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CARBON MONOXIDE EMISSION FROM STARS IN THE *IRAS* AND *REVISED AFGL* CATALOGS. II. MASSIVE CARBON STARS

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ABSTRACT

We surveyed infrared bright stars in the *IRAS* and *Revised AFGL* catalogs in the $J = 1 \rightarrow 0$ and, to a lesser extent, $J = 2 \rightarrow 1$ rotational transitions of carbon monoxide. Broad lines were detected in 25 objects not previously seen in CO emission, including some stars first discovered in the *IRAS* survey about which very little is known. We discovered a number of carbon-rich stars at low Galactic latitude with large outflow velocity V_∞, which are very likely to be among the most massive and luminous carbon-rich objects in the Galaxy. Two of these had $V_\infty \approx 34$ km s^{-1}, which is comparable to molecular outflow velocities measured for oxygen-rich stars with supergiant luminosities. By way of contrast, the high-latitude prototypical carbon star with a large mass loss rate, IRC +10216, has a very modest V_∞ of ~ 15 km s^{-1}. We suggest that IRC +10216 is considerably closer to Earth than is commonly believed, perhaps as close as 100–150 pc. We also found CO emission from a few stars with large radial velocities with respect to the local standard of rest, including V CrB, for which $V_{\rm lsr} = -100$ km s^{-1}.

We detected strong narrow CO emission associated with *IRAS* 0423+4336 and AFGL 5497, both of which we identify as young stars embedded in molecular clouds.

Subject headings: infrared: sources — stars: circumstellar shells — stars: mass loss

I. INTRODUCTION

In the previous paper in this series, we described new observations of the $J = 2 \rightarrow 1$ rotational transition of carbon monoxide in 39 evolved stars as well as some motivations for surveying stellar CO emission (Zuckerman and Dyck 1986*a*, hereafter Paper I). In Paper I and in other previous surveys there was a tendency to avoid stars at low Galactic latitudes because of contamination of stellar spectra by interstellar CO emission. Exhaustion of infrared bright stars at high Galactic latitudes motivates one to observe stars close to the galactic plane. In the present paper we describe CO observations of various bright *IRAS* and *Revised AFGL* (RAFGL, Price and Murdock 1983) sources that are mainly evolved stars. We detected 25 evolved stars for the first time in CO emission, 22 in the $J = 1 \rightarrow 0$ transition, two in $J = 2 \rightarrow 1$, one in both transitions. Of these stars a fair fraction is located close to the Galactic plane. Two, AFGL 2233 and AFGL 2901, were found to have outflow velocities of ~ 34 km s^{-1}. These are easily the largest CO outflow velocities ever measured for carbon-rich evolved stars, and they are comparable to molecular outflow velocities in oxygen-rich supergiants.

We investigated some bright *IRAS* and 5000 series RAFGL sources with uncertain classifications (e.g., were they pre– or post–main-sequence stars?). Our CO spectra resolve these ambiguities in four cases, two of which turn out to be pre–main-sequence and two post–main-sequence. One of the latter, *IRAS* 0713+1005, is located well out of the Galactic plane and has a radial velocity with respect to the local standard of rest $V_{\rm lsr}$ equal to 71 km s^{-1}. This star, X Her ($V_{\rm lsr} = -73$ km s^{-1}), detected in Paper I, and V CrB ($V_{\rm lsr} = -100$ km s^{-1}), detected in the present survey, have the highest CO radial velocities of all detected stars that are located far from the Galactic plane and, therefore, are not subject to differential Galactic rotation.

In the present paper, we discuss some of these interesting stars and investigate the distribution of outflow velocity versus C/O abundance ratios, Galactic latitude, and pulsation period for all stars detected to date in CO emission for which these quantities are known. We defer detailed analysis of mass loss rates, publication of most individual spectra, and discussion of most individual stars listed in Table 1 until a later date.

II. EQUIPMENT AND OBSERVATIONS

We used the 14 m telescope of the Five College Radio Astronomy Observatory[1] equipped with cooled mixer receivers at the $J = 2 \rightarrow 1$ (230,538 GHz) and $J = 1 \rightarrow 0$ (115.2712 GHz) transitions of carbon monoxide. The double sideband temperatures of the two receivers were measured by the FCRAO staff to be 150 and 100 K respectively. The full half-power beamwidths are 23″.5 and 46″. We found, from comparison of $J = 2 \rightarrow 1$ and $1 \rightarrow 0$ spectra for a few stars, that the signal-to-noise ratio was better at $J = 1 \rightarrow 0$. We attribute this to a combination of factors, including relative receiver sensitivity and antenna gain at the two frequencies; mediocre weather, which more adversely degraded sensitivities at 230

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[1] The FCRAO is operated with support of the NSF under grant AST 82-12252 and with permission of the Metropolitan District Commission of the Commonwealth of Massachusetts.

GHz; and possibly, erratic pointing, which would have a more detrimental effect on observations at 230 GHz. For example, the brightness temperature, $T_B = 12.3$ K, that we measured for the $2 \rightarrow 1$ line in IRC +10216 (Table 1) seems much too low when compared to the temperature 20.7 K, measured with the 12 m NRAO antenna (Paper I). This discrepancy may have been due to mispointing at the 14 m antenna. So most of the observations described in the present paper are at 115 GHz. An advantage to observing with the larger, lower frequency beam is that the best positions that exist for some sources are *IRAS* positions, which are sometimes known too imprecisely to search for CO with a 23″.5 beam. A disadvantage to observations with the larger beam is greater susceptibility to contamination of stellar CO spectra by interstellar CO emission along the line of sight.

The spectral line "back end" consisted of three filter banks: two with 256 channels, each channel being 1 MHz wide, and one of 512 channels, each 250 MHz wide. We used all three simultaneously so that by checking whether a given feature appeared in all appropriate places in the filter banks, we could discriminate between, for example, a bad channel and narrow galactic CO emission. At 230.5 and 115 GHz, 1 MHz corresponds to 1.3 km s^{-1} and 2.6 km s^{-1} respectively.

The data were obtained at the end of 1985 February by switching the telescope between a star and a reference position (typically, 3′ or 6′ away) at a rate of 1/60 Hz and subtracting the off-source spectra from the on-source spectra. Total integration times, including time spent at the reference position, varied between 24 minutes and a little over 3 hr for all sources listed in Table 1 that have not been detected previously by other observers.

As described in Paper I, our target list consisted of sources in the *IRAS* point source catalog that have fluxes greater than 100 Jy at 12 μm or greater than 50 Jy at 25 μm. Two objects that we detected in CO emission, AFGL 5497 and *IRAS* 0423+5336, turned out to be young stars embedded in molecular cloud and are discussed in § III*b* below. Data for the other newly detected stars, all apparently red giants, are summarized in Table 1. The listed 1950 epoch positions are usually of high quality, except for a few *IRAS* positions. The sixth column

TABLE 1

SOURCES WITH ASSOCIATED CO EMISSION

Object	RAFGL	α_{1950}	δ_{1950}	Position Reference	Spectral Type	Transition	T_B(K)	V_{LSR}(km/s)	V_∞(km/s)	Remarks
IRC+30021	168	1^{h}08^{m}30^s.6	30°22′10″	5	M	1 → 0	0.15	− 27.1	13.0	
W And	310	2 14 22.9	44 04 28	5	S(M)	1 → 0	0.20	− 35.2	11.0	
Mira	318	2 16 49.1	− 3 12 22	4	M(M)	2 → 1	7.2	46.6	8.3	Previously detected.
	341	2 29 21.1	57 48 53	2	C	2 → 1	0.82	7.0	14.2	
CIT4	349	2 31 41.6	64 55 54	5	M	1 → 0	0.24	12.9	16.8	
						2 → 1	0.63	14.9	12.2	
U Cam	505	3 37 29.1	62 29 19	1	C(SR)	1 → 0	0.16	8.5	22.0	
IRAS 0453+4427		4 53 05.9	44 27 59	3	C	1 → 0	0.14	14.2	19.6	Galactic CO in on source and reference positions.
S Aur	748	5 23 49.0	34 06 29	5	C(SR)	1 → 0	0.08	− 21.4	$\gtrsim$16.5	
Y Tau	5168	5 42 40.7	20 40 33	11	C(SR)	1 → 0	0.17	15.9	10.1	
	935	6 23 04.7	− 9 30 21	7	C	1 → 0	0.10	24.8	12.9	
	954	6 29 05.7	43 19 28	8	C	1 → 0	0.06	− 39.5	21.4	
UU Aur	966	6 33 06.6	38 29 16	1	C(SR)	2 → 1	0.26	7.6	12.4	
IRAS 0713+1005		7 13 25.4	10 05 08	3	M ?	1 → 0	0.36	71.0	10.0	See Fig. 1.
IRC+10216	1381	9 45 14.8	13 30 41	9	C(M)	1 → 0	10.7	− 26.8	15.0	Previously detected.
						2 → 1	12.3?	− 25.4	14.6	T_B too small?
CIT6	1403	10 13 11.0	30 49 17	9	C(SR)	1 → 0	2.5	− 1.0	16.5	Previously detected.
						2 → 1	4.6	− 2.9	17.8	Previously detected.
V CrB	5311	15 47 44.9	39 43 15	3	C(M)	1 → 0	0.11	−100.0	6.5	
	1922	17 04 54.4	−24 40 29	7	C	2 → 1	1.1	− 3.4	16.6	
MW Her	1988	17 33 24.8	15 37 02	5	M(M)	1 → 0	0.16	− 47.5	23.3	
	2154	18 23 57.6	− 6 55 55	7	C	1 → 0	0.25	3.4	27.0	
IRC+20370	2232	18 39 41.7	17 38 16	6	C	1 → 0	1.1	− 0.8	14.0	Previously detected.
IRC+00365	2233	18 39 48.4	− 2 20 24	10	C	1 → 0	0.29	2.8	34.5	See Fig. 5.
IRC+10374	2241	18 41 18.9	13 54 18	5	M	1 → 0	0.11	− 13.8	18.5	
	2259	18 47 31.4	9 26 34	11	C	1 → 0	0.17	22.0	21.8	
IRC+10401	2310	19 00 52.9	7 26 15	12	C	1 → 0	0.27	6.9	$\gtrsim$17.4	CO in ref. position.
R Cyg	2422	19 35 28.7	50 05 11	1	S(M)	1 → 0	0.19	− 18.3	9.6	
V Cyg	2632	20 39 41.3	47 57 45	1	C(M)	1 → 0	1.2	12.9	11.7	Previously detected.
IRAS 2131+5631		21 31 50.1	56 31 13	3	M ?	1 → 0	0.52	3.0	15.6	
PQ Cep	2805	21 44 01.2	73 24 11	5	C	1 → 0	0.15	3.3	21.7	
	2901	22 24 07.7	60 05 28	13	C	1 → 0	0.2	− 5.9	34.2	See Fig. 5
IRAS 2227+5435		22 27 13.2	54 35 41	3	M	1 → 0	0.68	− 30.9	11.6	See Fig. 2
	3011	22 58 29.7	64 02 38	2	C	1 → 0	0.28	− 4.9	21.4	
	3068	23 16 42.4	16 55 10	6	C	1 → 0	1.6	− 30.8	12.2	Previously detected.
IRC+40540	3116	23 32 00.4	43 16 17	6	C	1 → 0	1.7	− 16.6	13.8	Previously detected.

REFERENCES.—(1) SAO calalog. (2) Gehrz and Hackwell 1976. (3) *IRAS* point source catalog. (4) SAO catalog corrected for proper motion. (5) Kleinmann and Joyce positions given in *IRAS* catalog. (6) Zuckerman *et al.* 1977. (7) Joyce *et al.* 1977. (8) *IRAS* point source calalog; Grasdalen *et al.* 1983; Joyce *et al.* 1977. (9) Kleinmann and Payne-Gaposchkin 1979. (10) RAFGL catalog and Kleinmann and Joyce (see ref. 5). (11) RAFGL and *IRAS* point source catalogs. (12) RAFGL catalog; Zuckerman *et al.* 1977; Kleinmann and Joyce (see ref. 5). (13) *IRAS* point source calalog and Gehrz and Hackwell 1976.

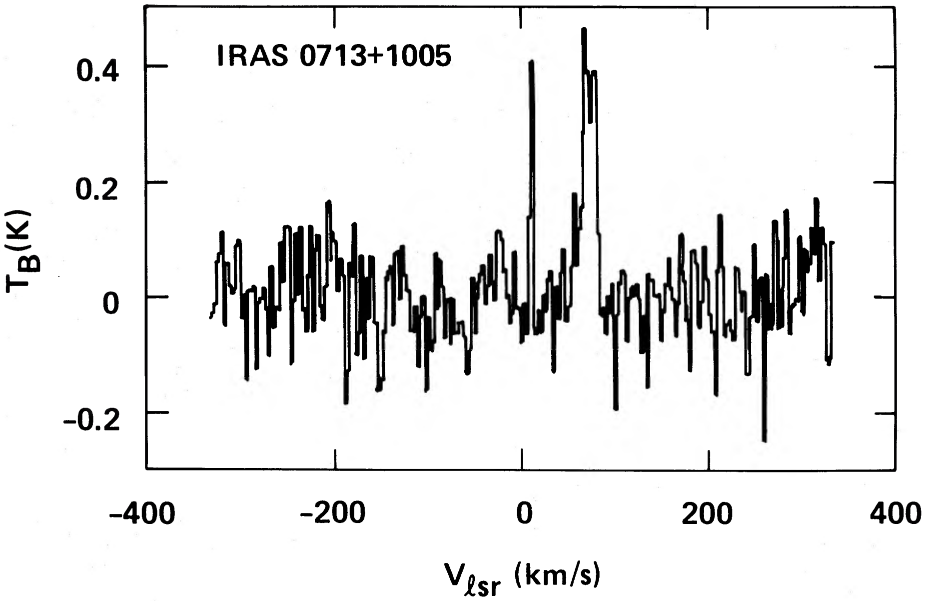

FIG. 1.—Spectrum of $J = 1 \rightarrow 0$ CO emission from *IRAS* 0713+1005 obtained with a 1 MHz filter bank. The ordinate is brightness temperature as defined in the text. The abscissa is radial velocity with respect to the local standard of rest. The narrow spike near +10 km s^{-1} is also present in the other filter banks and, very likely, is emitted by CO in an interstellar cloud along the line of sight to the star.

gives the spectral type of the central star. Here C, M, and S indicate stars that are believed to be carbon-rich (C/O > 1), oxygen-rich (C/O < 1), or neither (C/O ≈ 1) respectively. The letters SR and M in parentheses indicate semiregular and Mira-type variable stars respectively. Four of the stars listed in Table 1 are pure *IRAS* sources. Three of these were measured by the *IRAS* low-resolution spectrometer (LRS), and in each case we examined the LRS spectrum ourselves. For *IRAS* 0453+4427 we agree with the LRS classification as carbon-rich. *IRAS* 2227+5435 has a very unusual LRS spectrum which, however, probably indicates an oxygen-rich star. In Table 1 we have classified it as such because the relative *IRAS* fluxes at 12, 25, and 60 μm also indicate an O-rich classification (Zuckerman and Dyck 1986*b*). The LRS classification of *IRAS* 2131+5631 as O-rich appears marginal in our opinion. However, because its relative 12, 25, and 60 μm fluxes also suggest an O-rich star (Zuckerman and Dyck 1986), we have so classified it in Table 1. Finally, *IRAS* 0713+1005 (Fig. 1) was not classified by the LRS. Based on its 12, 25, and 60 μm fluxes, it is probably O-rich (Zuckerman and Dyck 1986*b*).

The seventh column indicates the transition to which the data given in the next three columns apply. For CIT 4, IRC +10216, and CIT 6, both transitions were observed. The eighth column is T_B, the peak brightness temperature averaged

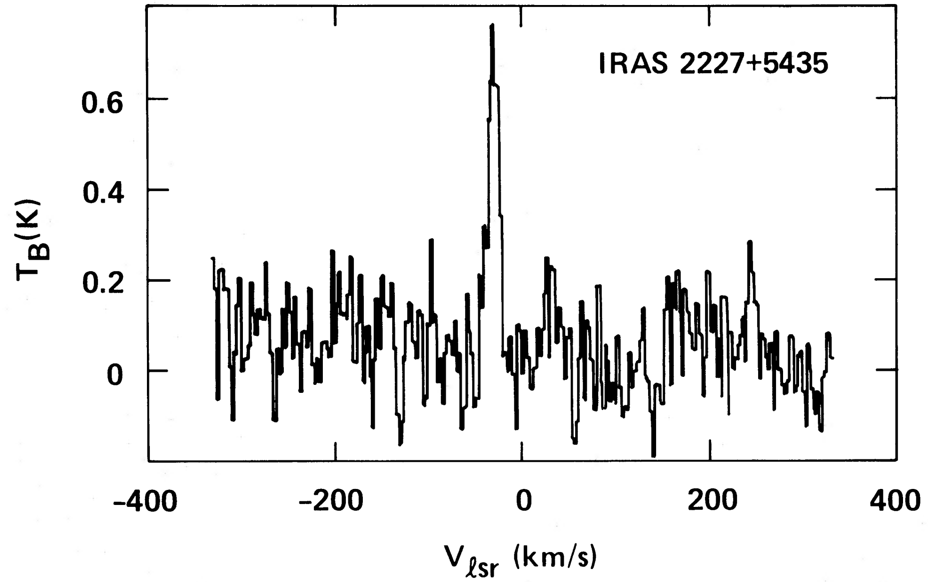

FIG. 2.—Spectrum of $J = 1 \rightarrow 0$ CO emission from *IRAS* 2227+5435 obtained with a 1 MHz filter bank. The ordinate and abscissa are the same as in Fig. 1.

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over the main beam and corrected for all telescope and atmospheric losses. That is, T_B is the Rayleigh-Jeans equivalent brightness temperature that would be measured by a perfect antenna above Earth's atmosphere. We estimate that errors in T_B for the $J = 1 \rightarrow 0$ lines are approximately 20% for the stronger sources (dominated by systematic errors) and perhaps twice as large for weaker sources with poor signal-to-noise ratios. For five sources that were also observed by Knapp and Morris (1985, hereafter KM), the ratio of our T_B to their T_B (called T_A^* in KM) varies between 3.38 and 4.17 with a mean of 3.6. For IRC +10216 this ratio equals 2.1, very probably because the CO source is extended in both beams (Morris, Stark, and Jura 1985). For the $J = 2 \rightarrow 1$ transition, errors in T_B may be substantially larger than 20% even for strong lines listed in Table 1.

The central velocity of the CO profile with respect to the local standard of rest $V_{\rm lsr}$ and the terminal outflow velocity V_∞ are given in Table 1 also. The quantity V_∞ is basically one-half the width of the profile at zero power. For most of the stars, the velocity centroid of the area under the line profile was calculated via a computer procedure available at the 14 m telescope, and this central velocity is listed as $V_{\rm lsr}$ in Table 1. For stars with circumstellar lines that are apparently contaminated by interstellar CO in the signal or reference position or both, $V_{\rm lsr}$ in Table 1 is the mean of the extreme velocities at the red and blue edges of the line profile. The quantity V_∞ was determined by direct hand measurements from the spectra. Line profiles in Paper I which were fitted by a computer program (see § II of Paper I) were also measured by hand. By comparison of the hand and computer determinations of $V_{\rm lsr}$ and V_∞ in Paper I, we estimate that the values of these quantities that are listed in Table 1 of the present paper are accurate, typically, to 1 and 2 km s^{-1} respectively. For S Aur, due to poor signal-to-noise ratio, the uncertainties are substantially greater. For AFGL 2310 the tabulated line width could be an underestimate due to blending with interstellar CO in the reference position.

In a few cases we obtained spectra near but off the target star to insure that the observed line was really associated with the star and was not interstellar. For example, *IRAS* 2227+5435 was classified by the LRS as either an O-rich star with an extremely thick envelope, or a hot spot in a molecular cloud. Although the width of our CO spectrum (Fig. 2) clearly points to the former, to double check we also observed 1'.5 north of the star. The CO signal disappeared completely, as expected for an evolved star. The shape and width of the lines tabulated in Table 1 strongly suggest that they all originate from evolved stars. In two cases, not listed in Table 1 but discussed in § III*b*, mapping around the stellar position helped to establish that the observed narrow CO lines were, in fact, associated with the infrared sources, but that the latter were very unlikely to be evolved stars.

III DISCUSSION

In this section we first consider the relationship between outflow velocity V_∞ and various other stellar characteristics and then discuss our observations of two bright *IRAS* sources that are associated with narrow CO emission lines.

a) Outflow Velocity

Figure 3 is a histogram of numbers of stars detected in $J = 1 \rightarrow 0$ or $J = 2 \rightarrow 1$ CO emission versus V_∞ and includes stars from the present paper, Paper I, KM, Zuckerman *et al.* (1985), Wannier and Sahai (1985), Zuckerman *et al.* (1977), Zuckerman *et al.* (1978), B. Zuckerman and P. Palmer (1978, unpublished), Jewell (1985), and Huggins (1985). Four stars, listed individually in the figure legend have in our opinion, uncertain classifications as O-rich or C-rich, but we have included them in the discussion of statistics that follows. The mean outflow velocities as a function of C/O ratio are listed in the top row of Table 2.

The carbon-rich stars have a somewhat larger mean V_∞ even

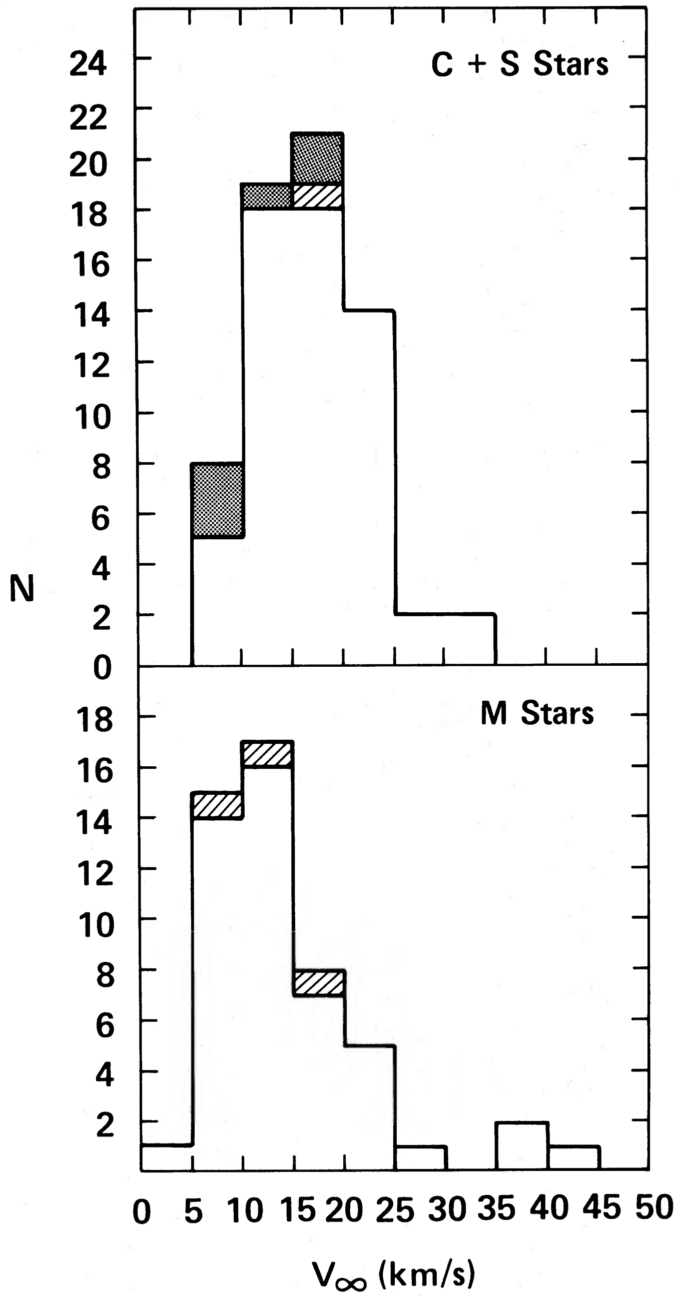

FIG. 3.—Number of stars vs. outflow velocity. The upper panel shows both carbon stars (the large majority) and six S-type stars, which are represented by the shaded rectangles. There is one star, AFGL 5250, indicated by the striped rectangle, which we have tentatively classified as carbon-rich (see the *note added in manuscript* to Paper I.) In the lower panel, the three striped rectangles represent *IRAS* 2002+3910, *IRAS* 0713+1005, and *IRAS* 2131+5631, which we tentatively classify as oxygen-rich.

TABLE 2

MEAN VALUE OF V_∞ (km s^{-1}) VERSUS C/O AND GALACTIC LATITUDE $|b|$

	OXYGEN-RICH (generally M-type)		CARBON-RICH (generally N-type)	C/O ≈ 1 (S-type)
	Without Supergiants	Including Supergiants		
All $|b|$	13.2 ± 6.4 (46)	14.6 ± 8.4 (50)	17.1 ± 5.8 (60)	11.7 ± 4.9 (6)
$|b| \leq 12°$	14.7 ± 7.2 (16)	17.9 ± 10.3 (20)	19.0 ± 5.9 (36)	...
$|b| \geq 14°$	12.4 ± 6.0 (30)	...	14.0 ± 4.4 (24)	...

Errors are one standard deviation of the mean. Parentheses enclose numbers of stars.

when the four supergiant stars are included in the oxygen-rich sample. From Figure 4 and Table 2 this may be seen to be due to an excess of C-rich stars with large V_∞ located at low Galactic latitudes. (The total sample is divided in half by the choice of $|b| = 13°$.)

The CO outflow velocities (~34 km s^{-1}) of AFGL 2233 and AFGL 2901 are comparable to those of O-rich supergiants: NML Cyg (29 km s^{-1}), VY CMa (36 km s^{-1}), and IRC +10420 (43 km s^{-1}), plotted in Figure 4; and VX Sgr and PZ Cas, which are known to have similar molecular outflow velocities as deduced from OH maser emission (e.g., Mutel *et al.* 1979). In Figure 5 we plot the $J = 1 \rightarrow 0$ spectra for AFGL 2233 and AFGL 2901 and, for comparison, that of IRC +10216, the prototypical late-type carbon star with large mass loss rate.

What causes the large V_∞ for AFGL 2233 and AFGL 2901? Since these stars, as well as other carbon-rich stars plotted in Figure 4 with large V_∞, are located near the Galactic plane, one suspects that such stars are more massive and, therefore, more luminous that carbon stars such as IRC +10216 that are located at high Galactic latitude. We have considered all stars, irrespective of C/O ratio, with $|b| \leq 10°$ that are plotted in Figure 4 and have attempted to deduce kinematic distances using a standard Galactic rotation curve. Of order 20% of the stars have radial velocities that lie outside the range permitted by the standard model, implying that there are significant deviations from circular motions in a plane for many of the stars in our sample.

If radiation pressure drives the mass outflow from these stars, then V_∞ would be proportional to the dust grain condensation temperature T_c, to the stellar luminosity L_* to the one-fourth power, and to the square root of the opacity per gram K_ν (Jura 1984). If O-rich and C-rich stars have the same T_c and K_ν, then the measured V_∞ for AFGL 2233 and AFGL 2901 implies that they have supergiant luminosities, i.e., they are not asymptotic giant branch (AGB) stars. If this is the case, then

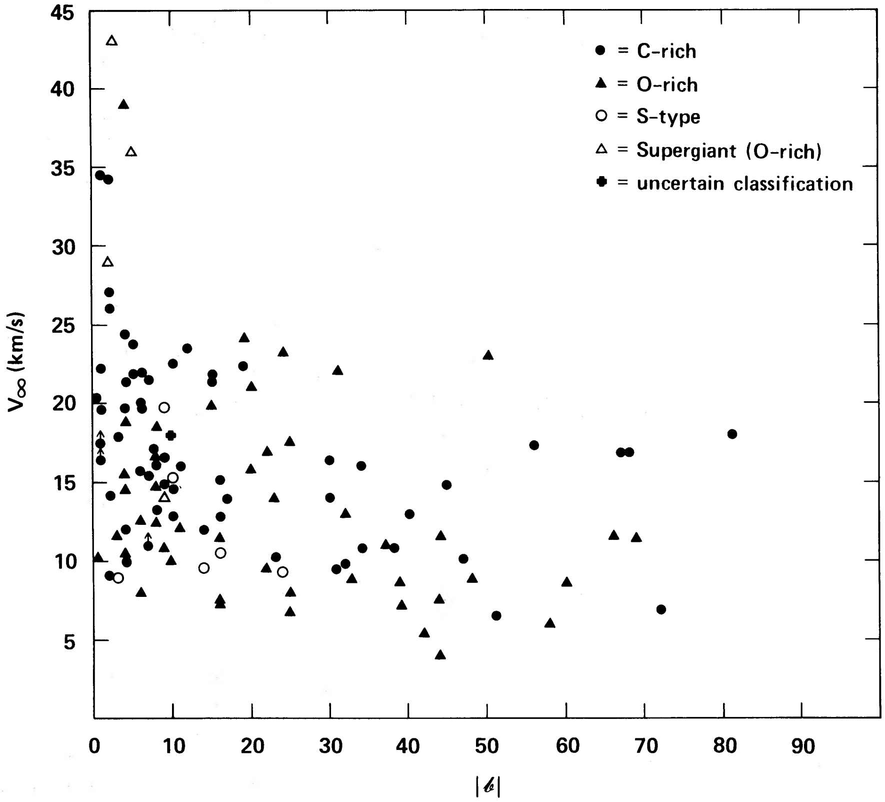

FIG. 4.—Plot of outflow velocity V_∞ vs. the absolute value of the Galactic latitude $|b|$ of the star in question. IRC +10216 is the undistinguished carbon star plotted at $|b| = 45°$. Note the concentration of carbon stars in the upper left corner of the plot. The one star of uncertain classification is IRC +60144 (see the legend to Fig. 1 and the *Note added in manuscript* in Paper I).

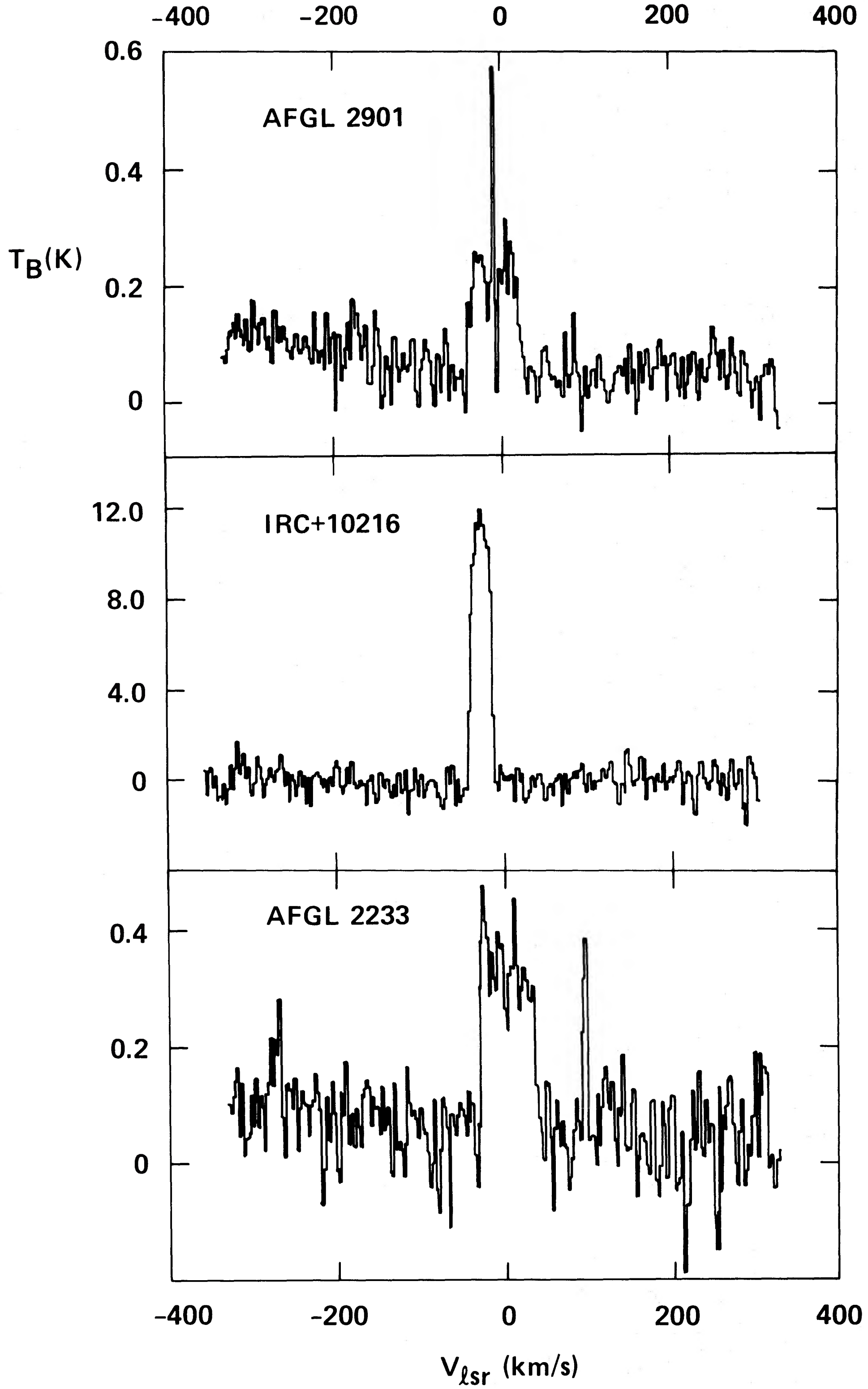

FIG. 5.—Spectrum of $J = 1 \rightarrow 0$ CO emission from AFGL 2901 (*top*), IRC +10216 (*middle*), and AFGL 2233 (*bottom*) obtained with a 1 MHz filter bank. The cordinate and abscissa are the same as in Fig. 1. The spikes near the center of the AFGL 2901 profile are due to incompletely canceled interstellar CO emission in both the "on" and reference positions. The spike near 100 km s^{-1} in the AFGL 2233 spectrum is probably due to interstellar CO near the tangential point (at Galactic latitude 30°).

these would be the first known examples of carbon-rich supergiant luminosity class stars. A less revolutionary possibility is that these stars are on the AGB (so $L_* < 6 \times 10^4\ L_\odot$), but they have unusually large dust grain opacities per gram of outflowing material. A conceivable way to check this suggestion would be to measure the dust-to-gas ratio in the envelopes around AFGL 2233 and AFGL 2901.

Since AFGL 2233 and AFGL 2901 both have small radial velocities, if they obey the standard Schmidt Galactic rotation law and if the former is at the near kinematic distance, then they would be located too close to the Sun to have supergiant-class bolometric luminosities (i.e., $\gtrsim 10^5\ L_\odot$). Even if they are located "only" at the distance, approximately 2 kpc, that corresponds to $L_* \approx 6 \times 10^4\ L_\odot$, their radial velocities would still deviate significantly (approximately 20 km s^{-1}) from those expected for standard circular velocities. If AFGL 2233 is located at the far kinematic distance, then it is one of the most luminous stars in the galaxy.

Of course, the mass outflow may be driven by some force other than radiation pressure on grains. As discussed in Paper I, the apparently large value of $\dot{M}V_\infty/(L_*/c)$ for some C-rich stars with large V_∞ may be difficult to explain if due to radiation pressure on dust grains. One conceivable alternative is the gravitational pull of a close binary companion to the red giant (Livio, Salzman, and Shaviv 1979; Morris 1981; Zuckerman and Aller 1986). But there is no particular reason to suspect that such a mechanism would favor stars near the Galactic plane.

We note that IRC +10216 is often regarded as a star near the tip of the AGB, which would be the case if it were located at its popularly assumed distance of 290 pc. According to Figure 7 in Iben and Renzini (1983), the maximum luminosity achieved by a star on the AGB is a function of its initial mass when it was on the main sequence. If this is the case, then IRC +10216 could be located near the tip of the AGB only if its initial mass was $\gtrsim 3\ M_\odot$. However, as mentioned above, our Figure 4 implies that carbon-rich AGB stars of large initial mass often (perhaps always?) display large outflow velocities. Therefore, because of its modest outflow velocity (Figs. 4 and 5), we suspect that IRC +10216 is substantially less luminous than $6 \times 10^4\ L_\odot$ and, therefore, is significantly closer to Earth than 290 pc, perhaps as close as 100–150 pc. In making the preceding statement, we have implicitly assumed that carbon stars with the largest measured V_∞ are located near the tip of the AGB. Should stars such as AFGL 2233 turn out to have supergiant-class luminosities, then our argument regarding the distance to IRC +10216 would not be valid.

In Figure 6 we compare V_∞ with period of luminosity variation in the IR or optical or both. We have subdivided the stars according to their variability classification (Mira-type or semiregular) and, also, according to C/O abundance ratio. There is a clear increase of mean outflow velocity for periods between 100 and 700 days. For Mira-types, the increase of V_∞ with period seems to be steeper than for the semiregulars. Six S-type stars, all Mira-type variables, are plotted. It is perhaps significant that four of these have $V_\infty \approx 10$ km s^{-1} and periods of approximately 400 days. It would be interesting to know the periods and variability type of the carbon stars with large V_∞ discussed above.

b) Young Stars with Previously Unknown Classifications

i) IRAS 0423+5336

Beckling *et al.* (1984) have called attention to this unusual *IRAS* source. The red and 1 μm images are double, separation 1″.6, with a faint surrounding optical nebulosity of 12″ diameter. The brighter component has the absorption spectrum of an A-type star.

We found a strong ($T_B \approx 9$ K), narrow ($\Delta V_{\mathrm{FWHP}} \approx 4$ km s^{-1}), $J = 1 \rightarrow 0$ line at $V_{\mathrm{LSR}} = -38$ km s^{-1}. A five-point map of the CO source suggested that the line equivalent width peaks slightly ($\sim 30''$) north of the *IRAS* source. The CO source also appeared to be extended on a scale of perhaps a few arcminutes. So the *IRAS* source is almost certainly a pre–

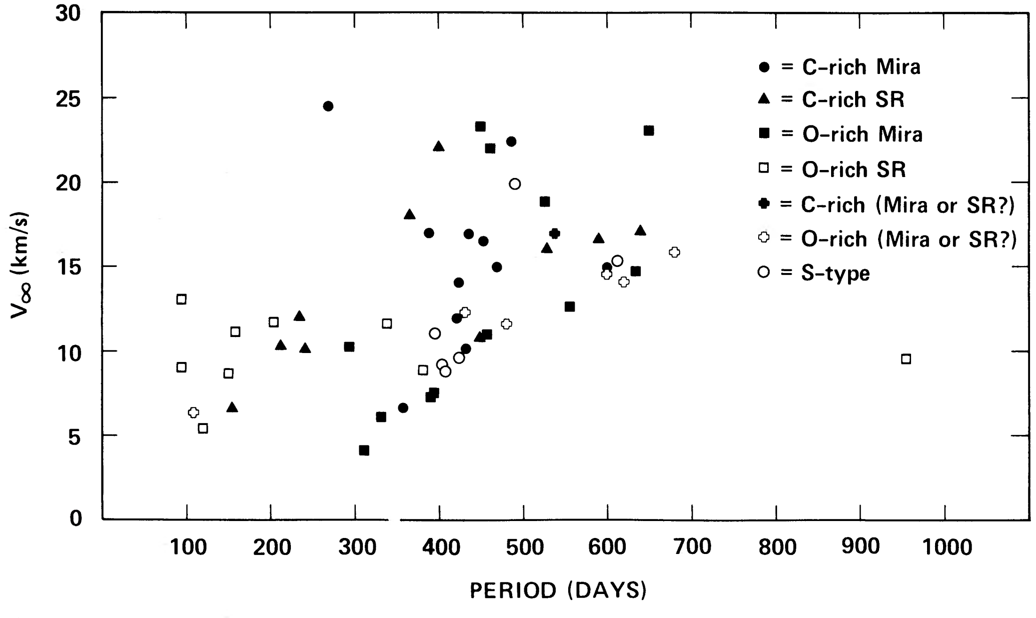

FIG. 6.—Plot of outflow velocity V_∞ vs. stellar pulsation period in days. Some of the stars have uncertain classifications as Mira or semiregular (SR) variables. The data on variability and pulsation period are from the American Association of Variable Star Observers.

rather than a post–main-sequence star. Its kinematic distance is ~4 kpc if the Sun is assumed to be 8 kpc from the Galactic center. If a majority of the bolometric luminosity is emitted between 12 and 100 μm, then at this distance the source would have the intrinsic luminosity of a late B main-sequence star.

ii) AFGL 5497

At the position of this star, we measured a $J = 1 \rightarrow 0$ CO line with $T_B \approx 1.2$ K, $\Delta V_{\rm FWHM} \approx 3$ km s^{-1}, and $V_{\rm LSR} \approx 68$ km s^{-1}. We also obtained a spectrum at a position 1$'$.5 south of AFGL 5497 and measured only an upper limit ($T_B < 0.4$ K) to CO emission at 68 km s^{-1}. So the CO source is probably quite small but, because of the very narrow line width, we believe that AFGL 5497 is a pre–main-sequence star. Its nearer kinetic distance is approximately 5 kpc.

IV. SUMMARY

We have identified a class of cool carbon-rich stars that are located close to the Galactic plane and which have molecular winds with large terminal outflow velocities. Very likely, these stars are among the most massive and luminous carbon-rich objects in our Galaxy. With our existing data, it is not yet possible to determine their absolute luminosities. This might be accomplished, however, if similar stars can be identified in external galaxies. It would also be of interest to determine the pulsational periods of these stars to see if the increase of period with V_∞ (Fig. 6) continues to larger V_∞.

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