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OH/IR STARS WITHIN 50 PARSECS OF THE GALACTIC CENTER

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ABSTRACT

A search for OH/IR stars close to the galactic center has been initiated using the VLA at 18 cm. Thirty-three stars were found in a 34′ × 34′ field centered on Sgr A West. The strong concentration toward the galactic plane and the bulk rotation around the nucleus reported by Habing *et al.* in 1983 in a 2° field around the galactic center are confirmed, but the random motion with a dispersion of 60 km s^{-1} in the radial direction is less than half the value found by them. The circumstellar shell expansion velocities are higher than found at larger distances from the galactic center, suggesting a relatively more massive population of stars near the nucleus or a more efficient conversion of radiation pressure to bulk motion of the circumstellar gas. The OH/IR stars are strongly concentrated toward the continuum source Sgr A West, suggesting a pronounced increase in the density of stars toward the galactic center.

Subject headings: galaxies: Milky Way — infrared: sources — masers — stars: stellar statistics

I. INTRODUCTION

The mass distribution within 1 kpc of the galactic center has been estimated in various ways: (1) from an assumed mass-to-luminosity ratio, where the luminosity distribution is observed in the infrared (Sanders and Lowinger 1972; Maihara *et al.* 1978; Hayakawa *et al.* 1981); (2) from the systematic velocities of the interstellar gas, under the assumption that they are governed by a large-scale gravitational potential (Pauls and Mezger 1980; Güsten and Downes 1980); and (3) from the distribution of planetary nebulae detected as weak radio continuum sources (Isaacman 1980). Each of these three methods has fundamental shortcomings.

Recently we have been able to demonstrate the feasibility of a method that may be more attractive than those mentioned above (Habing *et al.* 1983). It utilizes measurements of OH/IR stars which are easily identifiable through their characteristic 1612 MHz OH maser line profiles. Their intrinsically high OH luminosities make them detectable at distances well beyond the galactic center, and their radial velocities can be measured with high accuracy. Such objects are associated with late-type stars, and the kinematics of such stars found in the disk of the Galaxy indicate that they span a large range of ages from ~ 10^8 yr to a few times 10^9 yr (e.g., Baud *et al.* 1981). From an observed correlation with the kinematics, it follows that the age can be estimated, at least statistically, from the velocity separation between the two principal peaks in the OH line profile. The detection of a sufficiently large number of stars would allow "high-resolution" ($\lesssim$ 10 pc) mapping of the gravitational potential close to the galactic nucleus in the galactocentric distance range between the ~ 100 pc resolution limit of the near-infrared continuum observations (Maihara *et al.* 1978; Hayakawa *et al.* 1981) and the inner 1 pc where the Ne II clouds can provide a mass estimate (Lacy *et al.* 1980). At the same time this new method would be free of systematic uncertainties from which the other two methods are suffering (M/L unknown; Ne II clouds may not be in virial equilibrium with gravitational field). In addition, the recent history of the galactic center may be traced back by studying the distribution of OH/IR stars as a function of the peak velocity separation.

Observations with the 100 m Effelsberg telescope in a circular area of 2° diameter centered on $(l, b) = (0, 0)$ formed the basis of an initial study (hereafter referred to as "Deep Survey") by Habing *et al.* (1983), but the search was seriously hampered by selection effects.

The most important problem were the strong interstellar OH absorption lines that distorted the frequency baseline considerably and allowed the unambiguous detection of only the brightest OH/IR stars over a velocity range of several hundred km s^{-1} (e.g., Fig. 2 in Habing *et al.* 1983). Habing *et al.* (1983) estimate that they found less than half the number of stars actually present above the limit set by system noise.

An interferometer of suitable dimensions will eliminate most of the continuum background because it has an angular scale larger than ~ 1′. Since the OH maser emission occurs in compact (< 2″) circumstellar envelopes, aperture synthesis measurements with baselines longer than ~ 1 km should be adequate and a pilot survey with the Very Large Array (VLA) (Habing *et al.* 1983) of the National Radio Astronomy Observatory (NRAO)[1] in New Mexico confirmed this expectation. We have recently embarked on an ambitious project to map those regions near the galactic center where the selection effects are strongest. This *Letter* presents the preliminary results of the first field centered on Sgr A West.

II. OBSERVATIONS AND DATA ANALYSIS

The observations were carried out with the VLA spectral-line system at 1612 MHz on 1984 March 3, 4, and 5, utilizing 13 telescopes that spanned a range in baselines (on the ground) from 0.1 to 6.9 km. During the map-making procedure, (projected) baselines shorter than 0.9 km were excluded resulting in a synthesized beam of 7″.5 × 5″.5 with a position angle of ~ 60° for the major axis.

A single field centered on R.A. = $17^h42^m30^s.0$, decl. = −28°59′00″ was mapped. The spectral band was divided into 128 channels separated by 6.1 kHz (1.1 km s^{-1}) with a resolution of 7.3 kHz (1.4 km s^{-1}). It covered a radial velocity range of 144.4 km s^{-1} and was centered on −145, 0, and +145 km s^{-1} with respect to the LSR, respectively, on the three consecutive observing days. On each day the integration time was ~ 7 hr resulting in an rms sensitivity of ~ 0.02 Jy per beam in each channel, about twice as good as the best sensitivity reached in the "Deep Survey" and ~ 10 times the Effelsberg sensitivity close to Sgr A due to the fivefold increase in the system temperature of the 100 m telescope on this source. In addition to the increase in sensitivity because of the much longer integration time (7 hr instead of 15 minutes), the strong 1612 MHz absorption was virtually eliminated.

Instrumental phase calibration on the source NRAO 530 was performed regularly during the observations. For flux-density calibration, the sources 3C 286 and 3C 48 were used.

The "Pipeline" system at the VLA was used to produce 512 × 512–sized maps of all 384 frequency channels. With a pixel size of 4″ the maps covered 34′ × 34′, slightly larger than the primary beam of 27′ (FWHP). After subtracting the continuum emission (mainly Sgr A West with sidelobes), the maps were visually inspected for point sources. The spectra were obtained subsequently by combining the data from all the maps at the source position.

[1]The NRAO is operated by Associated Universities, Inc., under contract with the National Science Foundation.

TABLE 1

OH/IR STARS FOUND CLOSE TO SAGITTARIUS A WEST WITH THE VLA

Name (1)	R.A. (1950.0) (2)	Decl. (1950.0) (3)	LV (km s^{-1}) (4)	HV (km s^{-1}) (5)	S_{LV} (Jy) (6)	S_{HV} (Jy) (7)
OH 359.68+0.07	$17^h41^m23^s.4$	−29°09′19″	−43	−5	0.40	0.71
OH 359.68−0.02	17 41 45.7	−29 12 08	−171	−128	0.41	0.50
OH 359.75+0.14	17 41 18.6	−29 03 39	−145	−129	0.19	0.41
OH 359.76+0.12[a]	17 41 24.1	−29 03 19	−20	+9	2.38	5.47
OH 359.78−0.12	17 42 22.4	−29 10 12	+59	+85	0.44	0.15
OH 359.80−0.09	17 42 18.7	−29 08 04	−21	+14	0.34	1.30
OH 359.81−0.07	17 42 15.3	−29 06 52	−59	−15	0.21	0.17
OH 359.83−0.02	17 42 06.8	−29 04 40	−71	−32	0.19	0.31
OH 359.83+0.15	17 41 25.7	−28 59 03	−45	−10	0.34	0.19
OH 359.88−0.09[a]	17 42 29.7	−29 03 52	−34	−13	6.19	2.07
OH 359.90+0.22[a]	17 41 20.3	−28 53 07	+14	+49	0.36	0.55
OH 359.91−0.04	17 42 23.0	−29 01 04	−161	−121	0.29	0.26
OH 359.93−0.06	17 42 31.2	−29 00 28	−114	−75	0.57	0.48
OH 359.94−0.08[a]	17 42 35.5	−29 00 36	−95	−70	3.96	4.72
OH 359.94−0.05	17 42 30.0	−28 59 44	+35	+71	0.60	0.47
OH 359.95−0.05	17 42 30.0	−28 59 16	−47	−7	0.36	0.36
OH 359.951−0.035	17 42 27.9	−28 58 36	+69	+96	0.20	1.10
OH 359.953−0.041	17 42 29.4	−28 58 40	+51	+90	1.61	1.64
OH 359.97−0.12[a]	17 42 50.1	−29 00 16	−27	+11	0.40	0.22
OH 359.98−0.09	17 42 43.7	−28 58 52	−4	+28	0.58	0.44
OH 359.99−0.06	17 42 38.8	−28 57 40	−6	+33	1.23	0.98
OH 0.00−0.14	17 42 59.6	−28 59 44	−50	−16	0.19	0.09
OH 0.04−0.06	17 42 45.5	−28 54 44	+51	+92	0.36	0.44
OH 0.06−0.02	17 42 39.4	−28 52 28	−23	+16	0.12	0.46
OH 0.07−0.21[a]	17 43 24.6	−28 57 51	+100	+127	1.20	1.89
OH 0.08+0.15	17 42 03.5	−28 46 28	+1	+43	0.25	0.70
OH 0.08−0.12	17 43 04.7	−28 54 36	+37	+65	0.40	0.21
OH 0.11−0.06	17 42 57.1	−28 51 08	+71	+105	0.55	0.40
OH 0.13+0.10[a]	17 42 21.2	−28 45 08	−64	−41	0.38	1.10
OH 0.14+0.03	17 42 40.9	−28 46 56	+1	+48	0.36	0.77
OH 0.18−0.05	17 43 05.0	−28 47 36	−53	−19	0.21	0.74
OH 0.19+0.05	17 42 41.6	−28 43 40	−9	+30	0.58	0.33
OH 0.19+0.04[a]	17 42 45.5	−28 44 08	+145	+172	2.61	2.86

[a]Previously known. See Habing *et al.* 1983.

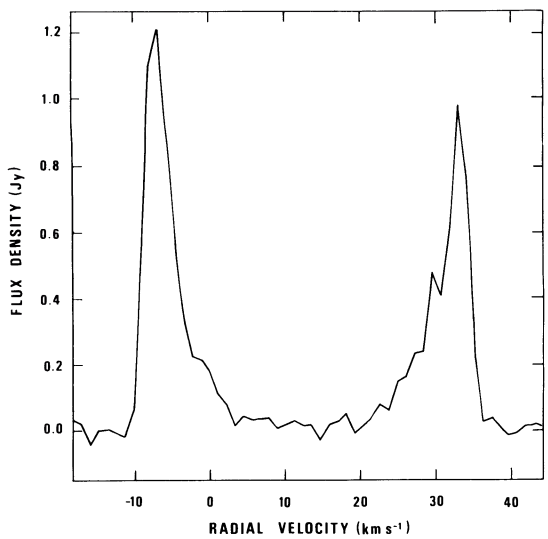

FIG. 1.—Profile of the 1612 MHz OH line of OH 359.99−0.06 as observed with the VLA. This line falls within the range of the deep OH absorption due to Sgr A and therefore was not detected in the survey with the 100 m telescope.

III. RESULTS

A total of 43 OH line emission sources were found, 33 of which show the double-peaked line profile characteristic of OH/IR stars. Eight of these stars are known from previous surveys. The 33 OH/IR stars are listed in Table 1 in order of increasing galactic longitude. Column (1) gives the name of the source in the usual galactic-coordinate nomenclature. Columns (2) and (3) give the positions in R.A. and decl. (1950), respectively. Columns (4) and (5) list the radial velocities of the low-velocity (LV) and the high-velocity (HV) components, respectively. Columns (6) and (7) list the flux density of the LV and HV components, respectively, corrected for the primary-beam attenuation assuming a Gaussian beam shape.

Due to the rather coarse gridding with a cell size of more than 1.3 times the synthesized beam width along the minor axis, the preliminary maps are undersampled. Full sampling (cell size $\approx 2''.5$) is expected to result in the detection of additional OH/IR stars. Moreover, the positional accuracy, which for the present data is only $1''$–$2''$, will increase considerably.

Figure 1 shows the line profile of the OH/IR star OH 359.99−0.06. This is only one of several stars that should have been detected easily in the Deep Survey had the selection effects been absent.

The 33 OH/IR stars found so far with the VLA are distributed on the sky as shown in Figure 2. The dispersion of the marginal distribution (cf. Trumpler and Weaver 1962) in galactic latitude of these stars is $0^\circ.095$, whereas the dispersion of the marginal distribution in galactic longitude is $0^\circ.145$. Thus the distribution on the sky is elongated and could be represented by an ellipse with its major axis nearly parallel to the galactic equator and with an axial ratio of ~ 1.5 corresponding to an eccentricity of ~ 0.8. However, a correct derivation of the sky distribution requires the allowance for the decreasing detection probability with increasing distance from the phase center due to the primary beam attenuation. This will be performed on the data obtained from the final, fully sampled maps.

It is obvious from Figure 2 that there is a small cluster of OH/IR stars close to Sgr A West. This cluster is shown in greater detail in Figure 3 superposed on the 2 cm continuum map of Sgr A West by Ekers *et al.* (1983). The numbers next to the stars give the radial velocities in km s^{-1}. There is no obvious correlation between the distribution of the OH/IR stars and the spiral pattern of the 2 cm radiation.

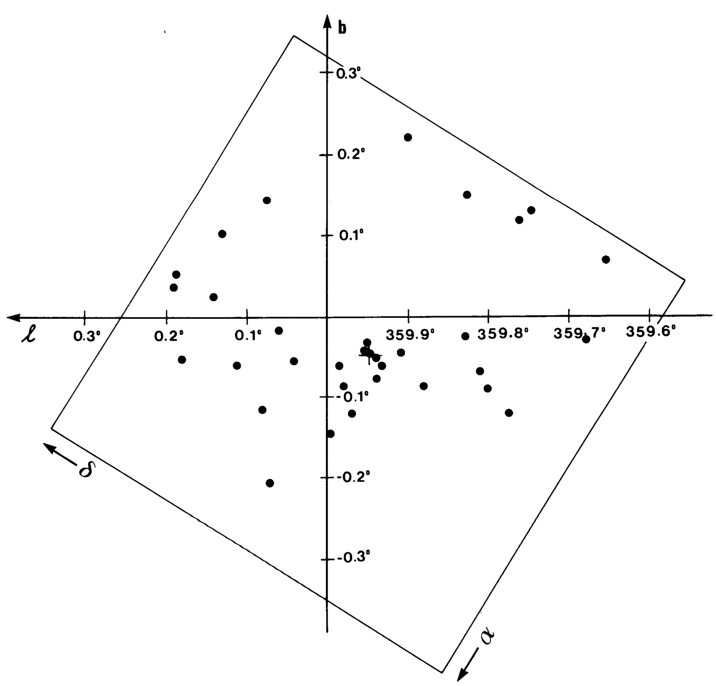

FIG. 2.—The sky distribution of the 33 OH/IR stars detected in the present survey. The cross marks the position of Sgr A West, and the tilted square delineates the synthesized field.

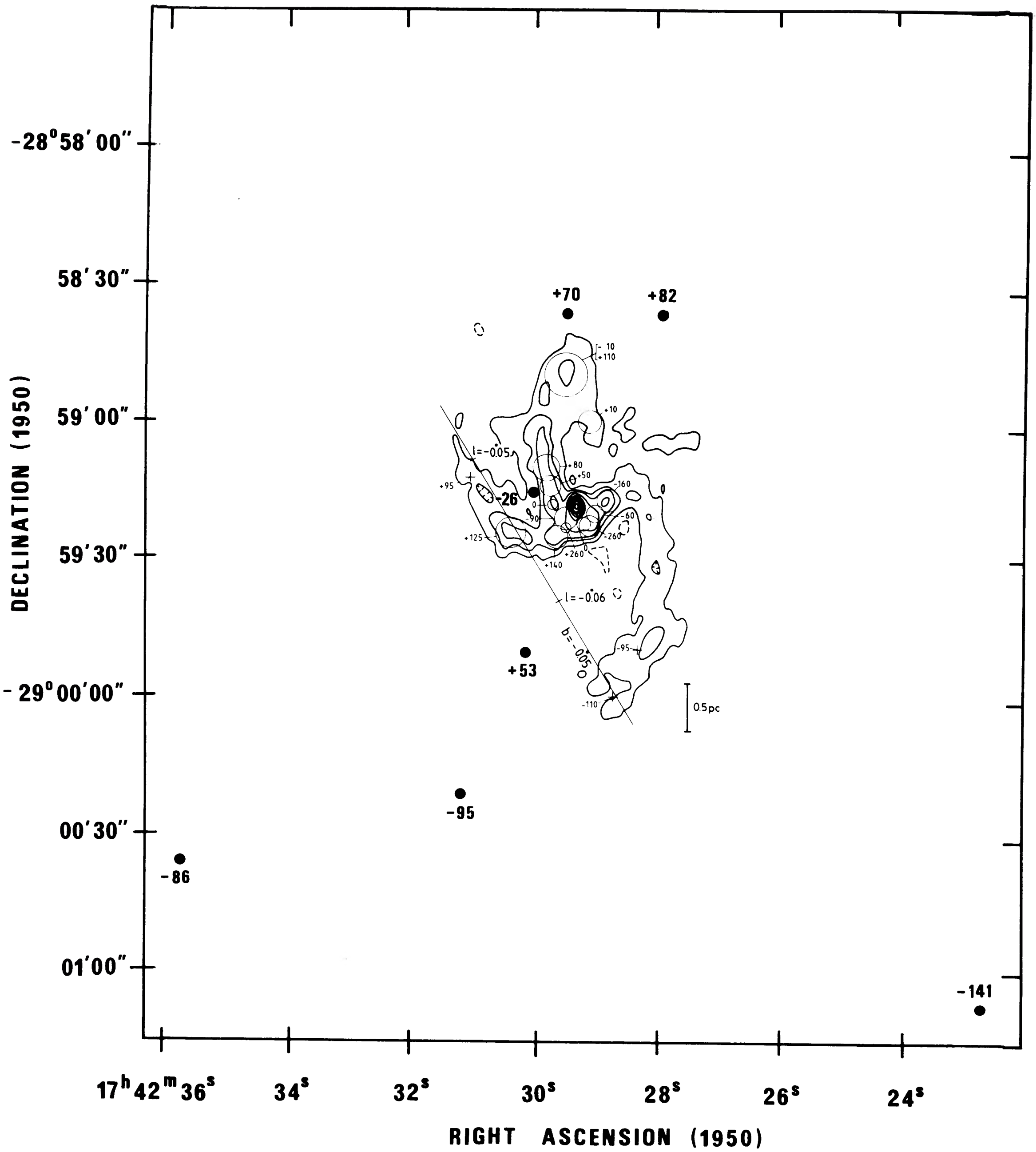

FIG. 3.—The distribution of seven OH/IR stars within 2′ of Sgr A West. The number beneath each point gives the radial velocities in km s^{-1}. The VLA contour map of Sgr A West published by Ekers *et al.* (1983) is superposed.

In Figure 4 the radial velocities (average between the LV and HV) of the 33 OH/IR stars are plotted against galactic longitude. From this diagram we confirm the net rotation of these stars around the galactic center already found for the 30 sources detected in the Deep Survey. A straight-line regression fitted to our data with uniform weighting gives $\langle v \rangle = (7 \pm 11) + (271 \pm 77)l$ with $\langle v \rangle$ in km s^{-1} and l in degrees. The dispersion in v from the regression line is 61 km s^{-1} and the correlation coefficient is 48%.

The derivative of (270 ± 80) km s^{-1} per degree is in accordance with the result of Habing *et al.* (1983) (200^{+50}_{-100} km s^{-1} per degree). However, the dispersion of 60 km s^{-1} is ~ 2.5 times smaller than the "best" value for the Deep Survey (150^{+25}_{-50} km s^{-1}). We do not yet understand this large discrepancy.

One explanation could be a very large uncertainty in the dispersion estimate. However, assuming a Gaussian distribution, the error in the dispersion of the VLA data is only ~ 8 km s^{-1}. Another explanation could possibly be the fact that we have not covered such a large radial velocity range as the Deep Survey. Our data cover ±217 km s^{-1}, whereas those of the Deep Survey cover ±465 km s^{-1}. It is possible that we have missed a few OH/IR stars with velocities $|v| > 217$ km s^{-1} thus decreasing the dispersion. However, in a Gaussian

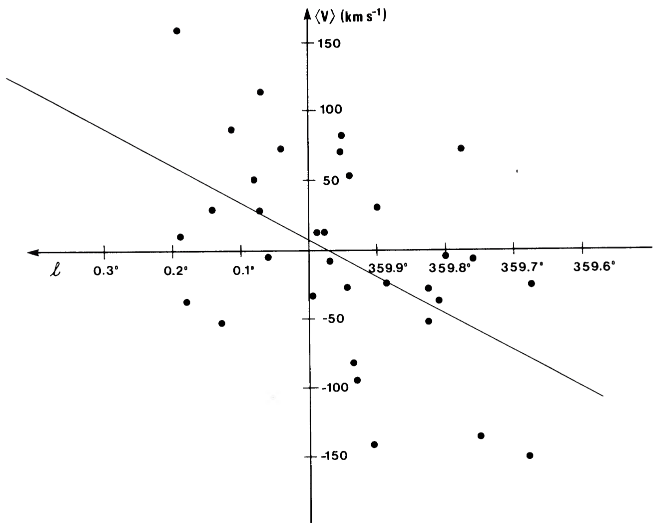

FIG. 4

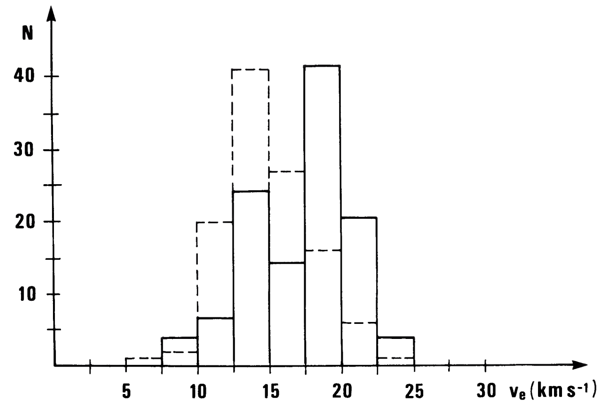

FIG. 5

FIG. 4.—The radial velocities of the 33 OH/IR stars as a function of galactic longitude. The regression line providing the best fit to the data is shown.

FIG. 5.—The distribution functions of the circumstellar envelope expansion velocity for the 33 OH/IR stars detected with the VLA (*solid lines*) and for the 114 OH/IR stars listed in Baud *et al.* (1981) and mostly localized in the galactic disk (*dashed lines*). The "VLA distribution" has been normalized by a factor of 114/33. This distribution is skewed to higher values than that for OH/IR stars in the general galactic disk.

distribution with a dispersion of 150 km s^{-1} the OH/IR stars with $|v| > 217$ km s^{-1} constitute only ~ 7% of the total sample. Also, subtracting the four OH/IR stars with $|v| > 217$ km s^{-1} from the Deep Survey sample only decreases the dispersion from ~ 150 to ~ 120 km s^{-1}. It is interesting to note that the velocity dispersion of OH/IR stars with $|b| \leq 0.^\circ25$ (excluding the high-velocity source OH 0.3-0.2) in the Deep Survey is ~ 70 km s^{-1}. The dispersion for the other stars (with $|b| > 0.^\circ25$) in this survey is ~ 170 km s^{-1}. Thus, there is an indication that we might see a population difference, i.e., stars with a larger latitude extent have a higher velocity dispersion than stars with a smaller latitude extent.

The distribution function of v_e, the circumstellar envelope expansion velocity, differs significantly from that of the OH/IR stars in the galactic disk (Fig. 5). The maximum in the distribution function for the 33 stars detected in the present survey is between 17.5 and 20.0 km s^{-1}, whereas most OH/IR stars in the disk have values of v_e between 12.5 and 15 km s^{-1}. This fact could suggest a more massive and therefore younger population of OH/IR stars close to the nucleus of the Galaxy or possibly a more efficient conversion of radiation pressure to bulk motion of the circumstellar wind. It is interesting to note that the v_e–distribution of the Deep Survey data peaks between 15 and 17.5 km s^{-1}, intermediately between the disk population and the present data.

Simplemindedly, the skew of the v_e–distribution toward higher values is in contradiction with the finding in Olnon *et al.* (1981) that OH/IR stars with small values of v_e ($\lesssim 15$ km s^{-1}) are more concentrated toward the galactic center than stars with large values of v_e ($\gtrsim 15$ km s^{-1}). However, the data in Olnon *et al.* (1981) are from a survey over a "strip" of sky along the galactic equator with a width of $1.^\circ25$. It is possible that v_e depends on galactic latitude just as suggested for the radial velocity dispersion. On the other hand the preference for higher values of v_e in the present data set is in accordance with the lower radial velocity dispersion (Baud *et al.* 1981).

The continuum radiation at $\lambda \approx 2$ μm is believed to originate mainly from late-type stars, whereas the radiation longward of $\lambda \approx 10$ μm is dominated by H II regions and dust. Three of the OH/IR stars detected in this survey coincide within the 1″–2″ positional uncertainties with 2.2 μm sources: OH 359.95−0.05 coincides with source 1 (IRS 1) in Becklin and Neugebauer (1975); OH 359.97−0.12 and OH 0.14+0.03 coincide with sources in the map published by Becklin and Neugebauer (1978). However, Storey and Allen (1983) resolve IRS 1 into two components (E and W), the declinations of which are both ~ 2″ south of the presently determined declination of OH 359.95−0.05 making its identification with the 2 μm source uncertain. It will be interesting to attempt further identifications by means of new ground-based IR observations. The *IRAS* catalog is very incomplete close to the galactic center (cf. *IRAS Explanatory Supplement*, 1985) due to confusion and detector saturation, and cannot be used as a complete source list.

We plan to continue our search at 18 cm in two ways: first, by adding new fields; second, by improving the source detection process.

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