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CO OBSERVATIONS OF THE EXPANDING ENVELOPE OF IRC+10216

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13. ABSTRACT

We have observed high-sensitivity emission profiles from the $J = 0 \leftarrow 1$ transitions of $^{12}C^{16}O$ and $^{13}C^{16}O$ towards IRC+10216. It appears that the spherically symmetric uniform mass-outflow model proposed by Morris (1975) is necessary to describe the line profiles. The outflow appears to be slightly accelerated, having a velocity of 15 km/sec at the edges of the CO cloud, compared with 12 km/sec for the more centrally confined molecules.

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ABSTRACT

We have observed high-sensitivity emission profiles from the J = 0←1 transitions of $^{12}C^{16}O$ and $^{13}C^{16}O$ towards IRC+10216. It appears that the spherically symmetric uniform mass-outflow model proposed by Morris (1975) is necessary to describe the line profiles. The outflow appears to be slightly accelerated, having a velocity of 15 km/sec at the edges of the CO cloud, compared with 12 km/sec for the more centrally confined molecules.

I INTRODUCTION

The infrared source IRC+10216 (Neugebauer and Leighton 1969) consists of a small (0"4) optically thick component at 600 K surrounded by a larger (2") optically thin component whose temperature is 375 K (Becklin et al. 1969; Toombs et al. 1972). Spectra of the source suggest that it is a late-type carbon star, surrounded by obscuring dust presumably produced in the atmosphere of the star itself (Miller 1970; Herbig and Zappala 1970).

The infrared source is surrounded by an envelope producing millimeter-wavelength from many interstellar molecules. Emission lines from CO (Solomon et al. 1971), CN and CS (R.W. Wilson et al. 1971; Turner et al. 1973) HCN (Morris et al. 1971; W.J. Wilson et al. 1973), C_2H (Tucker et al. 1974), and SiS, SiO and HC_3N (Morris et al. 1975) have all been observed. The large velocity width (24 km/sec) seen in these lines strongly suggests expansion of the envelope.

The size of the cloud emitting these molecular lines has been measured as $\lesssim$ 40" for HCN (Wilson et al. 1973) and ~2'1 for CO (Wilson et al. 1973; Ulich 1975). Morris (1975) has proposed a model for the IRC+10216 molecular envelope in which the molecules are contained in an expanding envelope surrounding the star and are excited by absorption of infrared radiation into the excited vibrational states, the subsequent decay leaving the molecules in higher-lying rotational states in the ground vibrational state. These considerations decrease the required envelope mass from $\gg 1\ \mathcal{M}_\odot$ if collisional excitation dominates (Morris et al. 1975) to about $10^{-2}\ \mathcal{M}_\odot$ (Morris 1975).

As a result of the IR excitation, the apparent size of the molecule-emitting region depends on the transition observed; the size of the region increases as J (the quantum number of the upper rotational state) decreases and as μ_o, the permanent dipole moment of the molecule, decreases (see the discussion by Morris, 1975). Thus the CO-emitting region is very much larger than that of any of the other observed molecules. In particular, it is resolvable by the 1-arcmin beam of the NRAO 11-meter telescope, so that the CO line shapes should show the effects of partial resolution discussed by Morris (1975).

In the present paper, we report high-sensitivity observations of ^{12}CO and ^{13}CO in IRC+10216, including partial mapping in the ^{13}CO line. The line shapes of ^{12}CO and ^{13}CO towards the center of the source appear to require a uniformly-expanding envelope model.

II. THE OBSERVATIONS

The observations described herein were made in March 1975 with the NRAO 11-meter telescope at Kitt Peak, Arizona. The $J = 0 \leftarrow 1$ transitions of ^{12}CO and ^{13}CO at 115.2712 and 110.2014 GHz respectively were measured; the observations reported here were all made in clear weather. The telescope beam efficiency was ~60% and the half-power beamwidth was ~65%. The receiver used the NRAO cooled mixer, giving effective single-sideband system temperatures (which incorporate factors due to the atmosphere and the beam efficiency) of ~1200K and ~900K at the ^{12}CO and ^{13}CO frequencies respectively. The system temperature and atmospheric attenuation were calibrated frequently using an oscillating vane (see Penzias and Burrus 1973). The observations were made by position switching

a reference point

1° from the source in azimuth, and typical integration times of about 1 hour per point were used. The observed position was $\alpha_{1950} = 09^{h}45^{m}16\overset{s}{.}8$, $\delta_{1950} = +13^{\circ}30'40''$ for both ^{12}CO and ^{13}CO; in addition, points 1 arcmin north and south of this position were observed in ^{13}CO. The lines were observed with two 256 channel filter banks, giving resolutions of 0.1 MHz ($\sim$ 0.26 km/sec) and 0.25 MHz ($\sim$0.65 km/sec) per channel respectively.

The observations are summarized in Figures 1 through 3 and Table 1. In Figures 1 and 2 the ^{12}CO and ^{13}CO profiles centered on IRC+10216 are presented; in Table 1 we list for each line the values of T_A^*, v_c and Δv. These quantities are defined as follows: T_A^* is the Rayleigh-Jeans equivalent brightness temperature in Kelvins (on this scale the peak temperature of Orion A is 60K - see Ulich and Haas 1975); v_c is the velocity with respect to the LSR; and Δv is the velocity half-power width. In Figure 3, the ^{13}CO profiles measured north and south of the central point are presented.

III ANALYSIS OF THE LINE PROFILES

The observational profiles presented in Figures 1 and 2 show qualitatively good agreement with the model profiles predicted by Morris (1975) and Mufson and Liszt (1975) for a spherically symmetric, uniformly expanding envelope. We apply Morris' description to our observations because it is more amenable to analysis. The treatment of Mufson and Liszt offers a more intuitive understanding and has been included where appropriate.

In the following discussion, we use the basic notation introduced by Morris (1975): r = radial distance from the center of the source; p = projection of r on the plane of the sky; z = projection of r along the line of sight; V = expansion velocity of source; $v_{\parallel}$ = projection of expansion velocity along the line of sight; $\delta z(p,v_{\parallel})$ = distance element along the line of sight for which the line-of-sight velocity falls within δv of $v_{\parallel}$; $G_R(p)$ = antenna pattern with a half-power beamwidth of R; $T_B(p,v_{\parallel})$ = brightness temperature in the spectral line.

The following relations will be used, explicitly or implicitly, in the subsequent derivations:

$$r = (z^2 + p^2)^{\frac{1}{2}} \tag{1a}$$

$$v_{\parallel} = Vz/r \tag{1b}$$

$$p/r = [1 - (v_{\parallel}/V)^2]^{\frac{1}{2}} \tag{1c}$$

$$\delta z = \delta v/\frac{dv}{dz} = \delta v\frac{p}{V}[1 - (\frac{v_{\parallel}}{V})^2]^{-\frac{3}{2}} \tag{1d}$$

The optical depth along the line of sight is defined as:

$$\tau(p,v_{\parallel}) = \int_0^{\infty}\frac{\alpha(r)}{\delta v}\ N(r)\ dz \tag{2a}$$

where $\alpha(r)$ is the absorption coefficient, δv is the local width of the line, and $N(r)$ is the CO density. Since the only contribution to $\tau(p,v_{\parallel})$ comes from a path length element δz (Eq (equation 1d),

$$\tau(p,v_{\parallel}) = \alpha(r)N(r)\ \frac{p}{V}\ [1 - (\frac{v_{\parallel}}{V})^2]^{-\frac{3}{2}} \tag{2b}$$

We define an equivalent excitation temperature by

$$T_x(r) = \frac{h\nu}{k}\left\{\left[\exp\left(\frac{h\nu}{kT_{exc}(r)}\right) - 1\right]^{-1} - \left[\exp\left(\frac{h\nu}{kT_{bb}}\right) - 1\right]^{-1}\right\} \tag{3}$$

where $T_{exc}(r)$ is the excitation temperature of the transition and T_{bb} is the temperature of the universal background radiation. The brightness temperature is then expressed as

$$\begin{aligned} T_B(p,v_{\parallel}) &= \int_0^{z_{max}} T_x(r)\,\exp\left[-\int_0^{z}\frac{\alpha(r)}{\delta v}\,N(r)\,dz\right]\,dz \\ &= T_x(r)\left[1 - \exp(-\tau(p,v_{\parallel}))\right] \end{aligned} \tag{4}$$

since the only contributions to the integral come from the path length element δz. In Equation (4), r is determined by p and $v_{\parallel}$ as given in Equation 1c.

The antenna beam pattern is assumed to be of the form

$$G(p) = \frac{4\ln 2}{\pi B^2}\,\exp\left(-4\ln 2\,\frac{p^2}{B^2}\right) \tag{5}$$

and the observed antenna temperature is

$$T_A(v_{\parallel}) = 2\pi\int_0^{\infty} G(p)\,T_B(p,v_{\parallel})\,dp \tag{6}$$

assuming that the beam is centered on the source.

A. Optically Thick Case ($^{12}C^{16}O$)

In the approach of Mufson and Liszt (1975), the optically thick case may be treated by considering equal velocity surfaces, which will be the interiors of cones opening towards the observer with their apices at the center of the envelope. If the cones are not resolved by the telescope,

$$T_A(v_{\parallel})/T(0) = \pi(r\sin\theta)^2/\pi r^2$$
$$= 1 - (v_{\parallel}/V)^2 ,$$

(see Figure 4).

As the source becomes resolved, lower velocity cones are truncated, thus reducing the line center relative to the edges. In the limit of complete resolution, the profiles are flat-topped.

Following Morris' treatment, the brightness temperature (Equation 4) is given by

$$T_B(p, v_{\parallel}) = T_x(r)$$

where r is given by Equation 1c. Then

$$T_A(v_{\parallel}) = \frac{8\ \ln 2}{B^2} \int_0^{\infty} T_x(r)\ \exp\left[-4\ \ln 2\ \frac{p^2}{B^2}\right]\ p\ dp$$
$$= \frac{8\ \ln 2}{B^2} \left[1 - \left(\frac{v_{\parallel}}{V}\right)^2\right] \int_0^{\infty} T_x(r)\ \exp\left[-4\ \ln 2\ \frac{\left\{1 - (v_{\parallel}/V)^2\right\}}{B^2}\ r^2\right] r\ dr \tag{7}$$

We see that $T_A(v_{\parallel})$ is characterised completely by the beamwidth B and the characteristic source radius R_C. Initially, T_x is assumed to be uniform out to radius R_C, with the integrand in Equation (7) being zero for $r > R_C$. Then, by a suitable transformation of variables,

$$T_A(v_{\parallel}) = T_x \left[1 - \exp\left\{-4\ \ln 2\ \frac{R_C^2}{B^2} \left(1 - (v_{\parallel}/V)^2\right)\right\}\right] \tag{8}$$

In Figure 1, we show a function of this form fitted to the observed $^{12}C^{16}O$, J = 0–1 profile. Since R_C, the source radius, and B, the half-power beamwidth, are each approximately 1 arcmin (based on the brightness distribution data of Ulich 1975) they are taken as equal.

To see to what extent the profile shape depends on the assumed form of $T_x(r)$, let us consider a gaussian distribution:

$$T_x(r) = T_{max} \exp \left[-\ln 2 \frac{r^2}{R_C^2}\right]$$

where R_C is now the half-intensity radius. Then

$$T_A(v_\parallel) = \frac{8 \ln 2}{B^2} \left[1 - (v_\parallel/V)^2\right] T_{max} \cdot \int_0^\infty \exp\left[-\ln 2 \frac{r^2}{R_C^2}\right] \exp\left[-4\ln 2 \frac{\left[1 - (v_\parallel/V)^2\right]}{B^2} r^2\right] r\,dr$$

$$= T_{max}\left[1 + (B/2R_C)^2 \left[1 - (v_\parallel/V)^2\right]^{-1}\right]^{-1} \qquad (9)$$

This line profile does not differ from that for uniform excitation temperature by more than 15% over the range $0 < v_\parallel < 0.95V$. By comparing $T_A(v_\parallel)$ as given by Equation (9) with the form given in Equation (8), we see that when the excitation temperature is tapered instead of abruptly terminated, the edges of the line profile are enhanced slightly, but not sufficiently to distinguish with present receiver sensitivity. We can conclude that the line profile agrees well with the assumptions of optical thickness and uniform expansion (or contraction) and that this conclusion is relatively independent of the form of $T_x(r)$. Since we have shown that the ^{12}CO line is optically thick, we may derive the excitation temperature of the CO, T_{exc}, from Equation (3), to be 7.5 K.

B. Optically Thin Case ($^{13}C^{16}O$)

In the geometrical approach of Mufson and Liszt, an optically thin, uniformly expanding atmosphere may be treated as a set of concentric shells. For each shell (assuming that it is unresolved by the telescope, (see Figure 4),

$$T_A(v_\parallel)\ dv_\parallel \Big/ \int_0^\infty T_A(v_\parallel)\ dv_\parallel = 2\pi r\ \sin\theta . r d\theta . t \Big/ 4\pi r^2 . t$$

$$= 0.5\ \sin\theta\ d\theta = dv_\parallel / 2V$$

So each unresolved shell has a line profile which is flat from $-V \leqslant v_\parallel \leqslant V$, and consequently, a uniformly expanding, unresolved envelope has flat profiles in optically thin lines. If the envelope is partially resolved, the low-velocity contribution of the outer shells is not seen by the beam, so that the center of the profile will be depressed. In the ultimate resolution limit, the profile will consist of spikes at $\pm V$.

To treat this case analytically, we use Equation (4) in the limit when $\tau(p, v_\parallel) \ll 1$. Then

$$T_B(p, v_\parallel) = \alpha T_x \frac{K}{r^2} \frac{p}{V} [1 - (v_\parallel / V)^2]^{-\frac{3}{2}}$$

We consider first the simple assumption that $T_x(r)$ is constant, that $N(r) = Kr^{-2}$, and that either (or both) of these distributions truncates at $r = R_C$. This corresponds to Morris' (1975) model. Thus

$$T_A(v_\parallel) = \alpha T_x(r) \frac{8 \ln 2}{B^2} \frac{K}{V} \int_0^{p_m(v_\parallel)} \frac{p}{r^2} [1 - \left(\frac{v_\parallel}{V}\right)^2]^{-\frac{3}{2}} \exp [-4 \ln 2\ \frac{p^2}{B^2}]\ p\ dp$$

where $p_m(v_\parallel) = R_C[1 - (v_\parallel/V)^2]^{\frac{1}{2}}$. This reduces to

$$T_A(v_\parallel) = \alpha T_x \frac{R_C}{V} K \left(\frac{4\sqrt{\ln 2}}{B}\right)^2 \mathcal{F}\left(2\sqrt{\ln 2}\,\frac{R_C}{B}\,[1 - (v_\parallel/V)^2]^{\frac{1}{2}}\right) \qquad (10)$$

where $\mathcal{F}(y) = \frac{1}{y}\int_0^y \exp(-x^2)\,dx$.

Figure 2 shows a function of this form fitted to the observed $^{13}C^{16}O$, $J = 0 \leftarrow 1$, profile for IRC+10216, again taking $R_C/B = 1$. Again, the agreement is excellent.

This profile is relatively sensitive to the r dependence of $\alpha T_x N$. For example, if we take a gaussian dependence for $T_x(r)$ and an inverse square dependence for $N(r)$, we find

$$T_A(v_\parallel) = \alpha T_{max} \frac{8\ln 2}{B^2} \frac{K}{V} \int_0^\infty \frac{p}{r^2} [1 - (v_\parallel/V)^2]^{-\frac{3}{2}} \exp[-\ln 2 \frac{r^2}{R_C^2}]$$

$$\cdot \exp[-4\ln 2 \frac{p^2}{B^2}]\ p\ dp$$

$$= \alpha T_{max} \frac{2\sqrt{\pi \ln 2}}{B} \frac{K}{V} \left\{(B/2R_c)^2 + 1 - (v_\parallel/V)^2\right\}^{-\frac{1}{2}} \qquad (11)$$

In this case, the peaks are less pronounced; for $R_C = B$ the peaks rise up to only 1.4 times the value at $v = 0$, whereas in the previous case, the ratio was two. We can also see intuitively that a steeper power law dependence will result in diminished peaks at $v_\parallel = \pm V$. Examination of Figure 2 shows that the model described in Equation (10) fits the observational profile very well within the noise limits, so that, to within a reasonable approximation, the quantity $\alpha T_x N$ does follow an inverse square dependence. Careful mapping of the source in the ^{12}CO line should be made to derive $T_x(r)$, thus separating the temperature and absorption coefficient/density distributions.

C. ^{13}CO Profiles Offset from Center

Figure 3 shows ^{13}CO line profiles observed one arcminute north and south of the center of IRC+10216. Although these positions do not easily lend themselves to an analytical treatment, we can draw some qualitative conclusions from their appearence.

From the central ^{13}CO profile, as well as on physical grounds, we conclude that the ^{13}CO line is optically thin eveywhere. For a source cylindrical along the line-of-sight with uniform density and T_x, we would expect $T_A(0)$ to be about half as strong as $T_A(0)$ from the central profile because of the relative sizes of the source and the beam. For a spherical source with an inverse-square density distribution, $T_A(0)$ should be significantly less than half as strong as the center position. In fact, the observed values of $T_A(0)$ are slightly more than half of the central value (see Table 1). This suggests that the density distribution exceeds an inverse-square law near the outer parts of the source.

We note also the absence of high- and low-velocity spikes in the off-center profiles, which is in accord with the model predictions. The spikes arise from the lines-of-sight which pass near the center of the source, and which receive very little weight when the antenna is positioned almost a full beamwidth from the source center.

D. The ^{13}CO Content of the Envelope

While the present observations cannot verify all the details of the model, they are consistent with constant excitation temperature and inverse-square law density dependence in the IRC+10216 molecular envelope. The previously derived expressions lead to

$$\alpha K = 0.0847 \frac{V}{R_C} \frac{T_A(V)_{13}}{T_A(0)_{12}} = 1.3 \times 10^{-14} \text{ cm}^{-1} \text{ sec}^{-1} \qquad (12)$$

where $V = 1.5\text{x}10^{6}$ cm/sec, $R_C = 5.5\text{x}10^{17}$ cm (assuming that the source distance is 290 pc [Herbig and Zappala 1970]), $T_A(V)_{13}$ is the ^{13}CO antenna temperature measured at the peaks, and $T_A(0)_{12}$ is the ^{12}CO antenna temperature at the line center. The total number of ^{13}CO molecules in the envelope is then given by $9\text{x}10^{4}/\alpha$.

IV DISCUSSION AND CONCLUSIONS

We have presented high-sensitivity ^{12}CO and ^{13}CO line profiles observed towards IRC+10216. The profile shapes are consistent with the ^{12}CO line being optically thick and the ^{13}CO line thin; the ^{13}CO line is double-peaked. These profile shapes are consistent with those predicted from a partially-resolved, expanding envelope, with constant excitation temperature, constant radial expansion velocity, and an inverse-square law density dependence (i.e. constant mass loss from the central star). This is the model developed for the molecular envelope of IRC+10216 by Morris (1975). Our analysis shows that the shape of the ^{12}CO line is determined largely by the motion of the gas, and is relatively insensitive to the distribution of excitation temperature within the envelope.

The CO excitation temperature in the envelope is 7.5 K.

Because the molecules are excited by infrared radiation from the central star, the CO envelope is much larger than that of any of the other observed molecules (e.g. HCN, SiO, etc.). Our observations show that the expansion velocity of the CO is 15 km/sec, while Morris (1975) and Morris et al. (1975) observed a velocity of 12 km/sec for the other molecules. These results suggest that (the magnitude of) the radial velocity increases slightly with distance from the central star; accelerated expansion due to radiation pressure on the dust is a possible explanation. The flow in the envelope is highly supersonic.

The shape of the optically thin ^{13}CO profile is consistent with an inverse square law dependence of the density. The intensities of the ^{13}CO lines measured one beamwidth away from the source center suggest density enhancement in the outer parts of the envelope, perhaps where the outflowing gas encounters the interstellar medium.

In all of the above discussion, we have tacitly assumed that the observed radial velocity flow is due to expansion of the envelope; but the observations are incapable of distinguishing between uniform expansion and contraction. In the case of IRC+10216, however, we can infer from other considerations (such as the observation of the 4.7μ CO absorption lines by Geballe et al. [1973]) that the envelope is in fact expanding.

Finally, in order to determine the CO mass of the envelope, and the ^{12}C/^{13}C isotope ratio, the whole cloud should be mapped to high sensitivity in both the ^{12}CO and ^{13}CO lines. Such observations should also be valuable for studying the temperature and density run in the envelope, and the interaction between the outflowing gas and the interstellar medium.

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REFERENCES

Beckin, E.E, Frogel, J.A., Hyland, A.R., Kristian, J., and Neugebauer, G. 1969, *Ap.J.* (Letters) **158**, L133.

Geballe, T.R., Wollman, E.R., and Rank, D.M., 1973, *Ap.J.* **183**, 499.

Herbig, G.H., and Zappala, R.R., 1970, *Ap.J.* (Letters) **162**, L15.

Loren, R.B., 1975, (private communication).

Miller, J.S., 1970, *Ap.J.* (Letters) **161**, L95.

Morris, M., 1975, *Ap.J.* (in press).

Morris, M., Zuckerman, B.M., Palmer, P., and Turner, B.E., 1971, *Ap.J.* (Letters) **170**, L109.

Morris, M., Gilmore, W.S., Palmer, P., Turner, B.E., and Zuckerman, B.M., 1975, *Ap.J.* (Letters), (in press).

Mufson, S.L., and Liszt, H.S., 1975, *Ap.J.* (in press).

Neugebauer, G., and Leighton. R.B., 1969, "Two-Micron Sky Survey - A Preliminary Catalogue" (NASA SP-3047). (Washington D.C., Government Printing Office).

Penzias, A.A., and Burrus, C.A. 1973, *Ann. Rev. Astron. Astrophys.* **11**, 55.

Solomon, P.M., Jefferts, K.B., Penzias, A.A., and Wilson, R.W., 1971, *Ap.J.* (Letters) **163**, L53.

Toombs, R.I., Becklin, E.E., Frogel, J.A., Law, S.K., Porter, F.C., and Westphal, J.A., 1972, *Ap.J.* (Letters) **173**, L71.

Tucker, K.D. Kutner, M.L., and Thaddeus, P., 1974, *Ap.J.* (Letters) **193**, L115.

Turner, B.E., Zuckerman, B.M., Palmer, P., and Morris, M., 1973, *Ap.J.* **186**, 123.

Wilson, R.W., Solomon, P.M., Penzias, A.A., and Jefferts, K.B., 1971, *Ap.J.* (Letters) **169**, L35.

Wilson, W.J., Schwartz, P.M., and Epstein, E.E., 1973, *Ap.J.* **183**, 871.

Ulich, B.L., 1975 (private communication).

Ulich, B.L., and Haas, R.W., 1975, *Ap.J.* (in press).

TABLE 1: Observed Parameters for the CO Lines in IRC+10216

Line	T_A^*(peak)	v_c (km/sec)	Δv (km/sec)
^{12}CO	4.2	-26.0±1.0	31.0±1.0
^{13}CO	0.24$^+$±.02	-26.0±1.0	29.0±1.0
^{13}CO-1'N	0.14 ±.02	-25.4±1.0	27.3±1.0
^{13}CO-1'S	0.18 ±.03	-25.4±1.0	29.3±1.0

[+] Refers to the central part of the profile at v = -26 km/sec.

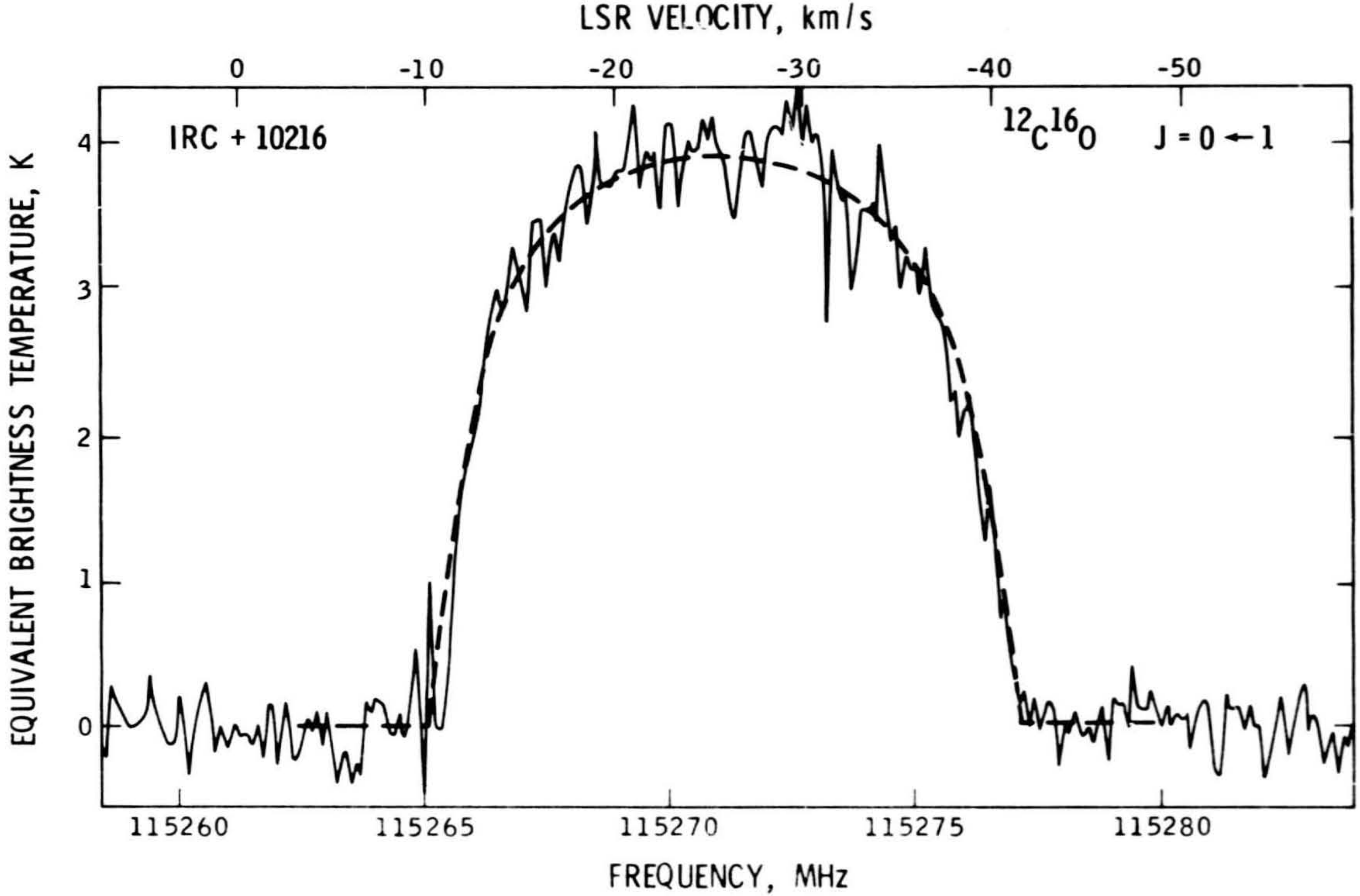
FIGURE CAPTIONS

Figure 1: $^{12}C^{16}O$ $J = 0 \leftarrow 1$ profile at the central position of IRC+10216 observed with a resolution of 100 kHz. The frequencies refer to the source rest frame at -26 km/sec. The dashed line represents a uniform mass-outflow model in which the excitation temperature is assumed constant throughout the envelope (Equation 8).

Figure 2: $^{13}C^{16}O$ $J = 0 \leftarrow 1$ profile at the central position of IRC+10216, observed with a resolution of 250 kHz. The frequencies refer to the source rest frame at -26 km/sec. The dashed line represents the uniform mass-outflow model with inverse-square-law density dependence given by Equation 10.

Figure 3: $^{13}C^{16}O$ line profiles measured (a) 1' north and (b) 1' south of the central position of IRC+10216. The resolution is 250 kHz.

Figure 4: Schematic representation of an expanding, spherically symmetric source distribution, after Mufson and Liszt (1975).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-10
-20
-30
-40
-50
IRC + 10216
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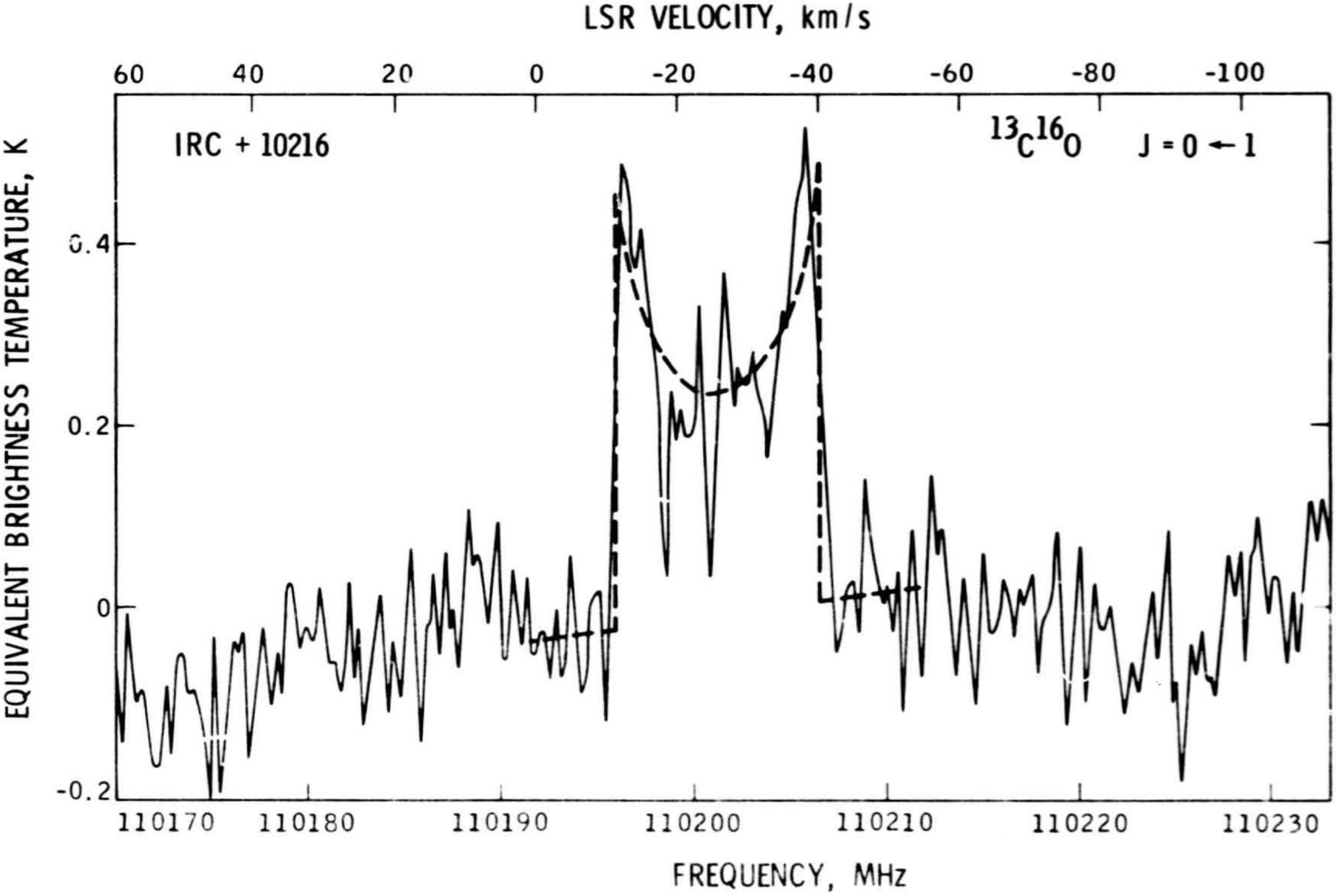
3
2
1
0
115260
115265
115270
115275
115280
FREQUENCY, MHz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20
0
-20
-40
-60
-80
-100
IRC + 10216
$^{13}C^{16}O$
J = 0 ← 1
EQUIVALENT BRIGHTNESS TEMPERATURE, K
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110190
110200
110210
110220
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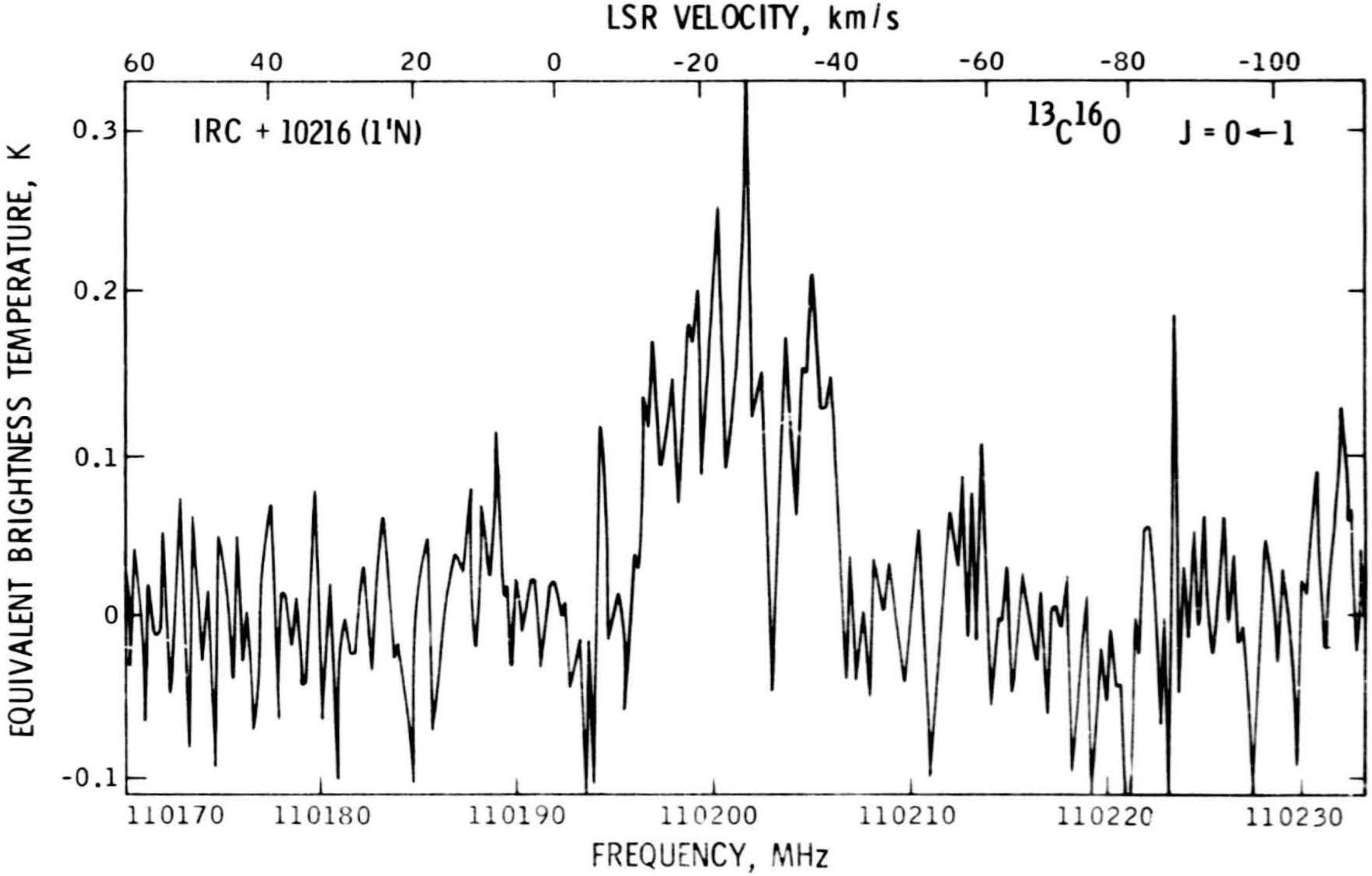
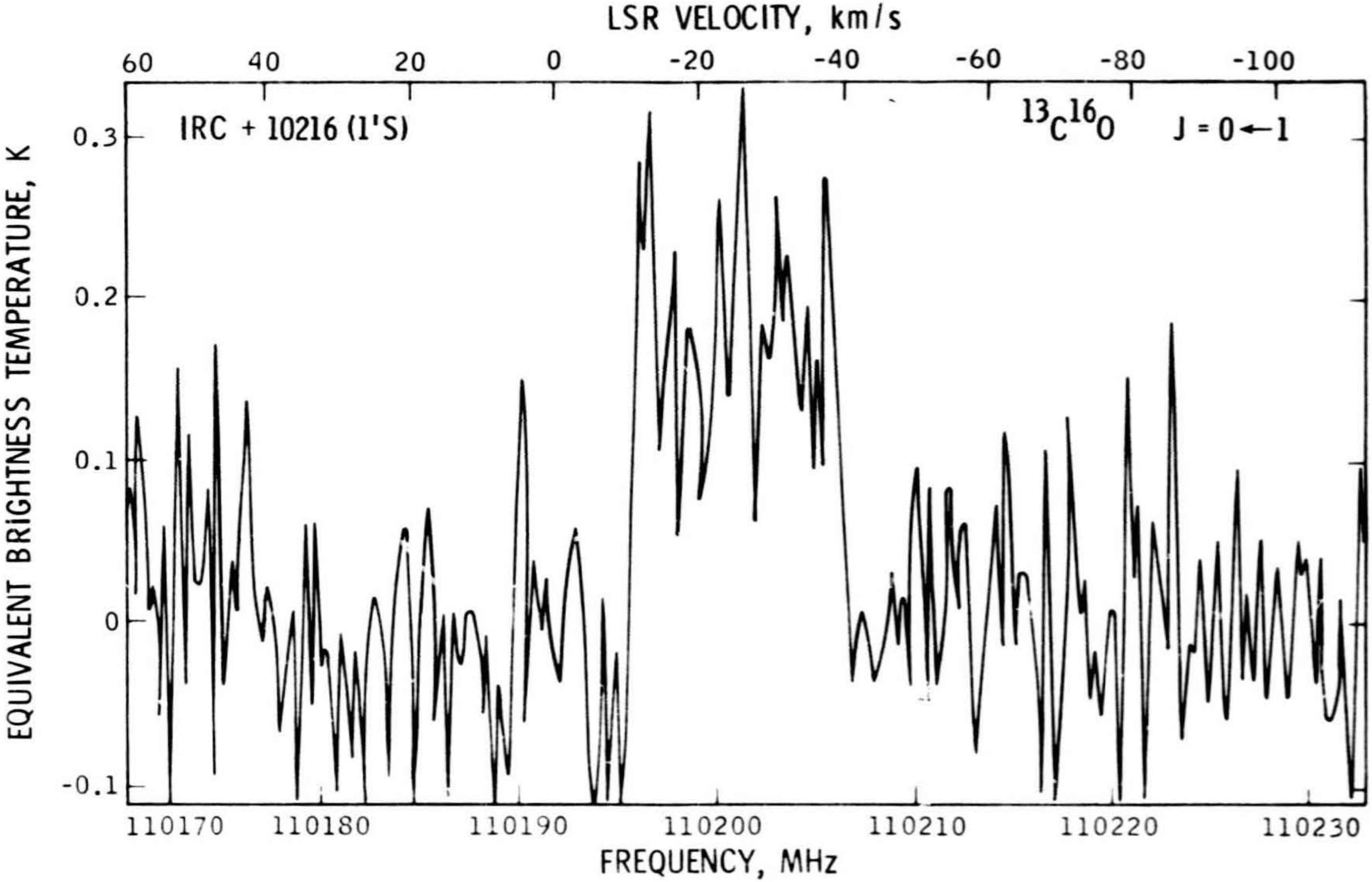
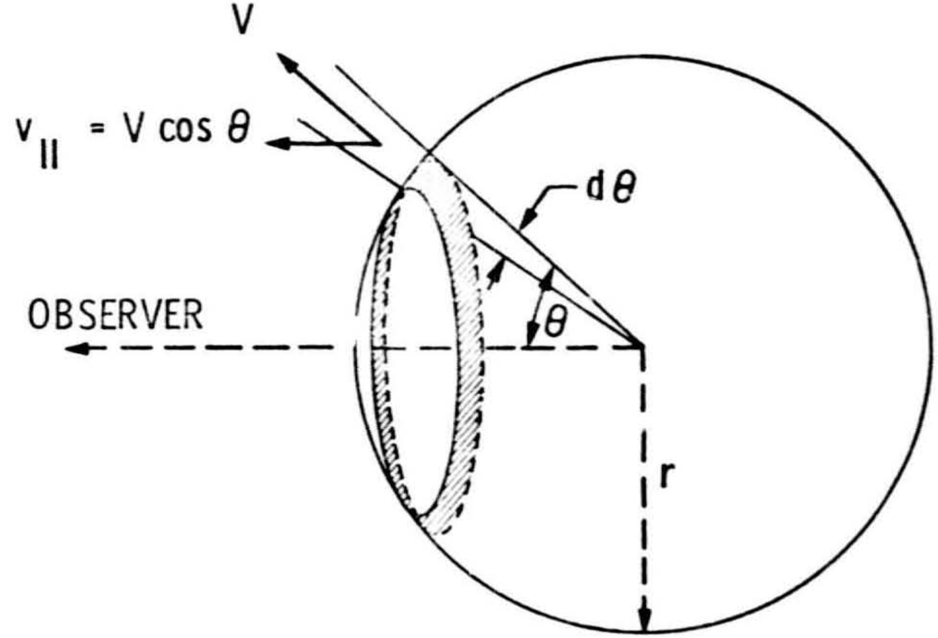

LSR VELOCITY, km/s
60
40
20
0
-20
-40
-60
-80
-100
IRC + 10216 (1'N)
$^{13}C^{16}O$
J = 0 ← 1
EQUIVALENT BRIGHTNESS TEMPERATURE, K
0.3
0.2
0.1
0
-0.1
110170
110180
110190
110200
110210
110220
110230
FREQUENCY, MHz

21.


LSR VELOCITY, km/s
60
40
20
0
-20
-40
-60
-80
-100
IRC + 10216 (1'S)
$^{13}C^{16}O$
J = 0 ← 1
EQUIVALENT BRIGHTNESS TEMPERATURE, K
0.3
0.2
0.1
0
-0.1
110170
110180
110190
110200
110210
110220
110230
FREQUENCY, MHz


V
$v_{\parallel} = V \cos \theta$
$d\theta$
θ
OBSERVER
r