PASJ: Publ. Astron. Soc. Japan **51**, 95–102 (1999)

SiO Masers in Stars in the Inner and Outer Galactic Disk

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(Received 1998 September 21; accepted 1998 December 18)

Abstract

Observations in the $J = 1$–0, $v = 1$ and $v = 2$ ^{28}SiO and $v = 0$ ^{29}SiO maser lines were made towards 97 outer- and 19 inner-disk IRAS sources with typical IRAS colors of AGB stars. 21 new ^{28}SiO and 1 new ^{29}SiO maser sources were detected above the 5 σ level of $\sim$ 1 Jy with the Nobeyama 45 m telescope. Collecting all of the observational data in SiO $J = 1$–0 maser lines taken with a 45 m telescope, a comparison is made between the outer-disk, inner-disk, and bulge samples. The samples, themselves, align a sequence of mid-infrared color, flux at 12 μm and IRAS variability index. The detection rates are 66%, 51%, and 31%, respectively, in the bulge, inner disk, and outer disk. This fact is consistent with the tendency of increasing proportion of C-rich stars in the IRAS sample and metallicity gradient with the galactocentric distance.

Key words: Infrared: sources — Masers — Stars: late-type — Stars: mass loss

1. Introduction

Most of the sources in IRAS PSC confined to the galactic disk or bulge with colors indicative of evolved late-type stars with a circumstellar envelope have been searched for the 43 GHz SiO maser lines with the 45 m telescope at Nobeyama Radio Observatory. With a 5 σ detection limit of $\sim$ 1 Jy, made possible by the large aperture and the sensitive receiver, these are the most sensitive observations available at this waveband. In the period 1991–93, 313 sources in the direction of the bulge were observed, of which 193 sources were found to have associated SiO masers (Nakada et al. 1993; Izumiura et al. 1994, 1995a, 1995b). Though these observations aimed at bulge objects, some disk stars in the same direction were also included. In 1994 and 1995, 161 sources in the second and third quadrants of the galactic plane were observed, 63 of which were detected in this line emission (Jiang et al. 1996). These two sets of systematic observations had already accumulated much data on SiO masers. However, because they were mainly intended for studying galactic kinematics, the samples were not chosen based on the same criteria, which made their inter-comparison difficult. Therefore, sources selected with the same criteria, but left out in the earlier observations, were observed in 1996 May. Here, we first report on the results of the 1996 observations. Then, some statistical comparisons are made between the bulge, inner-disk and outer-disk groups based on the entire data collected by the 45 m telescope.

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2. Observation

During 1996 May 10–14 and 16–19 mainly two groups of objects were observed: a larger outer-disk sample and a smaller inner-disk one. Table 1 lists the criteria based on which these sources were selected. Various studies of IRAS PSC sources have established that the IRAS colors are different for different types of sources, such as young stellar objects, late-type stars, and galaxies. Here, the IRAS colors, C_{12} [$= \log(F_{25}/F_{12})$], and C_{23} [$= \log(F_{60}/F_{25})$] (F_λ is the flux density at the wavelength λ), are set so as to pick up stars in late stages of evolution when they are surrounded by cold circumstellar envelope (CSE)s (van der Veen, Habing 1988). We have set an upper limit to the 12 μm flux density so as to avoid nearby sources, most of which have been observed earlier; the value used translates to a lower limit in distance of about 4 kpc for an M-type star with cold CSE. The demanded IRAS flux qualities ensure the reliability of the measured fluxes, and hence the colors calculated from them. From table 1 one can see that the objects are

Table 1. Selection criteria of the 1996 May observed sources.

	Outer disk	Inner disk
Galactic longitude..........	115°–155°	55°–70°
Galactic latitude............	[−10°, 10°]	
IRAS color..................	$C_{12} \subset [-0.4, 0.4]$	
	$C_{23} \leq -0.4$	
IRAS flux density...........	$F_{12} < 15$ Jy	
Qualities of IRAS fluxes.....	333 at 12, 25, and 60 μm	
Number of sources..........	97	19

Table 2. Number of detections.

	Outer disk	Inner disk	Miscellaneous
^{28}SiO......	13/97	8/19	5/13
^{29}SiO......	1/97	0/19	0/13

restricted to two longitudinal strips, one each in the first and second quadrants of the galactic plane. Because of the numerous IRAS objects present in the first quadrant, the inner-disk sources were further restricted to have no association with any other known catalogues of objects. Thus, the sample consists of 97 sources in the outer-disk and 19 in the inner-disk. Among the 97 sources in the outer disk, 15 had already been observed in 1994–95. Of these 15, 5 had been detected in SiO maser emission, and therefore were not observed this time. Although some of the 10 non-detections were observed again, no new detections were found.

In addition to the above sample, a third group of 13 sources that do not satisfy the above criteria strictly, were also observed; 6 of them were previous non-detections and 7 were new, but lie outside of the above-mentioned selection criteria. We treat this group separately.

The observational system has been described in detail elsewhere (e.g., Jiang et al. 1996). Here, we present only a few important and necessary observational parameters. The SIS receiver, S40 at the 45 m telescope, was tuned to receive three SiO maser lines (^{28}SiO $J = 1$–0, $v = 1$ and $v = 2$, ^{29}SiO $J = 1$–0, $v = 0$) around 43 GHz. AOS back-ends were used to obtain the spectra with a velocity resolution of about 0.26 km s^{-1}. The 5 σ detection limit is about 0.28 K ($\sim$ 1 Jy).

The results of observations are summarized in table 2. Of the 97 sources in the outer disk, 15 had been observed earlier with 5 detections. Of the 82 sources searched now, 8 new ^{28}SiO sources and 1 new ^{29}SiO source were detected. Thus, of the 97 sources, 13 have been detected in the ^{28}SiO maser line. Among the 19 sources in the inner disk, 8 new ^{28}SiO sources have been detected. In the miscellaneous 13 sources, 5 were newly detected among which IRAS 04264+3853, 04402+3426, and 22394+6930 were not detected in 1995 (Jiang et al. 1996); this may be attributed to the time variation of SiO maser emission. In total, 21 new ^{28}SiO and 1 new ^{29}SiO maser source were found in 114 searched this time (excluding the 5 detections from the 15 searched in earlier surveys).

The SiO maser spectra of newly detected emitters are displayed in figure 1 and figure 2, respectively, for the ^{28}SiO and ^{29}SiO lines. The related parameters including integrated intensity, center velocity, and FWHM of SiO maser lines are summarized in table 3 along with their IRAS PSC name in the first column and the observation time in the last column. All of the sources including non-detections are listed in table 4 along with their galactic coordinates.

3. Discussion

3.1. *The Sample of 116 Stars*

As described before, the same criteria have been used to choose the inner and outer disk samples. The most important and basic physical selection criteria are the IRAS color indexes, C_{12} and C_{23}. C_{12} is set to be in the range [−0.4, 0.4], typical of a late-type star with cold CSE having a temperature of about 600 K to 200 K. $C_{23} < -0.4$ further excludes the young stellar objects. Though no bias was imported when we picked up the samples, they may intrinsically exhibit different features. The averages of F_{12}, C_{12}, C_{23}, and IRAS variability index are 8.36 Jy, −0.23, −0.65, and 32, respectively, for the outer-disk sample of 97 sources, while 8.38 Jy, −0.19, −0.71, and 75, respectively, for the inner-disk sample of 19 sources. It can be seen that there is slight difference in average F_{12}, which means that the two samples are at a similar distance scale. Although there is a slight difference in the average C_{23} and C_{12}, the small family of 19 members in inner-disk sample makes it difficult to judge whether this small difference in color is real; we discuss this question later. An evident difference is found in the variability index, which is defined as the probability in the percentage of variability. That is to say, the objects in the inner-disk sample are generally more likely to be variable stars based on the IRAS observation. This difference could possibly be caused by the fact that the IRAS satellite did not scan the sky equally; some areas were observed more often than the others. However, in no way one can exclude the possibility of an intrinsic difference.

On the other hand, the difference concerning the SiO maser population is clear. In the outer-disk sample, 13 sources out of 97 are detected by SiO emission (about 13%), and in the inner-disk sample, 8 sources out of 19 are detected (about 42%). From the above analysis, one

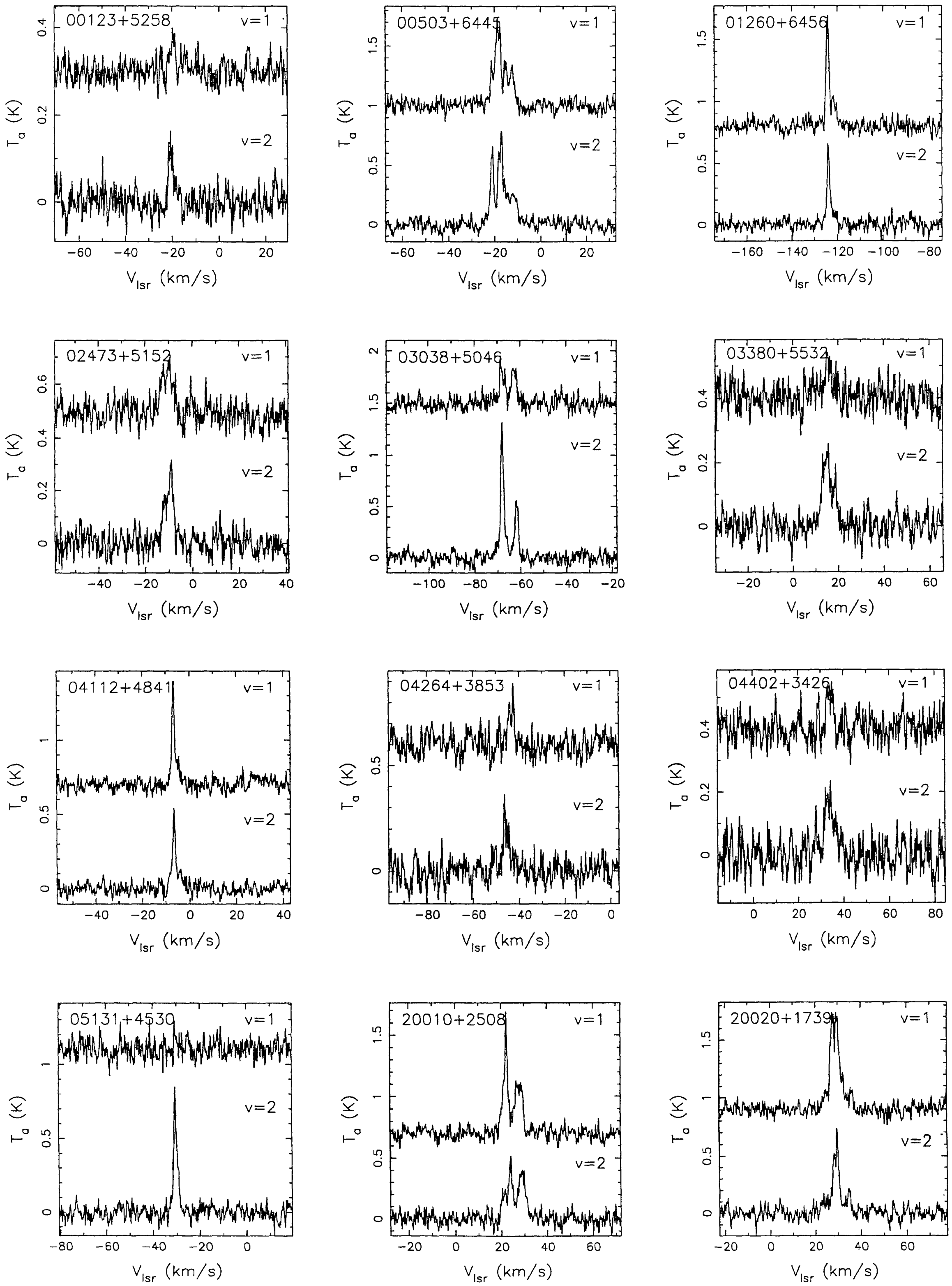

Fig. 1. Spectra of 21 ^{28}SiO new detections. The x-axis labels the velocity in LSR (Local Standard of Rest); the y-axis the intensity in antenna temperature, v at right side of the emission line, the vibrational state of the SiO maser line.

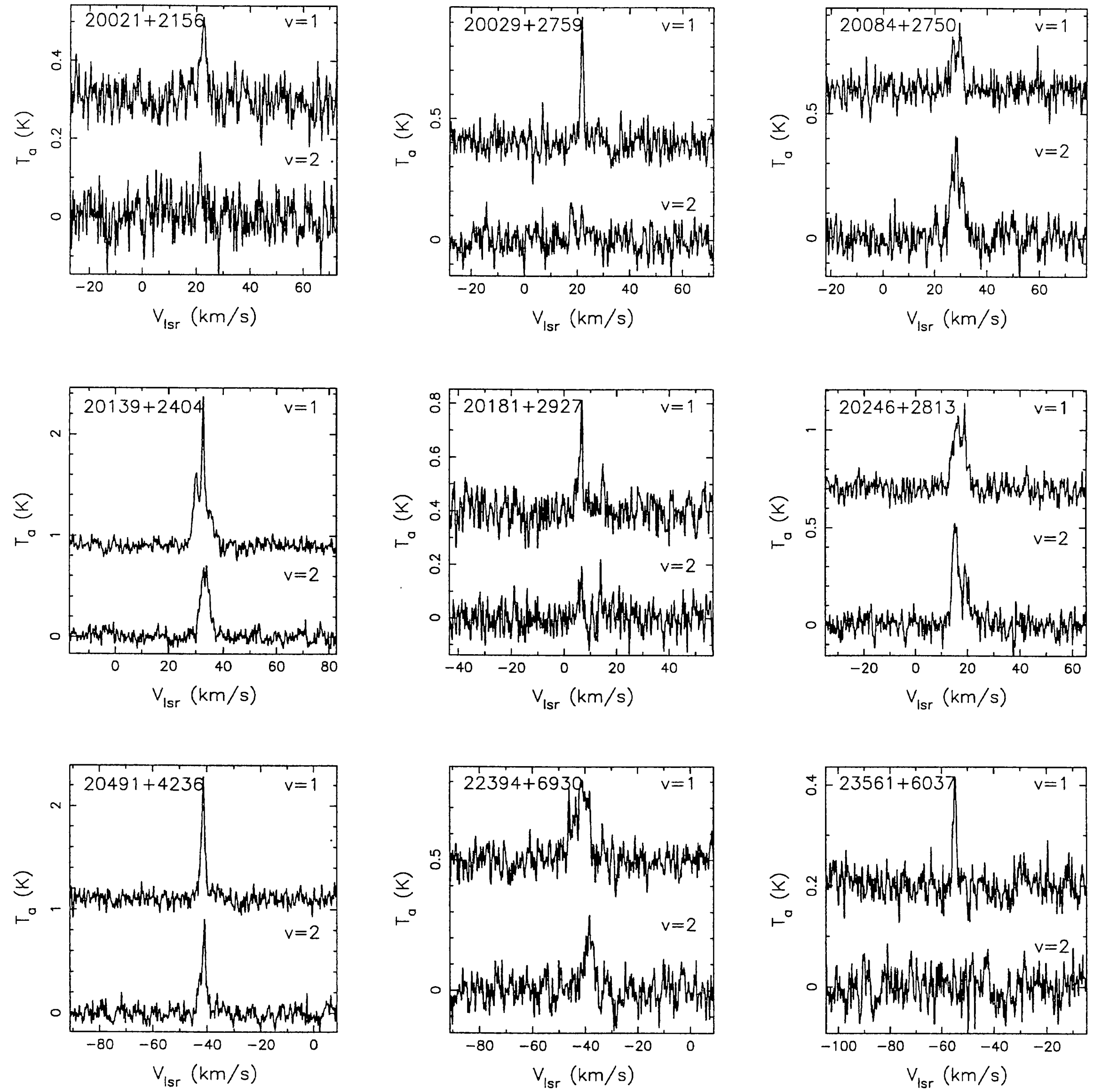

Fig. 1. (Continued)

can say that the distance effect on the apparent intensity of SiO maser emission may be taken as being equal in the two samples. Then, the difference in the detection rate of SiO maser emission means that, intrinsically, the inner disk has a larger percentage of SiO maser emitters among the late-type stars with cold circumstellar envelopes than does the outer disk.

3.2. The Larger Sample

Since 1991, more than 500 IRAS PSC sources having colors typical of late-type stars with a cold circumstellar envelope have been searched for SiO $J = 1$–0, $v = 1$ and 2 maser lines with the same 45 m telescope system at Nobeyama. These sources are distributed in the bulge as well as the inner and outer disk of the Galaxy. Because the observations were made to the same detection limit, we make a statistical comparison of observational results between the bulge, inner disk and outer disk samples without any bias effect induced by system difference.

The comparison includes the objects searched in the survey to the bulge direction, in the outer disk and in the inner disk from 1991 through 1996, except for 20 sources, whose color index, $C_{23} > -0.4$, infers the possible nature of YSOs. With the galactic latitude $|b| < 10°$, they are sources in the galactic plane. With $-0.4 < C_{12} < 0.4$ and $C_{23} < -0.4$, they are evolved late-type stars with a cold circumstellar envelope. In total there are 579 sources.

Table 3. Integrated line parameters of the ^{28}SiO detections.

IRASNAME	SiO $v=1$ $J=1$–0			SiO $v=2$ $J=1$–0			Date
	$S1$ (K km s^{-1})	$V_{\rm cen1}$ (km s^{-1})	$FWHM1$ (km s^{-1})	$S2$ (K km s^{-1})	$V_{\rm cen2}$ (km s^{-1})	$FWHM2$ (km s^{-1})	*yymmddhh*
00123+5258	0.13	−18.84	1.35	0.32	−20.18	2.34	96051710
00503+6445	3.95	−14.55	6.49	4.68	−16.27	7.91	96051810
01260+6456	1.94	−124.49	3.44	1.39	−125.59	3.33	96051712
02473+5152	0.87	−10.13	4.49	1.14	−9.64	3.67	96051612
03038+5046	1.88	−65.74	4.92	3.35	−65.39	4.96	96051213
03380+5532	0.32	16.99	2.25	1.35	18.37	4.99	96051614
04112+4841	1.22	−4.66	2.69	1.23	−5.23	3.78	96051814
04264+3853	0.55	−43.01	1.99	0.73	−46.04	2.55	96051314
04402+3426	0.44	34.74	2.89	1.06	34.69	5.78	96051315
04536+5726	9.32	−37.44	9.05	6.46	−37.06	7.81	96051315
05131+4530	—	—	—	1.44	−30.47	1.95	96051215
20010+2508	3.70	24.87	6.79	3.12	25.39	7.10	96051706
20020+1739	4.54	30.88	8.14	2.97	32.37	8.89	96051807
20021+2156	0.37	23.43	1.48	—	—	—	96051906
20029+2759	0.70	22.47	1.31	—	—	—	96051707
20084+2750	0.81	29.09	3.08	1.66	29.16	4.26	96051707
20139+2404	4.80	32.33	5.53	2.70	34.03	3.93	96051808
20181+2927	0.70	11.02	5.33	—	—	—	96051708
20246+2813	2.03	18.26	4.36	2.26	17.65	4.84	96051908
20491+4236	2.03	−42.19	1.72	1.82	−42.91	2.44	96051909
22394+6930	1.94	−42.46	7.06	0.91	−39.75	3.98	96051809
23561+6037	0.30	−54.91	1.20	—	—	—	96051409

They are first divided into three groups: the galactic bulge, inner disk, and outer disk, respectively. The 244 sources in the second and third quadrants belong to the outer-disk group, and the 22 sources with galactic longitude $30° < l < 90°$ belong to the inner-disk group without any argument. However, in a survey to the bulge direction, whether an object belongs to the inner disk or to the bulge group is not direct. Their memberships are judged by their galactocentric distance, which is calculated from light-variation period or luminosity function, depending on the available observational data involving individual sources, while the radius of the bulge is assumed to be 3 kpc. The details of assigning the membership of these sources have been described by Izumiura et al. (1995a,b), and the result is that 201 stars belong to the bulge group and 112 to the inner-disk group. As a consequence, 201, 134, and 244 sources make up the samples in the bulge, inner disk, and outer disk, respectively.

We first make a comparison of the features of the samples. The basic, and possibly most important, parameter of the samples is the IRAS color, since there are few other systematic observations to these optically thick sources except for IRAS. The samples were selected to have the IRAS color C_{12} within the range $[-0.4, 0.4]$, typical of a star with a CSE of about 600 K to 200 K. The IRAS color C_{23} should be used in combination with C_{12} to clarify the nature of sources. However, in the survey to the bulge direction, no limitation was set to the IRAS color C_{23} or the quality of flux at 60 μm. Some of the sources have $C_{23} > -0.4$, and would be suspected as being young stellar objects other than late-type stars. However, because the pollution from infrared cirrus to 60 μm flux is serious in the galactic plane to the bulge direction (Ivezić, Elitzur 1995), their apparent values of C_{23} are larger than the intrinsic value. A careful investigation furthermore indicates that the quality of F_{60} is unreliable for most such sources with $C_{23} > -0.4$. The apparent colors of young stellar objects can be regarded as being forged. Thus, the sources in the bulge survey are almost late-type stars, though there could be a few young stellar objects. In other surveys of the outer and inner disks, C_{23} is set to be < -0.4 in order to exclude young stellar objects, so that only late-type stars are left in the observations. Therefore, the statistical comparison of C_{12} can be reliable, while that of C_{23} can not be so. The other parameters of the samples include the flux at 12 μm F_{12} and the IRAS variability index *Var*. The survey to the bulge direction looked for sources with $F_{12} > 1$ Jy. and the other observations for sources with $F_{12} > 3$ Jy. One

Table 4. List of all observed sources and their galactic coordinates.

IRASNAME	$l(°)$	$b(°)$	IRASNAME	$l(°)$	$b(°)$	IRASNAME	$l(°)$	$b(°)$
00027+6952	119.01	7.64	00036+6117	117.58	0.84	00123+5258	117.42	9.23
00131+6925	119.84	7.05	00161+5820	118.69	3.98	00180+6414	119.64	1.84
00243+6316	120.23	0.81	00246+6837	120.77	6.13	00361+6515	121.65	2.70
00425+6820	122.40	5.76	00461+6439	122.69	2.07	00464+6430	122.73	1.91
00470+6448	122.79	2.20	00503+6445	123.14	2.16	00513+6317	123.27	0.69
00555+5353	123.97	8.70	00589+5743	124.33	4.85	00593+5836	124.36	3.97
01065+6452	124.86	2.34	01097+6154	125.44	0.59	01102+6153	125.51	0.60
01108+6059	125.64	1.50	01129+6352	125.63	1.40	01176+6710	125.78	4.72
01260+6456	126.91	2.62	01296+6813	126.78	5.92	01301+6118	127.92	0.91
01327+6503	127.60	2.85	01344+6232	128.21	0.40	01386+7010	127.22	7.98
01435+6007	129.75	1.76	01441+6026	129.76	1.43	01550+5901	131.41	2.50
01583+5508	132.87	6.13	02016+5802	132.51	3.22	02047+5901	132.62	2.15
02117+5559	134.44	4.77	02155+6410	132.25	3.14	02157+5843	134.07	2.00
02167+5926	133.95	1.29	02172+6752	131.19	6.69	02174+5655	134.88	3.62
02181+5738	134.73	2.93	02245+5823	135.26	1.92	02252+6630	132.40	5.68
02272+6327	133.73	2.91	02289+5404	137.42	−5.70	02294+6411	133.66	3.69
02321+6312	134.33	2.89	02367+5155	139.36	7.23	02408+5458	138.65	4.20
02467+5432	139.61	4.22	02473+5152	140.86	6.58	02570+5602	140.24	2.22
03022+5409	141.79	3.52	03038+5046	143.68	6.35	03078+6046	139.17	2.59
03151+5446	143.10	2.03	03205+5223	145.06	3.62	03316+5745	143.35	1.72
03317+6300	140.31	6.00	03347+6503	139.36	7.85	03380+5532	145.37	0.45
03409+6159	141.77	5.82	03466+4834	150.66	4.27	03525+5711	145.92	2.98
03549+5602	146.92	2.31	04004+5547	147.67	2.62	04026+4737	153.32	3.28
04050+4734	153.66	3.04	04071+5215	150.76	0.64	04079+5135	151.29	0.24
04091+5054	151.90	0.14	04112+4841	153.66	1.52	04130+3918	160.41	8.09
04166+5719	148.26	5.26	04264+3853	162.55	6.53	04402+3426	167.73	7.46
04470+3002	172.08	9.18	04536+5726	151.52	9.05	05131+4530	162.95	4.33
20005+1635	56.10	7.47	20010+2508	63.45	3.03	20020+1739	57.22	7.22
20021+2156	60.86	4.95	20029+2759	66.08	1.87	20046+2954	67.90	1.15
20053+2958	68.03	1.23	20084+2750	66.62	2.98	20121+1756	58.74	9.08
20127+2957	68.90	2.58	20137+2838	67.93	3.49	20139+2404	64.15	6.08
20178+2832	68.37	4.30	20181+2927	69.16	3.83	20190+2423	65.06	6.86
20246+2813	68.97	5.71	20285+2411	66.15	8.75	20287+2719	68.74	6.96
20304+2241	65.18	9.98	20491+4236	83.42	0.89	20567+4727	87.98	1.23
21149+4634	89.43	1.65	21415+5025	95.28	1.83	22045+6306	105.60	6.20
22112+5322	100.72	2.28	22367+5537	105.05	2.30	22394+6930	112.03	9.71
23280+7107	116.48	9.56	23361+6437	115.29	3.13	23384+7002	117.01	8.27
23431+6204	115.38	0.45	23457+6045	115.35	0.91	23561+6037	116.55	1.32

can simply conclude that the sample in the outer disk is closer and brighter than the samples in the bulge and inner disk. The index *Var* was set to > 50 in a 1995 survey of outer-disk sources, which artificially raised the average of this parameter of the outer-disk sample, as it is a free parameter for the observations to the inner-disk and the bulge sources. The averages of these parameters for the three groups of sources are listed in table 5.

As shown in table 5, the outer-disk, inner-disk and bulge samples align a reddening sequence of color index C_{12}. Since no correction to the colors is applied for interstellar extinction, which follow the same sequence in seriousness, the effect of interstellar reddening should be estimated in order to figure out if the color sequence is intrinsic. The SiO maser survey to the bulge objects tried to avoid the area $|b| < 3°$ of serious extinction. According to an estimation by Frogel (1988), the extinction at the K band $A_K = 0.17$ mag at $b = 3°$ where the most serious extinction occurs in the bulge survey. Based on the extinction law (Mathis 1990), $A_{12\ \mu\mathrm{m}} = 0.04$ mag and $A_{25\ \mu\mathrm{m}} = 0.02$ mag. Conservatively, the upper limit of color reddening is only 0.01 at C_{12}, much less than the difference presented by the samples. The C_{12} sequence is then mostly intrinsic. Recalling the result from the previous subsection, the small difference between the inner- and outer-disk samples should be real as well. Bedijn

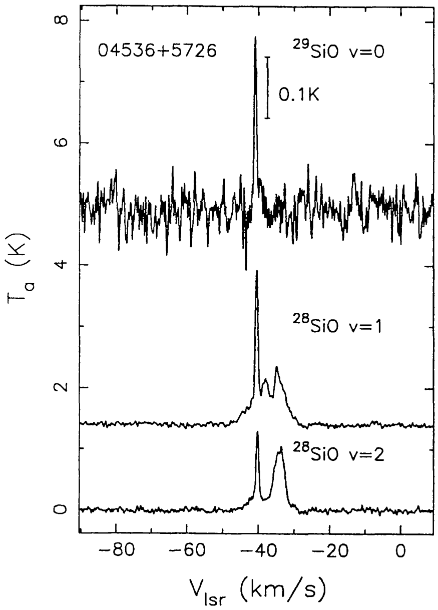

Fig. 2. Spectra of a unique new ^{29}SiO detection; the scale of the ^{29}SiO line is labeled beside the emission line.

(1987) showed that for a given model of a late-type star, C_{12} depends only on the optical depth in the infrared. Bedijn (1988) explained the IRAS color sequence of stars with cold CSEs as being due to an accelerated mass-loss rate with time, i.e., the redder stars have a larger mass-loss rate and are in a later stage of evolution. If this is true, the bulge sample would have the thickest CSE and would be in the latest stage of evolution among the three groups, as a general tendency. Besides the evolutionary effect on the IRAS colors, metallicity may also play a role. It is suspected that the metals would redden the stars (Habing 1996). Observations showed that the Long Period Variable stars in the Magellanic Clouds are not so red in IRAS colors as those in the galactic bulge with the same period, i.e. the same luminosity or mass. Though the metallicity gradient in the Galaxy is not clearly or quantitatively established, the declining tendency with galactocentric distance can be seen in several works. A study of globular clusters found a slope of $\sim \triangle[\mathrm{Fe/H}]/R_{\mathrm{gc}} = -0.091\ \mathrm{kpc}^{-1}$ (Friel 1995). Thus, the C_{12} sequence may indicate a sequence of metallicity in the samples.

As expected and explained above, the difference during selection determined the rising sequence of flux density (F_{12}) from the bulge sample to outer disk sample in table 5. Due to the inclusion of a few very bright sources, such as R Cas in the outer disk sample, the average is deviated to a value higher than that of most sources. Because the sources belong to the same type of objects,

Table 5. Averages of C_{12}, F_{12}, and Var of all sources and SiO maser detection rates.

Item	Bulge	Inner disk	Outer disk
C_{12}	0.03	−0.02	−0.22
F_{12}	5.55	13.24	32.61
Var	79.8	75.0	53.8
Number of sources ...	201	134	244
Detection rate	66%	51%	31%

F_{12} may be taken as being an indicator of distance. On average, the bulge sample is the furthest, the inner-disk sample moderate and the outer-disk sample the closest.

The average IRAS variability index, Var, is almost the same for the bulge and the inner-disk samples and is smaller for the outer-disk sample in spite of the artificial raise in the 1995 survey. In the presently selected range of F_{12}, the sources with $Var > 50$ are variable in light of the IRAS photometric accuracy (Jiang et al. 1996). Most of the stars in the bulge and inner-disk samples are variable, and there is quite a fraction in the outer disk sample which did not show any variation during IRAS observation. The IRAS survey strategy produced more confirmed observations in some regions than the others at time intervals suitable for detecting the variability and some spurious indications of variability in regions of high source density (Beichman et al. 1988). However, since the SiO-surveyed regions are not biased in the IRAS observation, it could be true that there is a greater proportion of variables in the bulge and inner-disk samples than in the outer-disk sample.

It has been noticed that the SiO maser detection rate in the outer disk is much lower than that in the bulge survey (Jiang et al. 1997). This rate in the three samples is 66%, 51%, and 31%, respectively, as shown in the last row of table 5. Combining this data with the result from the new observation described above, we can conclude that the SiO maser stars are concentrated in the bulge, and become even less dense in the inner and outer disk.

3.3. Radial Sequence in the Galaxy

From the above analysis of the sample features, it is found that the bulge, inner-disk and outer-disk samples consist a decreasing sequence in distance to the observer. Practically, this distance sequence may result in an increasing sequence, or slight effect in the SiO maser detection rate, depending on the matching between the detection limit of observation and SiO maser luminosity function. However, the real result is contrary, i.e., the detection rate decreases from the bulge to the inner-disk to the outer-disk samples; the detection rate must mainly be determined by other factors. As the IRAS color C_{12} and variability index Var align a sequential change from the bulge through the inner-disk to the outer-disk sample, they are correlated to the variation in the SiO maser detection rate. Indeed, the sequence of the detection rate may be understood from its correlation with C_{12} if the C_{12} sequence is a sequence of metallicity, which can be one possibility, as discussed above. A study of late-type stellar content of galaxies shows that the C- to M-type star number ratio anti-correlates with the metallicity, i.e., the ratio is high in a low-metallicity environment (Pritchet et al. 1987). Blanco (1965) discussed in detail the distribution of M-type and C-type stars in the galactic plane. He pointed out the fact concerning the concentration to the galactic-center direction of M-type stars. Since no C-type stars have ever been detected in these SiO maser lines, the increase of C-type stars from the bulge to the outer disk, that may have resulted from the galactic metallicity gradient, would yield a decreasing sequence of the SiO maser detection rate. This conclusion is consistent with the result based on a near-infrared photometric observation (Jiang et al. 1997). Blommaert et al. (1993) obtained similar conclusions from observations of OH/IR stars. They found that the detection rate of OH maser emission decreases with the galactocentric distance. They explained that the lower metallicity in the outer Galaxy led to an increasing number of O-rich stars to become C-rich, which led to a smaller number of very red sources.

The reason for the influence of the variability of objects on the production of SiO maser emission is not very clear. It has been pointed out that the detection rate is higher in variable sources than in non-variable sources based on a bulge survey (Jiang et al. 1995). The apparent correlation of the detection rate with variability index in the three samples confirms this conclusion. It has been found that SiO masing correlates with the optical-variation phase in late-type stars. The vibrationally excited SiO maser may occur in a region close to the star where stellar pulsation can have an influence (Cho et al. 1996). The effect of the IRAS variability index on the SiO maser detection rate may result from the influence of stellar pulsation, though the details are not known.

4. Summary

A survey in SiO maser line transitions $J = 1\text{–}0$, $v = 1$ and $v = 2$ and isotopic ^{29}SiO $J = 1\text{–}0$, $v = 1$ line was carried out using the 45 m telescope system at Nobeyama Radio Observatory from 1994 through 1996. This survey concentrated on IRAS PSC sources with typical colors of AGB stars surrounded by a cold circumstellar envelope, the same as in a survey towards the bulge direction. Combining these two survey data, a total of 579 stars, among which 201, 134, and 244 lie in the bulge, inner disk, and outer disk, respectively, were searched for SiO maser emission at a sensitivity limit of about 1 Jy at the 5 σ level. A comparison between the bulge, inner-disk and outer-disk samples found that they consist a sequence of IRAS color C_{12}, variability index, and flux at 12 μm. A decreasing sequence of SiO maser population possibly results as a consequence of a variation in the galactic metallicity and proportion of variable stars.

The authors thank the people of the 45 m group at Nobeyama Radio Observatory for help to complete the observation. B.W.J. was supported by the Japanese Government Scholarship for staying in Japan. This research was supported by Grant in-aid for Scientific Research (C) No. 10640238 of Ministry of Education, Science, Sports and Culture.

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