

OBSERVATIONS OF THE J=1→0 TRANSITIONS OF ¹²CO, ¹³CO and C¹⁸O TOWARD OMC-1

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ABSTRACT

Using the Daeduk Radio Telescope, we have observed J=1→0 transitions of ¹²CO, ¹³CO, and C¹⁸O toward OMC-1. The column densities of $1 \sim 5 \times 10^{17} \text{ cm}^{-2}$ and $1 \sim 3 \times 10^{16} \text{ cm}^{-2}$ have been derived, for ¹³CO and C¹⁸O, respectively, in the 11' × 11' region centered at Orion - KL. The double isotope ratio [¹³CO]/[C¹⁸O] was found to be larger than the cosmic abundance ratio by factors of 2 ~ 10 which may result from the chemical fractionation effect.

Key Words: interstellar cloud, interstellar molecule - Orion nebula.

I. INTRODUCTION

Numerous observations for the variety of interstellar molecules have been made since the first detection of the ¹²CO rotational transition in interstellar space at the early 1970s. Among the observed molecules ¹²CO is the most studied mainly because of its strong line intensities and the importance as a tracer of H₂ in molecular clouds. Accurate determination of ¹²CO abundances is, however, hindered by large optical depths of the ¹²CO lines in most cases and also by the probable chemical fractionation effect related to this species (Combes 1991). The rare isotope variants of ¹²CO, such as ¹³CO and C¹⁸O, could be used to determine the CO abundances since their transitions have smaller optical depths than those of ¹²CO. The cosmic abundance ratios of [¹²C]/[¹³C] and [¹⁶O]/[¹⁸O] are 89 and 490, respectively (Wilson & Matteucci 1992). The observations for the species containing these isotopes, however, show different abundance ratios compared to the cosmic values, for example, the column density ratios, [¹²CO]/[¹³CO], appear to be smaller than the cosmic value by factors of 2 ~ 3 in molecular clouds (Langer 1977, Wannier 1989, Langer & Penzias 1990). The small values of the ratio may be explained by chemical fractionation of ¹³CO which increases the ¹³CO abundance by the following equation (Caughlan 1977; Langer *et al.* 1980, 1984; Wilson *et al.* 1981; Young *et al.* 1982),



where k_f and k_r are rate coefficients of forward and reverse reactions, respectively, and ΔE is the zero point energy difference between the reactants and the products. In the laboratory, Smith & Adams(1980) measured these coefficients to be $6.8 \times 10^{-10} \text{ cm s}^{-1}$ and $4.1 \times 10^{-10} \text{ cm s}^{-1}$ at 80K for k_f and k_r , respectively. If reaction (1) reaches chemical equilibrium, the abundance ratio of ¹²CO and ¹³CO will be proportional to the ratio of rate coefficients and abundances of ¹²C⁺ and ¹³C⁺ as follows ;

$$\frac{[^{12}\text{CO}]}{[^{13}\text{CO}]} = \frac{k_r [^{12}\text{C}^+]}{k_f [^{13}\text{C}^+]} = e^{\frac{-35}{kT}} \frac{[^{12}\text{C}^+]}{[^{13}\text{C}^+]} \quad (2)$$

where $\Delta E = 35\text{K}$ was assumed (Watson *et al.* 1976). If such fractionations occur to a significant degree, the isotopic ratios of the elements deduced directly from molecular emissions will not be representative for the interstellar matter as a whole.

Table 1. Telescope Parameters

		$^{12}\text{CO}(J=1\rightarrow 0)$	$^{13}\text{CO}(J=1\rightarrow 0)$	$\text{C}^{18}\text{O}(J=1\rightarrow 0)$
Frequency	(GHz)	115.271	110.201	109.782
FWHP	(")	49	51	51
$T_{\text{sys}}(\text{SSB})$	(K)	~ 1700	~ 1300	~ 900
η_{B}		0.24	0.25	0.25

To reduce the optical depth effect in the isotopic ratios, we can derive the double isotope ratios such as, for example, $[\text{C}^{13}\text{CO}]/[\text{C}^{18}\text{O}]$. The C^{18}O fractionation may also occur in a similar way as for ^{13}CO , such as



The ^{18}O fractionation effect, however, may be ignored in interstellar cloud since this equation has very small rate coefficients (Watson 1977).

In this paper we observed the $J = 1\rightarrow 0$ transitions of ^{12}CO , ^{13}CO and C^{18}O toward Orion Molecular Cloud-1(OMC-1) which is a well known dense molecular cloud located at a distance of 470 pc from the sun (e.g. Genzel & Stutzki 1989; Kutner *et al.* 1976). We derive the column densities and their abundance ratios of ^{13}CO and C^{18}O and discuss the fractionation effect in this region.

II. OBSERVATIONS

The $J = 1\rightarrow 0$ transitions of ^{12}CO , ^{13}CO and C^{18}O were mapped toward OMC-1 using the 14m Daeduk Radio Telescope(DRT) of the Daeduk Radio Astronomy Observatory during October 1990 to February 1991. The frontend was a cooled Schottky diode mixer and the backend was a 256 channel \times 250 kHz filterbank which results in spectral resolutions of 0.65kms^{-1} at 115GHz. Table 1 lists the telescope parameters. The maps were made in the $11' \times 11'$ region centered at the KL position ($\alpha_{1950} = 5^{\text{h}}31^{\text{m}}47^{\text{s}}$, $\delta_{1950} = -5^{\circ}25'25''$). All data were taken by position switching method with a reference position $\alpha_{1950} = 5^{\text{h}}31^{\text{m}}44^{\text{s}}$, $\delta_{1950} = -5^{\circ}59'30''$. The typical rms noise levels are roughly 0.4K, 0.3K and 0.1K for the ^{12}CO , ^{13}CO , and C^{18}O spectra, respectively.

III. RESULTS

Fig.1 shows sample spectra obtained toward the KL position of OMC-1. Column densities of ^{13}CO and C^{18}O have been derived assuming LTE and also LVG and statistical equilibrium. In LTE method, we assumed a rotational temperature, T_{rot} , for ^{13}CO and C^{18}O of 40K since molecules observed by Blake *et al.*(1987) appear to have $T_{\text{rot}} = 20\sim 60\text{K}$ at the Orion extended ridge. Especially the abundance ratios of $N(^{13}\text{CO})/N(\text{C}^{18}\text{O})$ appear to be, almost constant along the different rotational temperatures. In Fig. 2-a, -b, and -c we show integrated intensity maps of the ^{12}CO , ^{13}CO and C^{18}O $J=1 \rightarrow 0$ lines in a region $11' \times 11'$ centered at KL. The $^{12}\text{CO}(1-0)$ map shows a strong intensity at KL, suggesting a concentration of hot gas in the region. The total column densities in the observed region, however, seem to be distributed rather "uniformly" as traced by $^{13}\text{CO}(1-0)$ and $\text{C}^{18}\text{O}(1-0)$ (Fig. 2 -b & -c).

We also derived column densities using a large velocity gradient(LVG) radiative transfer model to compare the abundances derived by assuming LTE(Goldreich & Kwan 1974, Goldsmith *et al.* 1983, Minh *et al.*1991). We assumed statistical equilibrium and a kinetic temperature of 40K. The collisional de-excitation rates for ^{13}CO and C^{18}O were adopted from those for ^{12}CO (Flower & Launary 1985), which are very insensitive to kinetic temperatures or energies of the transition levels. The uncertainties in collisional rates appear together with the uncertainties in H_2 volumn densities in the model calculation results. Fig. 4. shows the radiation temperatures along the hydrogen density, $n(\text{H}_2)$, and the column densities of ^{13}CO and C^{18}O .

In Table 2 we list the averaged results in six areas which were divided arbitrarily to improve the signal-to-noise ratio of the spectra and to reduce the spatial irregularities of the line intensities. The position offsets in Table 2 indicate the

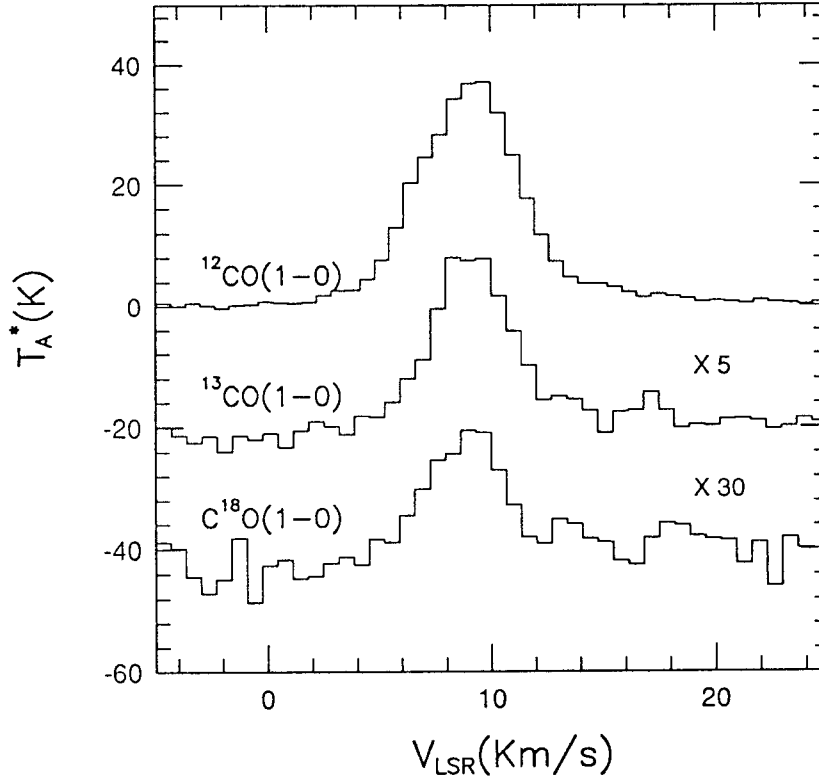
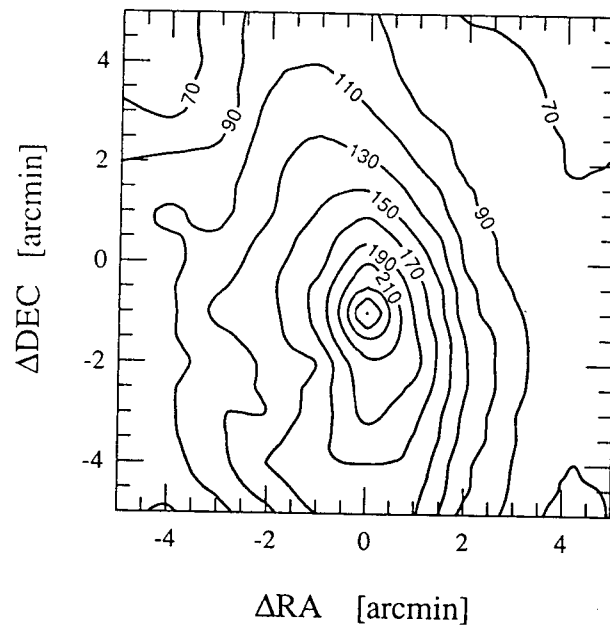


Fig. 1. Sample spectra of $J=1\rightarrow 0$ transitions of ^{12}CO , ^{13}CO , and C^{18}O obtained toward Orion-KL ($\alpha_{1950} = 5^{\text{h}}31^{\text{m}}47^{\text{s}}$; $\delta_{1950} = -5^{\circ}25'25''$).

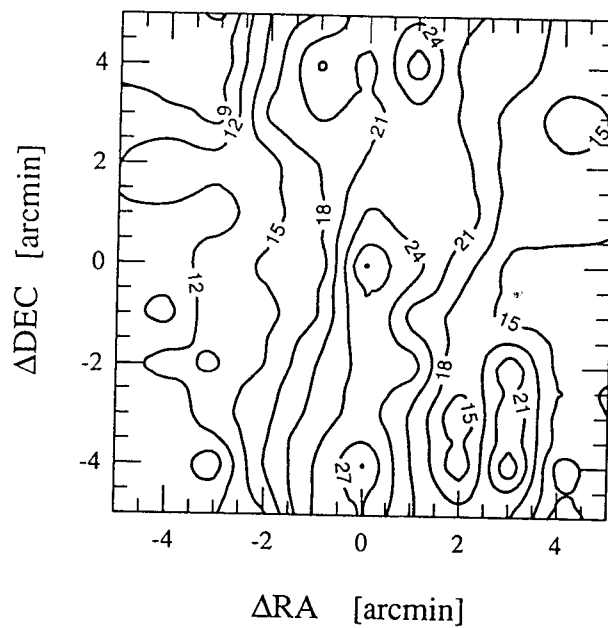
Table 2. The Column Densities in LTE and LVG Method

Position offsets ⁽¹⁾	(0,0)	(+1,+3)	(0,-4)	(+4,0)	(-3,+2)	(-3,-4)
	LTE	Results				
$N(^{13}\text{CO}) \times 10^{17} \text{ (cm}^{-2}\text{)}$	3.53	2.91	3.31	1.38	1.49	1.81
$N(\text{C}^{18}\text{O}) \times 10^{16} \text{ (cm}^{-2}\text{)}$	2.18	1.90	1.51	1.27	1.20	1.04
N_{13}/N_{18}	16.19	15.32	21.92	10.87	12.42	17.40
	LVG	Results				
$N(^{13}\text{CO}) \times 10^{17} \text{ (cm}^{-2}\text{)}$	2.09	1.91	2.00	1.05	1.10	1.26
$N(\text{C}^{18}\text{O}) \times 10^{16} \text{ (cm}^{-2}\text{)}$	1.26	1.17	1.05	0.79	0.79	0.55
N_{13}/N_{18}	16.60	16.22	19.05	13.18	13.80	22.91

NOTES.⁽¹⁾ Offsets from Orion-KL

^{12}CO INTENSITY MAP

(a)

 ^{13}CO INTENSITY MAP

(b)

Fig. 2. Integrated intensity maps. The contour levels are indicated in the figure and its unit is K Kms^{-1} . : (a) For ^{12}CO (1-0), (b) For ^{13}CO (1-0).

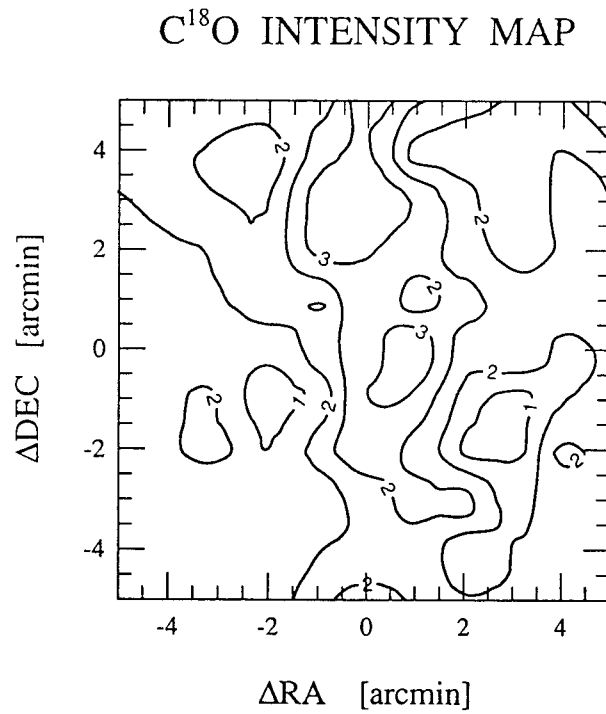


Fig. 2. Continued : (c) For C^{18}O (1-0).

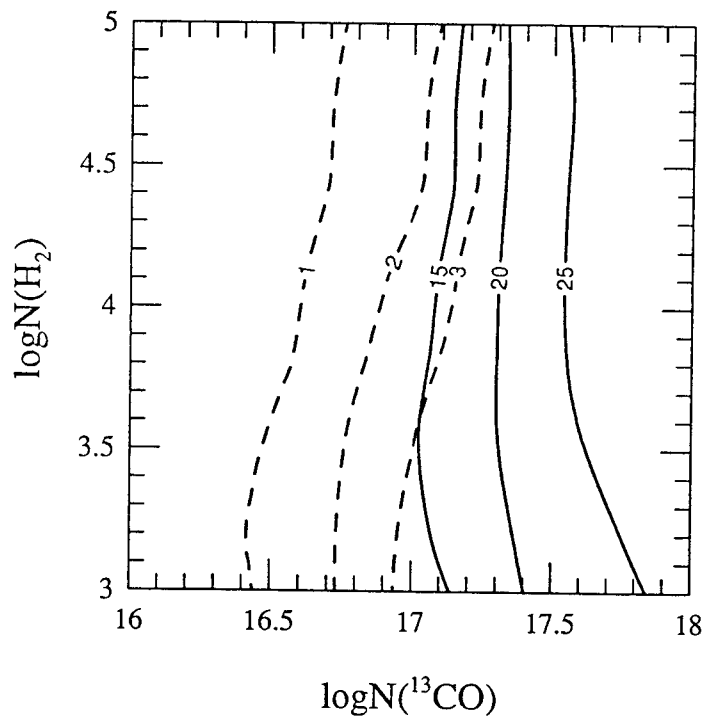


Fig. 3. LVG model results. The contour levels are indicated in the figure and its unit is K. The solid and dotted lines represent the antenna temperatures, for ^{13}CO and C^{18}O , respectively.

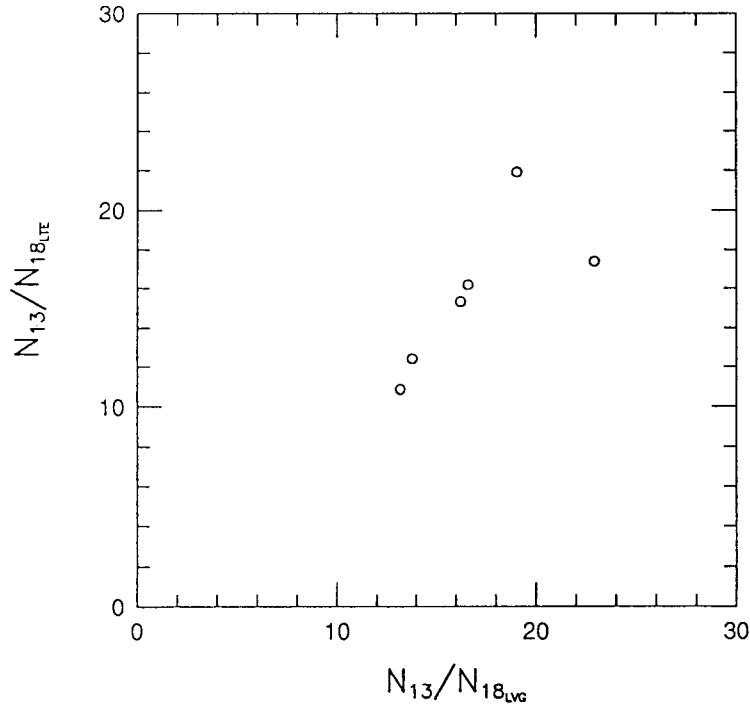


Fig. 4. The comparison of the double isotope ratios derived in LTE and LVG methods.

center positions for the 6 areas of $3' \times 3'$ size, since our main goal for this paper is to derive representative values of the double isotope ratio in OMC-1. In Fig.5 we plot the abundance ratios derived by two different methods (LTE and LVG) and it shows that two methods results in similar abundance ratios roughly. We use LTE results for discussion.

IV. DISCUSSION

We obtained the ^{13}CO column densities of $1 \sim 4 \times 10^{17} \text{cm}^{-2}$ (Table 2) which are similar to those of Castets *et al.*(1990). The distributions of the total gas column densities estimated from the ^{13}CO (1-0) and C^{18}O (1-0) maps suggest that OMC-1 has a somewhat uniform total column densities in the central $50(\text{arcmin})^2$ region. The double isotope ratios in OMC-1 appear to be enhanced by factors of $2 \sim 10$ as listed in Table 2 compared to the cosmic abundance ratio of 5.5 and in Fig. 6 we showed the change of the double isotope ratios along the density including all observed positions. The observed ratios are much larger than the cosmic value of 5.5 in most cases and appear to decrease at dense regions. It suggests that ^{13}CO abundances are enhanced in less dense regions compared to those in denser regions, which could result from the ^{13}CO chemical fractionation effect. In low extinction regions UV photons can generate a larger C^+ abundance than in dense regions and increase the chemical fractionations effect by the equation (1). In addition, OMC-1 has been known to have a complicated structure and its clumpy structure can also increase the chemical fractionation effect by the increment of the total cloud surface area which results in a larger abundance of C^+ than in a uniform large cloud.

The isotope selective photodissociation effect may also explain a part of the large double isotope ratios since C^{18}O could be reduced by selective photodissociation resulted from different shielding of the photodissociation photons(Bally & Langer 1982, Chu & Watson 1983, van Dishoeck & Black 1988, Glassgold *et al.* 1985). Self-shielding of the abundant species from the UV photons can increase the life time of the species in a UV irradiated environment. This effect is, however, thought to be small since the self-shielding effect showed depend on the abundance of the species and the ^{13}CO abundance may not be enough to shield themselves by being dissociated by UV photons.

In summary we derive the abundances of ^{13}CO and C^{18}O at OMC-1 and the double isotope ratios of $[^{13}\text{CO}]/[\text{C}^{18}\text{O}]$.

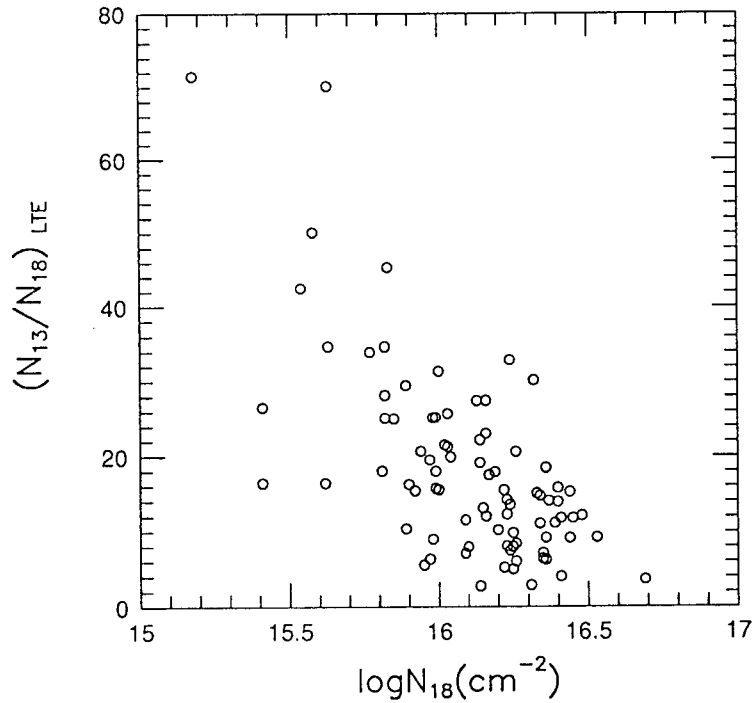


Fig. 5. $\log(N(\text{C}^{18}\text{O}))$ vs $[\text{C}^{13}\text{CO}]/[\text{C}^{18}\text{O}]$ from the abundances derived in LTE method.

The ratio shows to be enhanced by factors of 2~10 compared to the cosmic value. We discuss the possible scenarios to explain these large values but further studies are definitely necessary to understand the chemical fractionation effect at this region.

REFERENCES

- Bally, J. and Langer, W. D. 1982, ApJ, 225, 143
 Blake, G. A., Sutton, E. C., Masson, C. R., and Phillips, T. G., 1987, ApJ, 315, 621
 Castets, A., Duvert, G., Dutrey, A., Bally, J., Langer, W. D., and Wilson, R. W., 1990, A&A, 234, 469
 Chu, Y. -H. and Watson, W. D., 1983, ApJ, 267, 151
 Combes, F., 1991, ARAA, 29, 195
 Caughlan, G.R., 1977, in CNO Isotope in Astrophysics, ed. Audouze, J. (Dordrecht: D.Reidel), 121
 Flower, D. R. and Launary, J. M., 1985, MNRAS, 214, 271
 Genzel, R. and Stutzki, J., 1989, ARAA, 27, 41
 Glassgold, A. E., Huggins, P. J. and Langer, W. D., 1985, ApJ, 290, 615
 Goldreich, P. and Kwan, J., 1974, ApJ, 189, 441
 Goldsmith, P. F., Young, J. S. and Langer, W. D., 1983, ApJS, 51, 203
 Kutner, M. L., Evans, N. J., and Tucker, K. D., 1976, ApJ, 209, 452
 Langer, W. D. and Fenzias, A. A., 1990, ApJ, 357, 477
 Langer, W. D., 1977, ApJ, 212, L39
 Langer, W. D., Goldsmith, P.F., Carlson, E. R., and Wilson, R. W., 1980, ApJ, 235, L39
 Langer, W. D., Graedel, T.E., Frerking, M. A., and Armentrout, P. B., 1984, ApJ, 227, 581
 Minh, Y. C., Irvine, W. M. and Brewer, M. K., 1991, A&A, 244, 181

- Smith, D. and Adams, N. G., 1980, *ApJ*, 242, 424
Taylor, D. K. and Dickman, R. L., 1989, *ApJ*, 341, 293
Wannier, P. G., 1989, in *IAU Sym.*, 136, ed. M. Morris (Dordrecht: Kluwer), 107
Watson, W. D. 1977, in *CNO Isotopes in Astrophysics*, ed. J. Audouze (Dordrecht: Reidel), 105
Watson, W. D., Anicich, V. G. and Huntress, Jr. W. T., 1976, *ApJ*, 205, L65
Wilson, R. W., Langer, W. D. and Goldsmith, P. F., 1981, *ApJ*, 243, L47
Wilson, T. L. and Matteucci, F., 1992, *ARAA*, 4, 1
Young, J. S., Goldsmith, P. F., Langer, W. D., Wilson, R. W. and Carlson, E. R., 1982, *ApJ*, 261, 513
Van Dishoeck, E. F. and Black, J. H., 1988, *ApJ*, 334, 771