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CO EMISSION ASSOCIATED WITH SHARPLESS H II REGIONS

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ABSTRACT

Carbon monoxide emission has been found near eight Sharpless H II regions. Its presence appears to depend on the existence of a near-infrared excess (3.5 μ) from the optical nebula. The CO emission is strongly peaked near the H II region itself, and extends considerably beyond. High-resolution line profiles are generally asymmetric, the blue side displaying a wing, and are typically ~ 5 km s^{-1} wide.

Subject headings: infrared sources — molecules, interstellar — nebulae

I. INTRODUCTION

Recently, several attempts have been made to relate molecular line emission or absorption features associated with H II regions with the infrared emission from the same objects. Searches for spatial coincidences between 20-μ emission and OH and H_2O maser sources have been made by Wynn-Williams, Becklin, and Neugebauer (1974*a*) and Wynn-Williams, Werner, and Wilson (1974*b*). A correlation has tentatively been established between an absorption feature due to silicates at 10 μ and the optical depth of the 6-cm H_2CO line toward several powerful 20-μ sources (Frogel and Persson 1973*a*, 1974). Gillett and Forrest (1973) have detected H_2O absorption at 3.1 μ against the continuum in Orion. Far-infrared emission from the vicinity of the galactic center and Orion is certainly associated with the massive molecular clouds observed in these regions as discussed by Scoville, Solomon, and Jefferts (1974), Zuckerman (1973), and Harvey *et al.* (1973). Their work has established that the grains emitting the far-infrared and the H_2 molecules, which are probably responsible for the collisional excitation of various molecular lines, are co-spatial. Finally, progress has been made in understanding molecular formation on grain surfaces (see, e.g., Watson and Salpeter 1972), the composition of the grains (Kamijo and de Jong 1973; Field 1974), and the infrared emission from the grains or grain nuclei (see, e.g., Wright 1973).

The aims of this observing program are to look for and understand relations between molecular and infrared emission, and to determine the kinematic characteristics of the molecular clouds associated with newly formed H II regions.

In this paper we present our preliminary observations of 2.6-mm CO emission from H II regions, most of which we have also studied in the infrared and the optical. The regions are generally small ($\sim 1'.5$) optical nebulae selected from the list of Sharpless (1959). Some display an excess of emission at 3.5 μ (Frogel and Persson 1972; Persson, Frogel, and Goad 1974), which must arise from hot dust grains within the H II region and often increases with respect to the free-free emission toward the periphery of the objects. One H II region, S228, contains an unresolved ($< 3''$) infrared source whose energy distribution out to 20 μ and whose optical line spectrum are similar to those of K3-50 (Frogel and Persson 1973*b*; Persson and Frogel 1974). More detailed observations of CO and HCN emission will be published later.

II. OBSERVATIONS

The spectra of the H II regions were taken with the 36-foot (11-m) antenna of the National Radio Astronomy Observatory[1] at Kitt Peak. The receiver was operated in the total-power mode, with the telescope switching on- or off-source every 30 s. The off-source positions were checked for background CO emission and in one case (S156) it was necessary to correct for a small background signal. Two filter banks provided resolutions of 100 and 250 kHz per channel. Calibration was provided by a chopper wheel which eliminates atmospheric effects, to a first approximation. Pointing was checked by observing Jupiter. The half-power beamwidth of the system at 115 GHz is 67″.

III. RESULTS

We detected CO toward eight of the 13 Sharpless objects that were observed; the data are listed in table 1. The radial velocities of the Hα emission from the H II regions are taken from the work of Georgelin and Georgelin (1970). Limited mapping of CO emission was possible for several objects, and the brightness temperature contours are shown in figure 1. In figure 2 we display the high-resolution (0.7 km s^{-1}) spectra of four sources. The objects which were not detected ($T_A < 3°$ K) are S162, S208, S237, S288, and S307. The important results of these observations are summarized as follows:

1. From the infrared studies of the Sharpless objects (Frogel and Persson 1972, 1973*b*; Persson *et al.* 1974), we find that strong CO emission is present only when there is significant 3.5-μ excess emission from

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TABLE 1

CO Emission from Sharpless H II Regions*

Source	Position† (1950.0)		Peak T_A (° K)	LSR Radial Velocities ΔV (km s^{-1})	V(CO) (km s^{-1})	V(Hα) (km s^{-1})	FWHP‡ (arc min)	Optical Size (arc min)
S138.........	22^{h}31^{m}44^s	+58°13′.1	10	5.5	−53	...	11 × 5	0.7
S152.........	22 56 39	+58 29.8	18	5.0	−51	−63§	9 × 7	1.6
S156.........	23 03 05	+59 58.6	17	4.6	−52	−50	12 × 5	2.0
S157B	23 13 53	+59 45.7	23	4.7	−46	−46§	...	1.9 × 2.6
S159.........	23 13 23	+60 50.6	26	3.0	−56	...	...	5
S186.........	01 05 34	+62 51.6	8	2.8	−43	...	8 × 2	0.7
S201.........	02 59 10	+60 13.6	10	2.9	−41	...	...	irregular
S228.........	05 10 01	+37 23.7	16	3.0	−8	−12	2 × 2	2 × 2

* S162, S208, S237, S288, and S307 were not detected to a level of 3° K.

† For the sources having a measured FWHP, the position is that of peak T_A. For the other sources it is the antenna pointing position.

‡ The FWHP sizes are only estimates of the extent of the CO emission.

§ M. C. Lortet, private communication.

grains within the H II region. Those H II regions with little or no 3.5-μ excess have little or no detectable CO emission. There is no quantitative correlation, however, between the CO and infrared emission. S162 (=NGC 7635), which we did not detect, has been studied in the infrared by Cohen and Barlow (1973). Their data show a 10-μ excess from the vicinity of the exciting stars, but little or no 3.5-μ excess from the nebula itself.

2. The antenna temperatures we have measured are considerably higher than those found by Schwarz, Wilson, and Epstein (1973) in the direction of several thermal galactic radio sources having markedly stronger radio continuum emission.

3. For some of the objects (S157, S159, S201, and S228) there is substantial dust associated with the H II regions, as evidenced from the *Palomar Sky Survey* prints, whereas for the other objects the presence of such dust is questionable. However, in no case for T_A < 3° K is there any dust obviously associated with the object.

4. If CO is detected, its distribution is approximately centered on the optical and infrared nebula but is usually considerably more extended. The smallest CO source, S228, surrounds a composite infrared source consisting of a small (<3″) 10–20-μ core source within an extended nebula (Frogel and Persson 1973*b*).

5. The radial velocities vary little over each nebula (~ ±1 km s^{-1}) except for S228, in which the southeast is redshifted with respect to the northwest by 6 km s^{-1}.

6. The line widths are typically ~5 km s^{-1} in each source, some variation from source to source is noted in table 1. Seven positions were observed in S138, and they show that the line width decreases with the antenna temperature away from the center. This trend is present, but only weakly, in S152. Data on the other objects in table 1 are too limited at present to show this effect.

7. The typical high-resolution spectra in figure 2 are distinctly non-Gaussian; the peaks are not smooth and may be multiple. A wing which appears on the blue side of the line is nearly always seen, to some extent, at every location in the four objects for which the signal-to-noise ratio is adequate. For some sources the peak antenna temperatures are distinctly higher at higher spectral resolution (cf. fig. 2 and table 1). This results from the smoothing effect of the broad filters, and implies that some of the CO within the sources

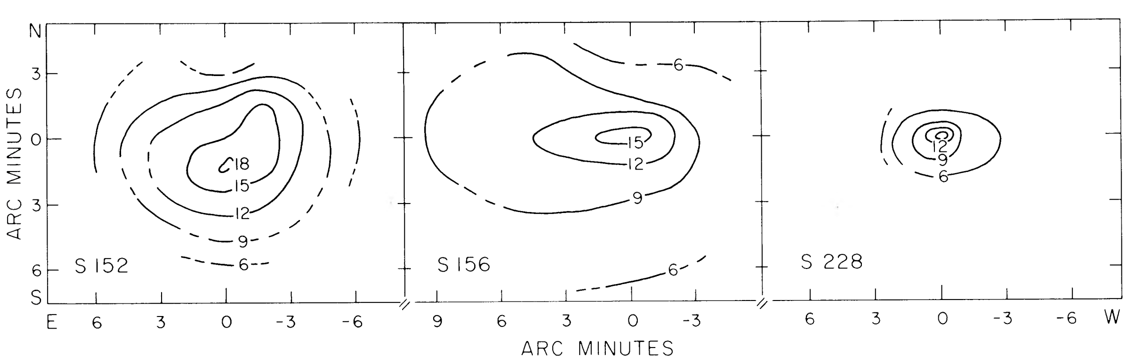

Fig. 1.—Distribution of $^{12}C^{16}O$ emission in three Sharpless H II regions. Units are antenna temperature in ° K.

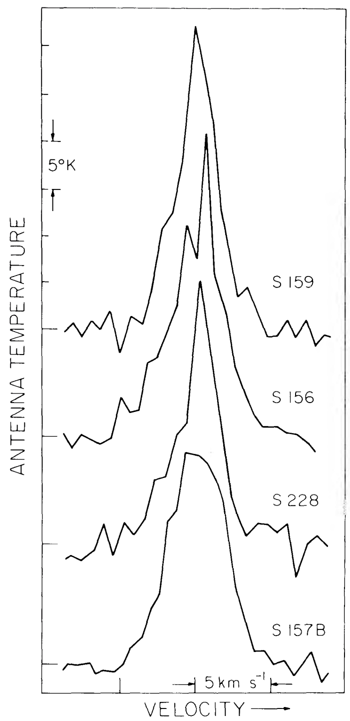

FIG. 2.—Spectra of $^{12}C^{16}O$ emission in four Sharpless H II regions. The velocity resolution is 0.65 km s^{-1}.

has a random velocity (turbulent plus Doppler) less than the velocity resolution of 0.7 km s^{-1}.

IV. DISCUSSION

The results listed above raise several questions about the excitation, kinematics, and velocity structure of the molecular emission regions. Strong CO emission appears to depend on the presence of a 3.5-μ excess. Since nearly all H II regions which are strong infrared emitters at $\lambda > 10\ \mu$ also have excess emission at 3.5 μ (see review by Wynn-Williams and Becklin 1974), it is reasonable to infer that those regions listed in table 1 with little or no 3.5-μ excess will be, at best, weak emitters at longer wavelengths and, in particular, in the far-infrared. Since far-infrared flux presumably arises from dust in cool, neutral circumnebular clouds, the lack of CO emission apparently follows from the lack of circumnebular dust. This in turn may imply one or more of several circumstances. For example, for those objects lacking CO emission, either there is no CO to begin with, or there is CO but dust is necessary as an intermediary to convert stellar energy into a form which can ultimately excite the CO.

The observed line structure is interesting, but enigmatic without knowledge of the excitation mechanism which is operative or the optical depth of the CO. The narrow spikes are real and show that some of the gas does not undergo turbulent broadening or mass motion.

REFERENCES

Cohen, M., and Barlow, M. J. 1973, *Ap. J.* (*Letters*), **185**, L37.
Field, G. B. 1974, *Ap. J.*, **187**, 453.
Frogel, J. A., and Persson, S. E. 1972, *Ap. J.*, **178**, 667.
———. 1973*a*, *Bull. AAS*, **5**, 408.
———. 1973*b*, *Ap. J.*, **186**, 207.
———. 1974, *Ap. J.*, in press.
Georgelin, Y. P., and Georgelin, Y. M. 1970, *Astr. and Ap.*, **6**, 349.
Gillett, F. C., and Forrest, W. J. 1973, *Ap. J.*, **179**, 483.
Harvey, P. M., Werner, M. W., Gatley, I., and Elias, J. 1973, Meeting of the Astronomical Society of the Pacific (Los Angeles).
Kamijo, F., and de Jong, T. 1973, *Astr. and Ap.*, **25**, 371.
Persson, S. E., and Frogel, J. A. 1974, *Ap. J.*, **188**, 523.
Persson, S. E., Frogel, J. A., and Goad, L. E. 1974, unpublished data.
Schwartz, P. R., Wilson, W. J., and Epstein, E. E. 1973, *Ap. J.*, **186**, 529.
Scoville, N. F., Solomon, P. M., and Jefferts, K. B. 1974, *Ap. J.* (*Letters*), **187**, L63.
Sharpless, S. 1959, *Ap. J. Suppl.*, **4**, 257.
Watson, W. D., and Salpeter, E. E. 1972, *Ap. J.*, **174**, 321.
Wright, E. L. 1973, *Ap. J.* **185**, 569.
Wynn-Williams, C. G., and Becklin, E. E. 1974, *Pub. A.S.P.*, **86**, 5.
Wynn-Williams, C. G., Becklin, E. E., and Neugebauer, G. 1974, *Ap. J.*, **187**, 473.
Wynn-Williams, C. G., Werner, M. W., and Wilson, W. J. 1974*b*, *Ap. J.*, **187**, 41.
Zuckerman, B. 1973, *Ap. J.*, **183**, 863.

Note added in proof.—We have recently detected $^{13}C^{16}O$ emission in S138, S152, S156, S159, and S186 using the millimeter-wave antenna of the University of Texas. The antenna temperatures are between 0.5° and 5° K. Details will be published later.

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