak (1967) |
| 4. Clark (1965) | 18. Robinson <i>et al.</i> (1964) |
| 5. Goss (1968) | 19. Gardner and Whiteoak (1970) |
| 6. Wilson <i>et al.</i> (1970b) | 20. Robinson <i>et al.</i> (1970) |
| 7. Manchester <i>et al.</i> (1970) | 21. Zuckerman <i>et al.</i> (1970) |
| 8. Whiteoak and Gardner (1970) | 22. Downes (1970) |
| 9. Menon (1970) | 23. Akabane and Kerr (1965) |
| 10. Robinson <i>et al.</i> (1971) | 24. Kazès and Nguyen-Quang-Rieu (1970) |
| 11. Reifenstein <i>et al.</i> (1970) | 25. Wilson <i>et al.</i> (1970a) |
| 12. Roslund (1966) | 26. Sato <i>et al.</i> (1967) |
| 13. Clark <i>et al.</i> (1962) | 27. Menon and Williams (1968). |
| 14. Weaver <i>et al.</i> (1968) | |

m) W22 (NGC 6357) (Figs. 16 and 17)

The sources G353.2+0.7 and G353.2+0.9 are the two components of this H II region with an optically determined distance of 1 kpc. As in the case of NGC 6334, these two components were observed as one source by CRW but have been separately observed here. The difference in the shape of the absorption profiles for the two sources is noticeable. We have made no attempt to fit Gaussians, because of the obvious multiplicity of features and the great optical depth. Goss found two OH absorption lines at -3.1 and 5.7 km s $^{-1}$.

Note the self-absorption feature in both emission profiles at $+6$ km s $^{-1}$.

n) G357.7-0.1 (MSH 17-39) (Fig. 18)

From its nonthermal spectrum this source has been presumed to be a supernova remnant and been given a distance of 7.2 kpc by Milne from its surface brightness. It is situated close to the galactic center, and according to Reifenstein *et al.* (1970) it shows no evidence of the H109 α recombination line. The H I profile shows the 4-kpc arm in absorption, indicating a distance in excess of 6 kpc from the Sun.

Note the self-absorption feature in the emission profile increasing in prominence.

o) Sgr A (Fig. 19)

The most interesting new result on this source which has been studied by numerous authors is the prominence of the $+50$ km s $^{-1}$ feature in the interferometer profile. Kerr and Vallak (1967) first noted an H I feature at this velocity where the OH absorption is so prominent. Kerr and Sandquist (1968) have shown from occultation measurements that the OH cloud is $3' \times 5'$ in size. The H I cloud must also be small, as seen from the difference in apparent optical depths between the interferometer and the single-dish measurements. As discussed in the Introduction, the reference profiles for the single-dish measurement contained absorption effects from the extended part of the source. The profiles were obtained in directions where the antenna temperature had dropped by 225° K from its peak value. The optical depths thus derived should refer to the central source only. That this is probably so is shown by the agreement of the single-dish and interferometer optical depths for the 4-kpc arm, in contrast to the disagreement between the interferometer measurements of BGC and the 25-m single-dish measurements of Rougoor (1964) discussed by BGC. Our measurements show only marginal evidence for the reality of the 135 km s $^{-1}$ feature claimed by Kerr and Vallak (1967).

p) Sgr B2 (Fig. 20)

This H II region has a H109 α velocity of 61.6 km s $^{-1}$, close to the velocity of the OH emission from it. Kerr and Vallak (1967) pointed out that the source must lie beyond the

TABLE 2
GAUSSIAN FITTING OF H I ABSORPTION LINES*

Source (1)	Frequency Resolution (kHz) (2)	Type of Measure- ment (3)	Radial Velocity (km s ⁻¹) (4)	$\tau_{\max}$ (5)	$\Delta V_{1/2}$ (km s ⁻¹) (6)	$N_{\mathrm{H}}/T_{\ast}^{\dagger}$ (cm ⁻² ° K ⁻¹) (7)	$N_{\mathrm{H}}^{\ddagger}$ (cm ⁻²) (8)	Kinematic Distance (kpc) (9)
G184.6-5.8....	1	SD	- 1.4 ± 0.3 2.84 ± 0.04 5.52 ± 0.03 7.95 ± 0.03 10.64 ± 0.02	0.16 ± 0.02 0.79 ± 0.02 0.52 ± 0.02 0.22 ± 0.02 1.17 ± 0.02	5.6 ± 0.6 3.4 ± 0.1 2.52 ± 0.07 1.47 ± 0.07 2.31 ± 0.05	1.7 × 10 ¹⁸ (10) 5.30 × 10 ¹⁸ (2) 2.57 × 10 ¹⁸ (3) 6.30 × 10 ¹⁷ (8) 5.29 × 10 ¹⁸ (1)	8.5 × 10 ¹⁹ 2.7 × 10 ²⁰ 1.3 × 10 ²⁰ 3.2 × 10 ¹⁹ 2.6 × 10 ²⁰	
G206.5-16.4...	1	SD	7.5 ± 0.2 11.0 ± 0.1 9.7 ± 0.1	0.8 ± 0.1 1.3 ± 0.1 5.3	3.7 ± 0.4 4.4 ± 0.2 5.8	5.7 × 10 ¹⁸ (8) 1.1 × 10 ¹⁹ (3) 6.0 × 10 ¹⁹	2.9 × 10 ²⁰ 5.5 × 10 ²⁰ 3.0 × 10 ²¹	0.8§ 1.2§ 1.0§
G206.5-16.4...	9.5	I	- 3.2 ± 0.4	0.11 ± 0.03	4.3 ± 1.0	9.3 × 10 ¹⁷ (20)	4.7 × 10 ¹⁹	...
G208.9-19.3...	1	SD	2.9 ± 0.1 5.51 ± 0.04	1.01 ± 0.02 1.05 ± 0.02	6.3 ± 0.2 3.7 ± 0.1	1.24 × 10 ¹⁹ (1) 7.55 × 10 ¹⁸ (2)	6.2 × 10 ²⁰ 3.8 × 10 ²⁰	0.3 0.5
G265.1+1.5....	9.5	I	4.8 ± 0.1	3.5	4.7	3.3 × 10 ¹⁹	1.7 × 10 ²¹	1.3
G267.9-1.0....	1	SD	- 2.7 ± 0.9 2.5 ± 0.1 7.1 ± 0.1	0.6 ± 0.3 3.6 4.3	5.2 ± 2.0 4.1 3.0	6.0 × 10 ¹⁸ (32) 2.9 × 10 ¹⁹ 2.5 × 10 ¹⁹	3.0 × 10 ²⁰ 1.5 × 10 ²¹ 1.3 × 10 ²¹	... 1.0 2.0
G345.4-0.9....	9.5	I	-33.3 ± 0.3 -21.7 ± 0.2 - 7.6 ± 0.2	1.5 ± 0.2 1.9 ± 0.1 0.7 ± 0.1	4.9 ± 0.7 8.5 ± 0.5 7.1 ± 0.5	1.4 × 10 ¹⁹ (11) 3.1 × 10 ¹⁹ (4) 1.0 × 10 ¹⁹ (10)	7.0 × 10 ²⁰ 1.6 × 10 ²¹ 5.0 × 10 ²⁰	2.7 3.8 1.1
G348.7-1.0....	9.5	I	1.4 ± 0.2 10.6 ± 0.2 -40.0 ± 3.0 -30.4 ± 0.4 -13.4 ± 0.2	0.58 ± 0.07 0.33 ± 0.04 0.2 ± 0.2 1.8 ± 0.3 3.1	7.1 ± 0.5 9.8 ± 0.5 4.1 ± 4.0 5.3 ± 1.0 7.5	8.0 × 10 ¹⁸ (12) 6.3 × 10 ¹⁸ (13) 1.9 × 10 ¹⁸ (70) 1.9 × 10 ¹⁹ (10) 4.5 × 10 ¹⁹	4.0 × 10 ²⁰ 3.2 × 10 ²⁰ 9.5 × 10 ¹⁹ 9.5 × 10 ²⁰ 2.3 × 10 ²¹	 5.3 4.2 2.2
G351.1+0.7....	9.5	SD	- 1.6 ± 0.2 + 6.5 ± 0.2 - 5.0 ± 0.6	0.7 ± 0.1 1.4 ± 0.2 1.6 ± 0.4	5.1 ± 0.5 3.5 ± 0.5 6.7 ± 1.4	6.0 × 10 ¹⁸ (23) 9.6 × 10 ¹⁸ (12) 2.0 × 10 ¹⁹ (16)	3.0 × 10 ²⁰ 4.8 × 10 ²⁰ 1.0 × 10 ²¹	0.3 ... 1.1
G351.2+0.5....	9.5	SD	4.8 ± 0.4 3.0 ± 0.6	1.7 ± 0.3 1.9	6.4 ± 0.9 14.0	2.1 × 10 ¹⁹ (10) 5.3 × 10 ¹⁹	1.0 × 10 ²¹ 2.7 × 10 ²¹	
G351.3+0.7....	9.5	SD	- 4.3 ± 0.2 7.1 ± 0.2	1.50 ± 0.06 1.29 ± 0.06	10.0 ± 0.4 6.4 ± 0.3	2.9 × 10 ¹⁹ (3) 1.6 × 10 ¹⁹ (3)	1.5 × 10 ²¹ 8.0 × 10 ²⁰	1.0 ...

* Errors quoted are twice the rms errors of the Gaussian fit.

† Figures in brackets are percentage errors.

‡ Calculated on the assumption of a spin temperature of 50° K for the absorbing clouds.

§ Kinematic distance greater than source distance.

TABLE 2—Continued

Source (1)	Frequency Resolution (kHz) (2)	Type of Measure- ment (3)	Radial Velocity (km s ⁻¹) (4)	τ_{max} (5)	$\Delta V_{1/2}$ (km s ⁻¹) (6)	$N_{\text{H}}/T_{\text{e}}^{\dagger}$ (cm ⁻² ° K ⁻¹) (7)	$N_{\text{H}}^{\dagger}$ (cm ⁻²) (8)	Kinematic Distance (kpc) (9)
G351.7-1.2.....	9.5	I	-28.7 ± 3.4	0.3 ± 0.2	17 ± 8	9.4 × 10 ¹⁸ (40)	4.7 × 10 ²⁰	5.1
			-18.1 ± 0.2	3.2 ± 0.3	4.0 ± 0.4	2.4 × 10 ¹⁹ (7)	1.2 × 10 ²¹	3.5
			-10.9 ± 0.1	3.3 ± 0.2	5.6 ± 0.3	3.7 × 10 ¹⁹ (4)	1.9 × 10 ²¹	2.3
			1.5 ± 0.1	1.7 ± 0.1	7.5 ± 0.3	2.4 × 10 ¹⁹ (5)	1.2 × 10 ²¹	...
G357.7-0.1.....	9.5	I	7.6 ± 0.1	1.1 ± 0.1	5.7 ± 0.3	1.2 × 10 ¹⁹ (9)	6.0 × 10 ²⁰	...
			-61.2 ± 4.0	0.4 ± 0.3	8.5 ± 5.0	6.8 × 10 ¹⁸ (60)	3.4 × 10 ²⁰	...
			-27.2 ± 4.0	0.2 ± 0.1	12 ± 5	4.0 × 10 ¹⁸ (60)	2.0 × 10 ²⁰	...
			-10.0 ± 0.5	3.5	9.3	6.3 × 10 ¹⁹	3.2 × 10 ²¹	...
G4.5+6.8.....	9.5	I	6.9 ± 0.4	3.1	9.9	5.9 × 10 ¹⁹	3.0 × 10 ²¹	...
			18.0 ± 0.4	0.5 ± 0.2	7.7 ± 1.0	7.8 × 10 ¹⁸ (40)	3.9 × 10 ²⁰	...
			5.3 ± 0.1	2.6 ± 1.6	4.7 ± 0.2	2.4 × 10 ¹⁹ (5)	1.2 × 10 ²¹	2.1 18.0
			12.3 ± 0.1	[0.6 ± 0.1]	[2.9 ± 0.2]	3.3 × 10 ¹⁸ (18)	1.7 × 10 ²⁰	4.2 15.9
G6.0-1.2.....	1	SD	5.6 ± 0.1	2.0 ± 0.2	2.0 ± 0.2	8.1 × 10 ¹⁸ (5)	4.1 × 10 ²⁰	1.6
G6.0-1.2.....	9.5	I	7.5 ± 0.1	1.9 ± 0.1	2.2 ± 0.2	8.1 × 10 ¹⁸ (4)	4.1 × 10 ²⁰	2.28
			5.4 ± 0.2	2.0 ± 0.3	3.0 ± 0.4	1.1 × 10 ¹⁹ (13)	5.5 × 10 ²⁰	1.7
			7.9 ± 0.1	[2.6 ± 0.2]	[3.4 ± 0.2]	1.7 × 10 ¹⁹ (6)	8.5 × 10 ²⁰	2.2
			15.4 ± 0.1	0.44 ± 0.05	8.0 ± 0.2	6.8 × 10 ¹⁸ (12)	3.4 × 10 ²⁰	4.0
G6.6-0.2.....	9.5	SD	7.3 ± 0.2	4.3	3.5	2.9 × 10 ¹⁹	1.5 × 10 ²¹	2.0
G12.8-0.2.....	9.5	I	17.6 ± 0.2	[0.7 ± 0.4]	[2.4 ± 0.5]	3.6 × 10 ¹⁸ (50)	1.8 × 10 ²⁰	4.1
			4.1 ± 2.4	0.5 ± 0.5	7.2 ± 5.0	7.5 × 10 ¹⁸ (60)	3.8 × 10 ²⁰	0.7
			17.3 ± 0.5	[1.9 ± 1.8]	[1.6 ± 1.4]	6.2 × 10 ¹⁸ (50)	3.1 × 10 ²⁰	2.4
			26.0 ± 0.3	3.1	8.8	5.2 × 10 ¹⁹	2.6 × 10 ²¹	3.4
G16.9+0.8.....	9.5	SD	36.3 ± 0.2	2.9	10.4	5.8 × 10 ¹⁹	2.9 × 10 ²¹	4.4
			1.9 ± 0.3	1.5 ± 0.2	4.0 ± 0.7	1.1 × 10 ¹⁹ (12)	5.5 × 10 ²⁰	0.2
			5.9 ± 0.1	[2.0 ± 0.2]	[2.8 ± 0.3]	1.1 × 10 ¹⁹ (8)	5.5 × 10 ²⁰	0.7
			19.5 ± 0.1	1.3 ± 0.1	8.2 ± 0.3	2.1 × 10 ¹⁹ (4)	1.0 × 10 ²¹	2.2
G25.4-0.2.....	9.5	I	6.0 ± 0.3	2.2 ± 0.4	5.7 ± 0.7	2.5 × 10 ¹⁹ (12)	1.3 × 10 ²¹	0.6
			16.6 ± 0.2	3.6	5.6	3.9 × 10 ¹⁹	2.0 × 10 ²¹	1.4
			35.4 ± 0.2	0.3 ± 0.1	8.9 ± 0.5	6.1 × 10 ¹⁸ (30)	3.1 × 10 ²⁰	2.8
			52.0 ± 0.2	1.7 ± 0.1	10.3 ± 0.5	3.5 × 10 ¹⁹ (5)	1.8 × 10 ²¹	4.0
G28.8+3.5.....	1	SD	66.4 ± 0.2	0.2 ± 0.1	8.5 ± 0.5	3.6 × 10 ¹⁸ (40)	1.8 × 10 ²⁰	5.0
			2.5 ± 0.4	0.4 ± 0.2	1.5 ± 1.0	1.2 × 10 ¹⁸ (50)	6.0 × 10 ¹⁹	0.2
			5.6 ± 0.2	1.1 ± 0.2	3.2 ± 0.4	7.1 × 10 ¹⁸ (7)	3.5 × 10 ²⁰	0.5
			7.2 ± 0.1	2.5 ± 0.2	2.4 ± 0.2	1.2 × 10 ¹⁹ (4)	6.0 × 10 ²⁰	0.6

TABLE 2—Continued

Source (1)	Frequency Resolution (kHz) (2)	Type of Measure- ment (3)	Radial Velocity (km s ⁻¹) (4)	$\tau_{\max}$ (5)	$\Delta V_{1/2}$ (km s ⁻¹) (6)	$N_{\text{H}}/T_s^\dagger$ (cm ⁻² ° K ⁻¹) (7)	$N_{\text{H}}^\dagger$ (cm ⁻²) (8)	Kinematic Distance (kpc) (9)
G28.8+3.5.....	9.5	SD	6.6 ± 0.2	3.7	4.3	3.1×10^{19}	1.6×10^{21}	0.6
G30.8-0.0.....	9.5	I	6.5 ± 1.4	0.55 ± 0.24	9.1 ± 3.2	9.9×10^{18} (30)	5.0×10^{20}	0.5
			12.9 ± 0.2	3.7 ± 0.3	4.0 ± 0.4	2.9×10^{18} (5)	1.5×10^{21}	1.0
			22.0 ± 0.2	0.27 ± 0.08	8.0 ± 0.4	4.2×10^{18} (30)	2.1×10^{20}	1.7
			56.0 ± 0.2	1.2 ± 0.1	7.0 ± 0.4	1.6×10^{19} (7)	8.0×10^{20}	4.0
			66.9 ± 0.2	1.3 ± 0.1	6.1 ± 0.4	1.5×10^{19} (7)	7.5×10^{20}	4.7
			81.0 ± 0.1	3.1 ± 0.2	7.7 ± 0.3	4.6×10^{19} (2)	2.3×10^{21}	5.8
			89.2 ± 0.1	1.5 ± 0.1	6.8 ± 0.3	2.0×10^{19} (5)	1.0×10^{21}	6.5
			97.6 ± 0.1	1.33 ± 0.08	6.7 ± 0.3	1.7×10^{19} (5)	8.5×10^{20}	7.6
G31.9+0.0.....	9.5	I	12.0 ± 0.2	2.9 ± 0.3	6.0 ± 0.3	3.3×10^{19} (7)	1.7×10^{21}	0.9 (16.0)
			22.4 ± 0.2	0.8 ± 0.1	8.5 ± 0.5	1.3×10^{19} (14)	7.0×10^{20}	1.7 (15.3)
			76.2 ± 0.2	0.9 ± 0.1	9.5 ± 0.5	1.6×10^{19} (10)	8.0×10^{20}	5.4 11.6
			80.4 ± 0.2	0.9 ± 0.1	9.4 ± 0.5	1.6×10^{19} (9)	8.0×10^{20}	5.7 11.3
			101.0 ± 0.2	0.8 ± 0.1	8.4 ± 0.5	1.4×10^{19} (9)	7.0×10^{20}	8.5
			107.5 ± 0.1	[2.8 ± 0.3]	[3.6 ± 0.3]	2.0×10^{19} (5)	1.0×10^{21}	8.5
G35.2-1.8.....	9.5	I	12.7 ± 0.4	2.1 ± 0.5	4.0 ± 1.0	1.6×10^{19} (17)	8.0×10^{20}	1.0
			30.6 ± 0.3	1.6 ± 0.3	4.8 ± 0.7	1.6×10^{19} (13)	8.0×10^{20}	2.2
			39.6 ± 0.2	[3.0 ± 0.4]	[3.9 ± 0.5]	2.3×10^{19} (7)	1.2×10^{21}	2.8
			44.3 ± 0.1	3.5	4.2	2.9×10^{19}	1.5×10^{21}	3.1
G49.1-0.4.....	9.5	SD	6.3 ± 0.4	2.0 ± 0.5	3.6 ± 1.0	1.4×10^{19} (21)	7.0×10^{20}	0.5
			24.6 ± 0.4	0.7 ± 0.2	7.1 ± 1.0	9.5×10^{18} (24)	4.8×10^{20}	1.8
			48.0 ± 0.3	2.4 ± 0.2	9.0 ± 0.7	4.1×10^{19} (5)	2.0×10^{21}	3.6
			61.2 ± 0.3	3.2	8.9	5.5×10^{19}	2.3×10^{21}	6.1
G49.5-0.4.....	9.5	SD	6.3 ± 0.2	1.3 ± 0.1	4.4 ± 0.4	1.2×10^{19} (7)	6.0×10^{20}	0.5
			11.8 ± 0.2	0.8 ± 0.1	4.0 ± 0.4	6.3×10^{18} (10)	3.2×10^{20}	0.9
			23.8 ± 0.2	0.53 ± 0.04	7.4 ± 0.4	7.6×10^{18} (7)	3.8×10^{20}	1.8
			51.2 ± 0.1	1.70 ± 0.05	11.4 ± 0.2	3.8×10^{19} (1)	1.9×10^{21}	4.3 (8.7)
			65.4 ± 0.1	3.2	7.7	4.7×10^{19}	2.4×10^{21}	6.5

4-kpc arm in the galactic-center region, and this is amply confirmed by our measurements. Note the enormous increase in the optical depth of the 4-kpc arm in this direction over that in the direction of G357.7-0.1, although the emission temperatures at -40 km s^{-1} in both directions are comparable. The brightness temperature at that velocity is less than 15° K and is by far the lowest ever measured in a direction where the optical depth is in excess of 2.

The self-absorption line is even more prominent in the direction of Sgr B2 than in that of MSH 17-39.

q) 3C 358 (Kepler's Supernova) (Fig. 21)

The continuum properties of this well-known supernova remnant have been discussed by Milne. From its surface brightness he derives a distance of 11.4 kpc. At the latitude of the source this would imply that it is located 1.4 kpc above the plane! The H I measurements can throw no light on the distance to the source because of its proximity to the galactic-center direction.

r) M8 (Figs. 22a, 22b)

The H109 α velocity for this H II region is 3.0 km s^{-1} . SG cite various optical references to place this source at a distance of 1.4 kpc. The kinematic distances of some of the absorption features are greater than this, presumably because of the closeness to the galactic-center direction. The 15.4 km s^{-1} feature in the interferometer profile is not seen with the single dish, presumably because of the emission variations in the region of the source.

The self-absorption feature is most striking in the direction of this source and shows some variation in different directions around the source. Its shape is well seen in the emission profile obtained with the 1-kHz filter bank (Fig. 22b, *middle*), and two components responsible for the 5.6 and 7.5 km s^{-1} features in the absorption profile can be distinguished. The high optical depth indicates a spin temperature of less than 40° K for at least one of the two components, whereas the width of this component in the absorption profile ($\sim 2 \text{ km s}^{-1}$) is equivalent to a kinetic temperature of $\sim 85^\circ \text{ K}$. Turbulent motions must be responsible for the discrepancy. Riegel and Jennings (1969) have made observations of this cloud over a large area near the galactic center.

s) W28 (Fig. 23)

The self-absorption feature discussed under M8 is just as conspicuous in the direction of this supernova remnant. The similarity of the absorption profile to that of M8 is very clear in spite of its poor baseline. The extended nature of this source required a greater separation between the reference regions, with consequent inaccuracies. Milne gives a distance of 1.5 kpc from the surface brightness. Any kinematic determination is likely to be unreliable because of the closeness to the galactic-center direction. (In the case of the neighboring source M8, absorption velocities were encountered that corresponded to distances beyond the source.) OH absorption at a velocity of $+7 \text{ km s}^{-1}$ is seen in the direction of this source, and also OH emission at 1720 MHz (Goss and Robinson 1968).

t) W31 (Fig. 24)

The source W31 is a prominent H II region with an H109 α velocity of 13.9 km s^{-1} corresponding to a kinematic distance of 2.5 or 17.2 kpc. The question of the distance to this source has been discussed by GMR, who considered only the single-dish profile showing absorption extending to $\sim +60 \text{ km s}^{-1}$. The subsequent interferometer measurement also shown in Figure 24 (*lower*) indicates a cutoff in the absorption at 45 km s^{-1} corresponding to a minimum distance of 6 kpc, at which distance the separation from the galactic plane is $\sim 40 \text{ pc}$. One is forced to conclude either that the layer of cold

absorbing clouds is only 40 pc thick in this direction and the source is at the far distance, or that the source is near the galactic center and has an anomalous radial velocity. If the H109 α radial velocity is not anomalous and the source is at the far distance of 17.2 kpc, the inferred mass of $10^4 M_{\odot}$ implies that it is one of the most massive H II regions in the galaxy and comparable to W49 A and NGC 3603 (Goss and Radhakrishnan 1969). No attempt was made to fit Gaussians to the absorption profile because of its complexity and the high optical depths encountered.

The high-velocity end of the emission profile is in error, for subsequent observations have shown that low-level emission extends to velocities beyond those depicted in Figure 24 (*middle*). The self-absorption feature is still very prominent in this direction. OH absorption has been measured by Goss for this source at velocities of 11.6 and 27.6 km s⁻¹. Attempts to measure the H I absorption in the spectrum of the neighboring source G10.3-0.1 showed that it was too weak to provide any meaningful results.

u) G11.2-0.3 (Figs. 25a, 25b)

This relatively weak nonthermal source, situated about 1° away from W31, has been studied by GS and Milne. The latter suggests a distance of 10.3 kpc from its surface brightness. Although the interferometer absorption profile is of poor quality, it clearly shows evidence of absorption up to a high velocity limit of ~ 50 km s⁻¹, as in the case of W31. From our observations we can say only that the distance is definitely greater than 5 kpc.

Absorption is also clearly discernible at the velocity of the self-absorption feature in the emission profile (Fig. 25a, *upper*). This feature is shown in greater detail in Figure 25b as observed with 1-kHz bandwidth.

v) W33 (Fig. 26)

GS have observed this H II region. Although it is a double source, most of the flux at high frequencies comes from one component. OH emission observations by Robinson, Goss, and Manchester (1970) suggest that the other component is at a different distance and not physically associated. The highest-velocity feature in the H I absorption spectrum has the same velocity (36.3 km s⁻¹) as the H109 α line, and the corresponding distance to the source is 4.6 kpc.

w) M17 (Figs. 27a, 27b)

The distance of this well-known nebula is generally taken to be between 2 and 2.5 kpc. SG have adopted a distance of 2.4 kpc from various considerations. The absorption profile is bandwidth-limited when observed with a resolution of 9.5 kHz. The 1-kHz bandwidth profile indicates higher values for the optical depth and at least five features, but we have not attempted to fit Gaussians to it. At least one of the features has a velocity corresponding to a kinematic distance greater than that adopted for the source. An OH absorption line was detected at a velocity of 19.6 km s⁻¹ by Goss. More recent observations by Gardner and McGee (1971) show that OH absorption is detected over most of the velocity range of the H I absorption profile. They find further that the four distinguishable velocity groups within their OH profile are centered on slightly different positions in the sky.

x) M16 (Fig. 28)

This well-known H II region has been studied by SG, who have adopted a distance of 2.2 kpc from various optical references. H I absorption is definitely present up to the H109 α velocity of 24.5 km s⁻¹. The feature in the absorption spectrum at $\sim +45$ km s⁻¹ is almost certainly spurious.

y) G21.8—0.6 (Fig. 29)

As seen from the upper half of Figure 29, there are enormous variations between the four reference profiles. We consider that for sources in the galactic plane the intensity of this source ($T_A = 18.7^\circ \text{ K}$) is marginal for distance determination from a single-dish measurement of the main H I absorption features. An interferometer observation was not possible because of the distributed nature of the continuum radiation from this source which has been discussed by SG and Milne. The source is a supernova remnant and shows a partial shell structure when seen with high resolution. No H109 α line has been detected from this source. Milne estimates a distance of 2.9 kpc from its surface brightness.

The features in the absorption spectrum at velocities higher than 60 km s⁻¹ are undoubtedly the result of the large variations in the emission near the tangential velocity, but it seems likely that real absorption is present in the velocity range 0–60 km s⁻¹. A velocity of 50 km s⁻¹ corresponds to a distance of ~ 4 kpc, and this is perhaps the best possible estimate for the distance of the source.

z) G25.4—0.2 (NRAO 272) (Fig. 30)

An H109 α velocity of 60.4 km s⁻¹ has been obtained by Reifenstein *et al.* (1970) for this H II region. The two possible kinematic distances corresponding to this velocity are 4.7 and 13.4 kpc. The interferometer profile suggests a cutoff in the absorption at ~ 66 km s⁻¹, well short of the tangential point velocity of 115 km s⁻¹, thus favoring a near distance of ~ 5 kpc.

aa) W40 (Figs. 31a, 31b)

This H II region is associated with a heavily obscured faint optical nebula. Reifenstein *et al.* (1970) have found an H109 α line at 0.7 km s⁻¹. Of the two possible corresponding distances of 0.1 and 17.0 kpc, they have rejected the latter alternative on the basis of the optical appearance and the high Z distance. Downes (1970) has found a strong OH absorption line at 6.3 km s⁻¹ similar to the H I absorption line in Figure 31a (*lower*). We conclude that if the H I gas is in circular motion, the best estimate for the distance is 0.6 ± 0.3 kpc. In Figure 31b we show measurements on the same source with the 1-kHz filters. At least two and possibly three components are suggested by the shape of the absorption profile.

bb) G29.9—0.1 (Fig. 32)

With an antenna temperature of less than 10° K, this source is too weak to produce a meaningful absorption profile as measured with the single dish. We have, however, included the profile obtained on it (Fig. 32, *lower*) for comparison with that obtained on its neighboring source G30.8—0.0 (Fig. 33, *lower*). Both these sources have been studied by SG. There is a strong suggestion that absorption effects are present up to a velocity of about 100 km s⁻¹. The H109 α velocity is 96.4 km s⁻¹, corresponding to a distance of 7.3 or 10.0 kpc. It is not possible from our H I measurement to discriminate between these two possibilities.

cc) G30.8—0.0 (W43) (Fig. 33)

This H II region has an H109 α velocity of 92.3 km s⁻¹. The H I absorption is definitely cut off well before the tangential-point velocity of 110 km s⁻¹, as seen in Figure 33 (*upper* and *lower*). We conclude that the source is on the near side of the tangential point in the Scutum spiral arm at a distance of 7 kpc.

At least eight features are discernible in the absorption profile obtained with the

9.5-kHz filter bank. Higher resolution is sure to indicate that many of these features are in fact blends. There are significant differences in the apparent optical depths as measured with the single dish and the interferometer, with the trend that the former are higher. Whether this is due to structure in the brightness temperature or in the optical depth distribution or both cannot be established without more detailed interferometer observations.

dd) 3C 391 (Fig. 34)

The interferometer absorption profile of this source is shown in the lower half of Figure 34. Absorption is clearly present right up to the edge of the H I emission and past the velocity of the tangential point ($\sim 105 \text{ km s}^{-1}$). In this direction the tangential point is at a distance of 8.5 kpc. The source may be situated at less than 13.4 kpc (the distance of the solar circle), but we cannot rule out the possibility that it may be extragalactic. It has an interesting continuum spectrum and is discussed in detail by Caswell *et al.* (1971).

ee) W48 (Fig. 35)

Reifenstein *et al.* (1970) obtained an H109 α velocity of 46.5 km s^{-1} for this H II region and have adopted the corresponding near distance of 3.4 kpc on the basis of the galactic latitude (-1.8°). Our interferometer measurement, presented in Figure 35 (*lower*), shows the H I absorption as stopping far short of the tangential-point velocity ($+90 \text{ km s}^{-1}$) and supports their choice of the near distance.

ff) W44 (Fig. 36)

The source W44 is a well-known supernova remnant of large angular size whose continuum properties have been summarized by Milne. From its surface brightness he has estimated a distance of 1.5 kpc. Goss found OH absorption lines at 12.5 and 42.4 km s^{-1} , leading him to suggest 3 kpc as the likely distance. Our H I measurements shown in Figure 36 support the OH determination. H I absorption clearly extends up to $\sim 50 \text{ km s}^{-1}$, although the details in the shape of the profile are grossly inaccurate. For this reason we have made no attempt to fit Gaussians to the absorption profile. Note the large variation in the emission distribution at 55 km s^{-1} shown in the difference profile. We conclude that the distance is about 3 kpc. The source W44 is one of the few non-thermal sources in the direction of which OH emission has been detected (Goss and Robinson 1968).

gg) G41.1-0.3 (3C 397) (Fig. 37)

A nonthermal source, presumably a supernova remnant, discussed by Fomalont (1968), Holden and Caswell (1969), and Milne. The single-dish absorption profile is unreliable because of the low antenna temperature of the source (11.8° K). However, the interferometer measurement shows absorption right up to the cutoff in the emission. This was indicated in all the separate integrations for this source. The interferometer measurements were unfortunately not extended to cover the entire emission spectrum, and we have no information as to whether there is any absorption in the distant spiral arms with a velocity of $\sim -40 \text{ km s}^{-1}$. The distance of the tangential point is 7.5 kpc, and we can only say that the source is at or beyond this point. Milne gives a distance of 5.3 kpc for the source from its surface brightness. As in some other cases discussed in this paper, his value appears to be an underestimate of the true distance.

We have not attempted to fit Gaussian components to the absorption profile of this source.

hh) W49 A (G43.2-0.0) and W49 B (G43.3-0.2) (Figs. 38a-38f)

A number of papers have been written on the distance to these two radio sources at the same declination but separated by $12'$ in right ascension. The most recent of these,

by Kazès and Nguyen-Quang-Rieu (1970), includes a discussion of all the earlier papers on this subject. Our conclusions, based on detailed observations, essentially support the views of those authors that the thermal component (W49 A) is at ~ 14 kpc, whereas the nonthermal component (W49 B) is situated closer, probably at ~ 10 kpc.

Our observations made in several different ways, all with a filter bandwidth of 2 km s^{-1} , are presented in Figures 38*a*–38*f*. In Figures 38*a* and 38*b* are shown the single-dish absorption profiles for W49 A and W49 B, respectively. These were obtained by subtracting the average of three reference regions for each source from the respective on-source profiles. As the beam pattern goes to zero at a distance of $\sim 15'$ from the axis and the separation of the sources was only $12'$, both of these absorption profiles suffer from contamination by effects from the unwanted source. However, this is only a minor effect compared with the errors introduced by the nonuniform emission in the general direction of these sources. In Figure 38*c* we show the difference between the mean *emission* profiles used for each source. The mean emission profile was obtained by averaging the profiles $15'$ to the north, south, and west for W49 A, and north, south, and east for W49 B. All these six profiles were free of the effects of either source, and the centroids of the two groups of three were separated by only $22'$. Nevertheless, there are enormous differences in the two means, as shown in Figure 38*c*, and the fact that these differences are in the range of velocities of the main absorption features makes single-dish determinations of the optical depths particularly unreliable.

In Figure 38*d* we show absorption profiles obtained for the two sources by using the beam “slope” method discussed earlier in this paper. Although not really satisfactory, they did show some improvement, particularly in the optical depths of source A as judged by comparison with the interferometer absorption profile shown in Figure 38*e*. The three main absorption features are those first observed by Akabane and Kerr (1965). Note the superior quality of the interferometer profile as compared with the corresponding single-dish profile shown in the lower half of Figure 38*d*. However, there is still some contamination in the profile of Figure 38*e* from source B which is due to its presence within the $18.5'$ primary beamwidth of the interferometer. To evaluate the difference in optical depths in the directions of the two sources, we have made interferometer observations both in the precise directions of these sources and also in directions $6'$ away from the sources. These off-axis measurements somewhat reduce the signal from the wanted source but eliminate contamination from the unwanted source. In Figure 38*f* we present the difference in optical depths for the two sources obtained by both methods. They are essentially in agreement, showing that when the interferometer was pointed directly at each source, the contamination was not appreciable.

The major differences in optical depth are at velocities of $+10$ and $+55 \text{ km s}^{-1}$. Kazès and Nguyen-Quang-Rieu (1970) obtained peaks at $+12$ and $+63 \text{ km s}^{-1}$ by using a velocity resolution of 12.7 km s^{-1} . Their optical depths are also generally lower than ours, presumably because of their lower velocity resolution. It must be pointed out that the plot of optical depth differences in Figure 38*f* is only *qualitative*. The combined effect of noise and the high optical depths measured for source A with the interferometer preclude the determination of any precise differences. Any calculation of the excess path length to one source over the other in the manner of Kazès and Nguyen-Quang-Rieu (1970) would in our opinion not be meaningful. A discrepancy in the distance to the two components is indicated, however, and we are in qualitative agreement with their conclusions.

ii) G45.5+0.1 (NRAO 601) (Fig. 39)

SG have studied this source and have found it to have a peculiar continuum spectrum and a small diameter ($\sim 2'$). It does not show evidence of any $\text{H}109\alpha$ recombination line but does have OH emission at 1665 MHz of the kind normally associated with H II regions (Downes 1970). The source is superposed on a larger source which predominates

at 178 MHz (Holden and Caswell 1969) but whose spectrum is also peculiar. The interferometer profile of Figure 39 (*lower*) shows absorption extending from 0 to $+70 \text{ km s}^{-1}$, but with anomalously large relative intensity values around $+55 \text{ km s}^{-1}$. In Paper I we discussed the significance of the line-to-continuum relative intensity having a value less than -1 in the case of Orion A. There it was interpreted in terms of optical-depth structure smaller than the source size. In the present instance the smaller diameter of the source and the decreased resolution of the interferometer at the declination of the source make this explanation less likely.

Very distinct self-absorption can be seen in the single-dish emission profile (Fig. 39, *upper*) over the same velocity range as the anomalously large relative intensity. However, the minimum angular diameter necessary even for a self-absorbing cloud at 0° K would cause the cloud to be resolved out by the interferometer and could not account for the anomaly. We considered the possibility that the observations are affected by the presence of the neighboring source G45.1+0.1, but concluded that the $20'$ separation would exclude its effects. Absorption of part of the extended source surrounding G45.5+0.1 or of the galactic continuum background might be more reasonable explanations of the observed effect. A more detailed investigation is certainly called for.

In his OH investigation, Downes (1970) measured velocities of $55\text{--}60 \text{ km s}^{-1}$ which would indicate a distance of 6 kpc. Our H I measurements show absorption up to the cutoff in emission around 75 km s^{-1} corresponding to a distance $\geq 7 \text{ kpc}$. As discussed above, some of this absorption may refer to a source or sources other than G45.5+0.1. We conclude that the distance of G45.5+0.1 is in the range 6–7 kpc.

jj) G49.1–0.4 and G49.5–0.4 (W51) (Figs. 40 and 41)

These two components of W51 have recently been given different distances by WMGMA on the basis of their recombination-line velocities. They have suggested that G49.1–0.4 ($\sim 67 \text{ km s}^{-1}$) is at the tangential point at a distance of 6.5 kpc, whereas G49.5–0.4 ($\sim 59 \text{ km s}^{-1}$) is beyond the tangential point at a distance of 8.0 kpc. The H I single-dish measurements are shown in Figures 40 and 41. Both sources show absorption over the range from 0 to the cutoff in the emission at positive velocities, with the absorption spectrum of G49.5–0.4 extending up to the very edge of the emission. These observations are completely consistent with those of WMGMA, and we conclude that the distances are 6.5 and 8.0 kpc, as suggested by them.

Note the anomalously large negative temperature at 60 km s^{-1} in the absorption profile of G49.1–0.4. This is undoubtedly caused by severe emission variations in the region at this velocity, and an indication of this can be seen in the corresponding dip in the difference profile. In the case of this source, as in several others, the profile was truncated for the Gaussian fitting computation. As discussed earlier, this enabled one to obtain reasonable parameters for the other features in the profile.

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REFERENCES

- Akabane, K., and Kerr, F. J. 1965, *Australian J. Phys.*, **18**, 91. *
 Beard, M., Thomas, B. M., and Day, G. A. 1969, *Australian J. Phys.*, *Ap. Suppl.*, **11**, 27.
 Caswell, J., Dulk, G. A., Goss, W. M., Radhakrishnan, V., and Green, Anne J. 1971, *Astr. and Ap.*, **12**, 271.
 Clark, B. G. 1965, *Ap. J.*, **142**, 1398.
 Clark, B. G., Radhakrishnan, V., and Wilson, R. W. 1962, *Ap. J.*, **135**, 151.
 Downes, D. 1970, *Ap. Letters*, **5**, 53.
 Fomalont, E. B. 1968, *Ap. J. Suppl.*, **15**, 203.
 Gardner, F. F., and McGee, R. X. 1971 (in press).
 Gardner, F. F., and Whiteoak, J. B. 1970, *Ap. Letters*, **5**, 161.

- Goss, W. M. 1968, *Ap. J. Suppl.*, **15**, 131.
- Goss, W. M., Murray, J. D., and Radhakrishnan, V. 1970, *Proc. Astr. Soc. Australia*, **1**, 332.
- Goss, W. M., and Radhakrishnan, V. 1969, *Ap. Letters*, **4**, 199.
- Goss, W. M., and Robinson, B. J. 1968, *Ap. Letters*, **2**, 81.
- Goss, W. M., and Shaver, P. A. 1970, *Australian J. Phys.*, *Ap. Suppl.*, **14**, 1.
- Heeschen, D. S. 1955, *Ap. J.*, **121**, 569.
- Holden, D. J., and Caswell, J. L. 1969, *M.N.R.A.S.*, **143**, 407.
- Johnson, H. L. 1967, *Ap. J. (Letters)*, **150**, L39.
- Johnson, H. L., and Mendoza V., E. E. 1964, *Bol. Obs. Tonantzintla y Tacubaya*, **3**, 331.
- Kazès, I., and Nguyen-Quang-Rieu. 1970, *Astr. and Ap.*, **4**, 111.
- Kerr, F. J., and Knapp, Gillian R. 1970, *Australian J. Phys.*, *Ap. Suppl.*, **18**, 9.
- Kerr, F. J., and Sandquist, A. 1968, *Ap. Letters*, **2**, 195.
- Kerr, F. J., and Vallak, R. 1967, *Australian J. Phys.*, *Ap. Suppl.*, **3**, 1.
- Manchester, R. N., Robinson, B. J., and Goss, W. M. 1970, *Australian J. Phys.*, **23**, 751.
- Menon, T. K. 1970, *Astr. and Ap.*, **5**, 240.
- Menon, T. K., and Williams, D. R. W. 1968 (private communication).
- Milne, D. K. 1970, *Australian J. Phys.*, **23**, 425.
- Muller, C. A. 1959, *Paris Symposium on Radio Astronomy*, ed. R. N. Bracewell (Palo Alto, Calif.: Stanford University Press), p. 360.
- Reifenstein, E. C., Wilson, T. L., Burke, B. F., Mezger, P. G., and Altenhoff, W. J. 1970, *Astr. and Ap.*, **4**, 357.
- Riegel, K. W., and Jennings, M. C. 1969, *Ap. J.*, **157**, 563.
- Robinson, B. J., Caswell, J. L., and Goss, W. M. 1971, *Ap. Letters*, **9**, 5.
- Robinson, B. J., Gardner, F. F., van Damme, K. J., and Bolton, J. G. 1964, *Nature*, **202**, 989.
- Robinson, B. J., Goss, W. M., and Manchester, R. N. 1970, *Australian J. Phys.*, **23**, 363.
- Roslund, C. 1966, *Ark. f. Astr.*, **4**, 101.
- Rougoor, G. W. 1964, *B.A.N.*, **17**, 381.
- Sato, F., Akabane, K., and Kerr, F. J. 1967, *Australian J. Phys.*, **20**, 197.
- Shaver, P. A., and Goss, W. M. 1970, *Australian J. Phys.*, *Ap. Suppl.*, **14**, 133.
- Shuter, W. L. H., and Verschuur, G. L. 1964, *M.N.R.A.S.*, **127**, 387.
- Trimble, V. 1968, *Australian J. Phys.*, **73**, 535.
- Weaver, H., Dieter, N. H., and Williams, D. R. W. 1968, *Ap. J. Suppl.*, **16**, 219.
- 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. 1970a, *Ap. Letters*, **5**, 99.
- . 1970b, *Astr. and Ap.*, **6**, 364.
- Zuckerman, B., Buhl, D., Palmer, P., and Snyder, L. E. 1970, *Ap. J.*, **160**, 485.

PLATE 1

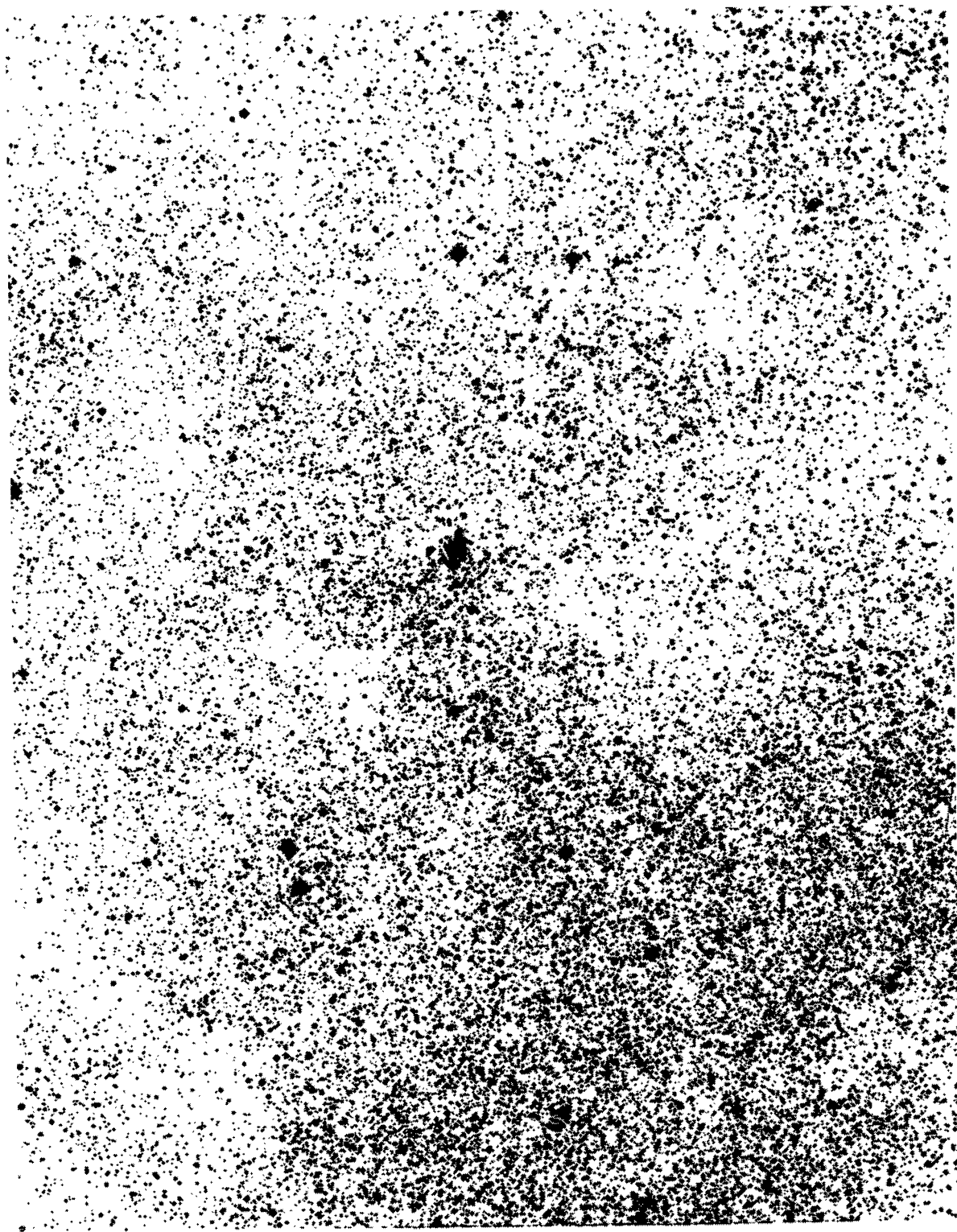


FIG. 15c.—RCW 117 is the $2' \times 2'$ nebula seen here on a portion of the 17^h , -42° plate of the Whiteoak extension to the Palomar Sky Atlas (effective wavelength $6000 \text{ \AA}$). The nebula is to the right of the center. North is at the top and east to the left. The east-west dimension is approximately 1° .

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PLATE 2

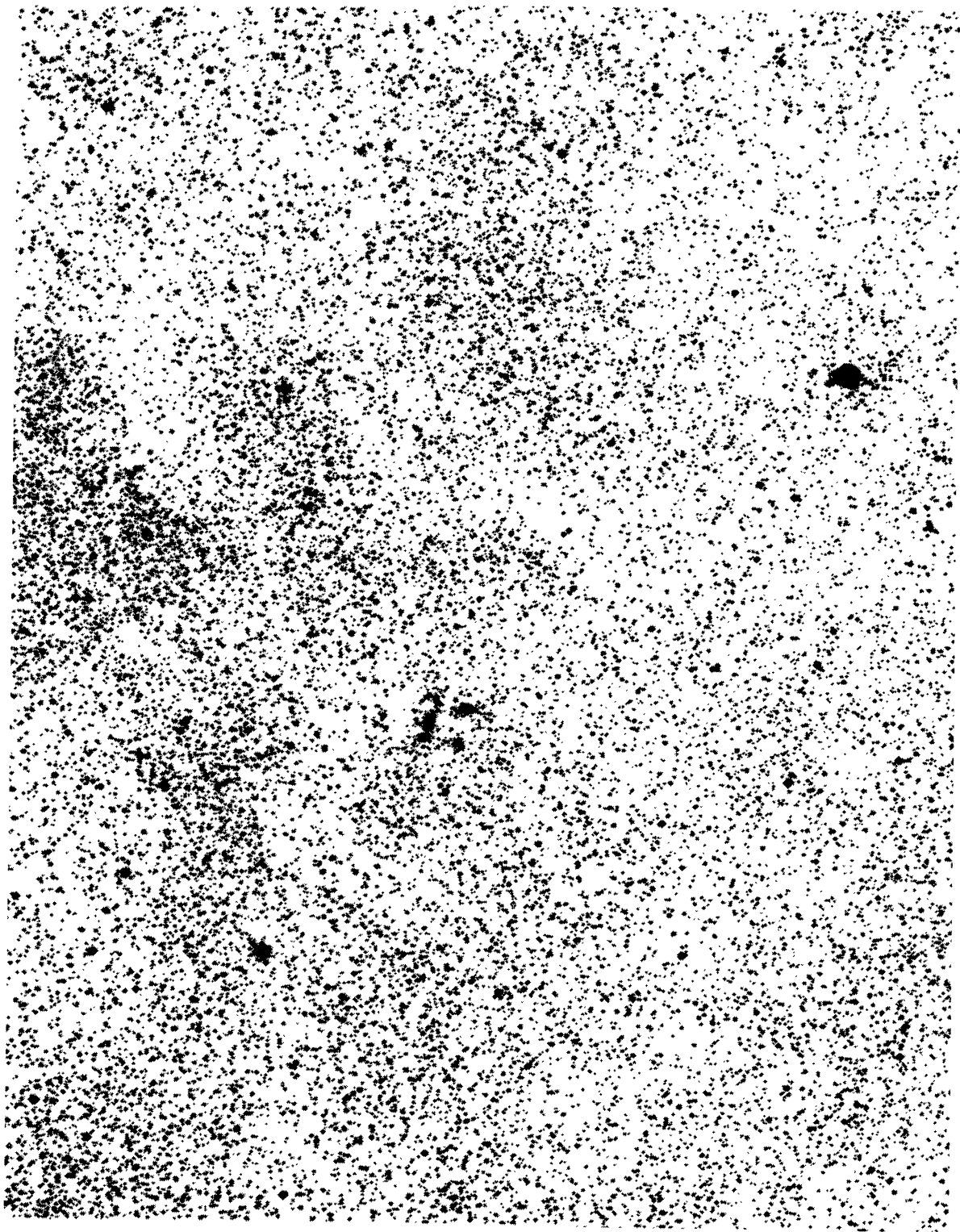


FIG. 15*d*.—RCW 121 is the bright $3' \times 2'$ nebulosity seen in the right-hand lower corner. RCW 122 is the faint nebulosity ($2' \times 2'$) to the left of the center. This picture was taken from the $17^{\text{h}}16^{\text{m}}, -36^{\circ}$ plate of the Whiteoak extension to the Palomar Sky Atlas. The orientation and east-west extent are the same as for Fig. 15*c*.

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