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SIMULTANEOUS OBSERVATIONS OF SiO AND H_2O MASERS TOWARD SYMBIOTIC STARS

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ABSTRACT

We present the results of simultaneous observations of SiO $v = 1$, 2, $J = 1$–0, ^{29}SiO $v = 0$, $J = 1$–0, and H_2O 6_{16}–5_{23} maser lines performed with the KVN Yonsei 21 m radio telescope from 2009 November to 2010 January. We searched for these masers in 47 symbiotic stars and detected maser emission from 21 stars, giving the first time detection from 19 stars. Both SiO and H_2O masers were detected from seven stars of which six were D-type symbiotic stars and one was an S-type star, WRAY 15-1470. In the SiO maser emission, the ^{28}SiO $v = 1$ maser was detected from 10 stars, while the $v = 2$ maser was detected from 15 stars. In particular, the ^{28}SiO $v = 2$ maser emission without the $v = 1$ maser detection was detected from nine stars with a detection rate of 60%, which is much higher than that of isolated Miras/red giants. The ^{29}SiO $v = 0$ maser emission was also detected from two stars, H 2-38 and BF Cyg, together with the ^{28}SiO $v = 2$ maser. We conclude that these different observational results between isolated Miras/red giants and symbiotic stars may be related with the presence of hot companions in a symbiotic binary system.

Key words: binaries: symbiotic – circumstellar matter – masers – radio lines: stars

1. INTRODUCTION

Symbiotic stars are interacting binaries comprising a hot white dwarf and a cool red giant (Kenyon 1986) transferring material to a white dwarf via stellar wind. Until now, about 200 symbiotic stars are known as published by Belczyński et al. (2000). There are two major types of symbiotic stars, S(stellar)-type and D(dusty)-type according to their near-infrared properties. The S-type system contains a normal giant star and the D-type system contains a Mira variable. Therefore, molecular species such as SiO, H_2O, and OH can be found in the circumstellar envelope of cool red giant and Mira components of symbiotic stars.

Several SiO and H_2O maser surveys were conducted toward limited symbiotic stars (Cohen & Ghigo 1980; Hall et al. 1987; Allen et al. 1989; Ivison et al. 1994). However, those searches for maser emission from symbiotic stars have so far resulted in only two SiO and H_2O discoveries. Namely, SiO masers were detected from R Aqr (Lepine et al. 1978) and H 1-36 (Allen et al. 1989), and H_2O masers were also detected from R Aqr and H 1-36 (Ivison et al. 1994). Ivison et al. (1994) suggested that these detections unequivocally demonstrate that dust can shield some maser molecules from dissociation, even in systems that possess intense local sources of ultraviolet radiation.

It must be clear that masers will be a useful probe for investigating morphology and dynamics of the dusty circumstellar envelope of cool components influenced by the hot ionized gas from hot components in symbiotic binary systems. In addition, masers also play an important role in the investigation of evolutionary status and mass loss of symbiotic binaries on and beyond the asymptotic giant branch including bipolarity of symbiotic stars. Therefore, we have performed systematic SiO and H_2O maser surveys toward numerous symbiotic stars using the first completed telescope of the Korean VLBI Network (KVN) radio telescopes, the KVN Yonsei 21 m telescope, which is simultaneously operated at 22 and 43 GHz bands. By combined surveys of SiO and H_2O masers for symbiotic stars using the KVN Yonsei telescope, we can search for both SiO and H_2O masers effectively.

In this paper, we present the results of simultaneous observations of SiO and H_2O masers toward symbiotic stars including 19 new detections.

2. SOURCE SELECTION AND OBSERVATIONS

Our 47 observed sources were selected from a catalog of symbiotic stars (Belczyński et al. 2000) with the following criteria. (1) The cool-star spectrum should be late M-type or Mira in order to increase the detectabilities of masers. (2) The declination of a star should be above $-35°$ in order for it to be observed at our KVN Yonsei site. As a result, 42 stars were selected from the main catalog of Table 1 and 5 stars from suspected symbiotic stars of Table 2 among the Belczyński et al. catalog of symbiotic stars. They consist of 28 S-type symbiotic stars, 15 D-type stars, 2 both D-type and S-type stars (V4141 Sgr, AS 245), and 2 no IR-type stars (NSV 11776, V335 Vul).

Simultaneous observations of SiO $v = 1$, 2, $J = 1$–0 (43.122080 GHz and 42.820587 GHz), ^{29}SiO $v = 0$, $J = 1$–0 (42.879916 GHz), and H_2O 6_{16}–5_{23} (22.235080 GHz) maser lines were performed with the KVN Yonsei 21 m radio telescope at the Yonsei University campus, Seoul, from 2009 November to 2010 January. The KVN antenna optics were designed for simultaneous observations of four bands of the H_2O 22 GHz and SiO 43, 86, 129 GHz bands (Han et al. 2008). The 22 GHz and 43 GHz beams are split by a low pass filter (cutoff ∼30 GHz) and are simultaneously received by both 22 GHz and 43 GHz band receivers installed on the same plate. The observational method was similar to Kim et al.'s H_2O/SiO maser survey toward known stellar maser sources (Kim et al. 2010). The half-power beam widths and aperture efficiencies were 137″, 0.72 (at 22 GHz) and 70″, 0.69 (at 43 GHz), respectively (S. S. Lee et al. 2010, in preparation). Pointing was checked every 2 hr

Table 1
Peak Antenna Temperatures and Velocities of SiO and H_2O Maser-detected Sources

No.	Name(IR Type)	Cat. ID[a]	T_A^*(Peak) (K)				V_{LSR}(Peak) (km s^{-1})				Date(Phase)
			^{28}SiO		^{29}SiO	H_2O	^{28}SiO		^{29}SiO	H_2O	(yymmdd)
			$v = 1$	$v = 2$	$v = 0$		$v = 1$	$v = 2$	$v = 0$		
1	UV Aur(S)	016	0.15	0.09	<0.08	<0.08	−4.4	−8.1	...	...	091110(0.79)
2	BX Mon(S)	023	<0.09	0.15	<0.11	<0.09	...	29.3	...	...	091110
3	WRAY 15-1470(S)	063	0.14	<0.10	<0.10	0.17	40.2	...	...	31.3	091104
4	Hen 2-171(D)	064	0.15	<0.09	<0.12	<0.06	−127.8	...	...	...	091206
5	AS 221(S)	076	0.14	<0.10	<0.11	<0.06	−24.0	...	...	...	091207
6	V2110 Oph(D)	096	<0.07	0.09	<0.07	<0.06	...	−87.4	...	...	100117
7	H 1-36(D)	100	0.29	0.24	<0.10	0.16	−115.9	−115.4	...	−118.1	091206
8	WRAY 16-312(D)	102	<0.12	<0.17	<0.12	0.23	...	...	...	−71.2	091208
9	H 2-38(D)	120	<0.09	0.16	0.10	0.09	...	−21.5	−28.7	−21.9	100119
10	V2905 Sgr(S)	139	<0.15	0.22	<0.14	<0.15	...	−110.7	...	...	091208
11	NSV 11776	161	<0.06	<0.06	<0.05	0.11	...	...	...	−2.1	091208
12	V335 Vul	s24	<0.08	0.08	<0.08	<0.05	...	−42.9	...	...	091206
13	V850 Aql(S)	s25	0.12	0.11	<0.06	<0.05	29.4	28.8	...	...	091207
14	BF Cyg(S)	166	<0.08	0.10	0.11	<0.07	...	−2.6	−6.5	...	091203
15	HM Sge(D)	169	<0.07	0.11	<0.07	0.07	...	−98.9	...	−94.4	091205
16	V1016 Cyg(D)	174	0.15	<0.09	<0.08	<0.08	−46.1	...	...	...	091202
17	IRAS 19558+3333(D?)	s27	<0.07	0.11	<0.06	<0.06	...	6.1	...	...	091204
18	V1329 Cyg(S)	181	<0.10	0.14	<0.08	<0.08	...	−19.1	...	...	091202(0.17)
19	V407 Cyg(D)	183	0.47	0.47	<0.07	0.11	−28.1	−27.9	...	−31.5	091202
20	V627 Cas(D)	s28	4.29	2.35	<0.09	0.64	−55.3	−55.1	...	−51.6	091112
21	R Aqr(D)	188	5.62	9.79	<0.14	0.08	−22.5	−23.6	...	−18.1	091114(0.82)

Note. [a] Symbiotic star catalog number from Belczyński et al. (2000).

Table 2
Detected SiO and H_2O Maser Transitions According to Symbiotic Stars

H_2O	^{28}SiO		^{29}SiO	Stars
	$v = 1$	$v = 2$	$v = 0$	
○	○	○		7. H 1-36(D), 19. V407 Cyg(D), 20. V627 Cas(D), 21. R Aqr(D)
○		○	○	9. H 2-38(D)
○	○			3. WRAY 15-1470(S)
○		○		15. HM Sge(D)
○				8. WRAY 16-312(D), 11. NSV 11776
	○	○		1. UV Aur(S), 13. V850 Aql(S)
		○	○	14. BF Cyg(S)
	○			4. Hen 2-171(D), 5. AS 221(S), 16. V1016 Cyg(D)
		○		2. BX Mon(S), 6. V2110 Oph(D), 10. V2905 Sgr(S), 12. V335 Vul 17. IRAS 19558+3333(D?), 18. V1329 Cyg(S)
9	10	15	2	21

Note. Open circles indicate detected transitions.

using nearby strong SiO maser sources. Cryogenic 22/43 GHz high electron mobility transistor receivers were used with a left circular polarized feed during our observations.

The system noise temperatures (SSB) ranged from 80 K to 240 K (at 22 GHz) and from 140 K to 300 K (at 43 GHz) depending on weather conditions and elevations. We used a digital spectrometer to choose total bandwidths of one 64 MHz mode for the H_2O 6_{16}–5_{23} line and three 64 MHz modes for SiO $v = 1$, 2, $J = 1$–0 and ^{29}SiO $v = 0$, $J = 1$–0 lines, respectively. These bandwidths cover the range of radial velocities of 450 km s^{-1} (at 22 GHz) and 220 km s^{-1} (at 43 GHz), and the velocity resolutions correspond to 0.21 km s^{-1} (4096 channels at 22 GHz) and 0.22 km s^{-1} (2048 channels at 43 GHz), respectively.

The data were calibrated by the chopper wheel method, which was corrected for atmospheric attenuation and antenna gain variations depending on elevation, to yield an antenna temperature T_A^*. Integration time was 30–50 minutes to achieve 0.05 K at the 3σ level. The conversion factor from the antenna temperature, T_A^*, to the flux density is about 11.07 Jy K^{-1} at 22 GHz and 11.55 Jy K^{-1} at 43 GHz.

3. OBSERVATIONAL RESULTS AND DISCUSSION

We detected SiO and H_2O maser emission from 21 stars among 47 symbiotic stars from the Belczyński et al. (2000) catalog. Table 1 gives observational results for the peak antenna temperatures and velocities according to SiO and H_2O maser transitions. In Table 1, the identification number and the source name (infrared type) are given in Columns 1 and 2. Column 3 gives the symbiotic star catalog number of Belczyński et al. (2000). Column 4 gives the peak antenna temperature of ^{28}SiO $v = 1$ and 2, $J = 1$–0, ^{29}SiO $v = 0$, $J = 1$–0, and H_2O masers. Column 5 gives the peak velocities with respect to the

Table 3
Negative Results

Name(IR Type)	Cat. ID[a]	T_A^*(Peak) (K)				Date(Phase)
		^{28}SiO		^{29}SiO	H_2O	
		$v = 1$	$v = 2$	$v = 0$		
AX Per(S)	008	<0.09	<0.10	<0.10	<0.07	091111(0.93)
ZZ CMi(S)	s05	<0.11	<0.09	<0.10	<0.07	091110
V695 Mon(S)	024	<0.11	<0.10	<0.10	<0.10	091110
RW Hya(S)	045	<0.14	<0.14	<0.14	<0.13	091104
T CrB(S)	057	<0.06	<0.06	<0.06	<0.05	091105
AS 210(D)	069	<0.08	<0.12	<0.12	<0.11	091106
V455 Sco(S)	073	<0.11	<0.10	<0.11	<0.06	091206
V2116 Oph(S)	084	<0.07	<0.09	<0.11	<0.05	091207
Hen 2-251(D)	089	<0.20	<0.16	<0.18	<0.17	091208
V4141 Sgr(D,S)	103	<0.07	<0.07	<0.09	<0.07	100117
AS 245(S,D)	105	<0.10	<0.09	<0.10	<0.08	100119
V2416 Sgr(S)	113	<0.10	<0.07	<0.09	<0.06	100121
SS73 122(D)	118	<0.09	<0.08	<0.09	<0.06	100121
AS 270(S)	119	<0.08	<0.10	<0.10	<0.07	100121
AS 281(S)	127	<0.09	<0.07	<0.09	<0.07	100119
Hen 2-374(S)	136	<0.08	<0.07	<0.08	<0.05	100122
V3804 Sgr(S)	144	<0.15	<0.16	<0.17	<0.13	091208
V443 Her(S)	145	<0.05	<0.05	<0.06	<0.05	091205
K 3-9(D)	150	<0.11	<0.11	<0.11	<0.09	091208
Pe 2-16(S)	157	<0.09	<0.09	<0.10	<0.06	100117
Ap 3-1(S)	162	<0.09	<0.06	, 0.06	<0.06	091205
CH Cyg(S)	167	<0.09	<0.07	<0.08	<0.07	091203
QW Sge(S)	171	<0.07	<0.07	<0.08	<0.06	091205
CI Cyg(S)	172	<0.08	<0.08	<0.07	<0.06	091204(0.17)
PU Vul(S)	176	<0.06	<0.04	<0.06	<0.03	091205
Z And(S)	187	<0.08	<0.11	<0.10	<0.05	091113

Note. [a] Symbiotic star catalog number from Belczyński et al. (2000).

local standard of rest (LSR) for each maser line. The dates of observations with the corresponding phase of the optical light curve (0.0 = maximum light) are listed in Column 6. The optical phase was calculated from the optical data provided by the American Association of Variable Star Observers (AAVSO[5]).

Except from H 1-36 and R Aqr, 18 stars contain first time detections of both SiO and H_2O maser emission and V407 Cyg contains the first time detection of H_2O maser emission. Deguchi et al. (2005) detected SiO $v = 1$ and $v = 2$, $J = 1$–0 masers from V407 Cyg. Both SiO and H_2O maser emission were detected from seven stars (six D-type stars and one S-type star). Nineteen symbiotic stars show SiO maser emission, while nine stars show H_2O maser emission. We tabulated 21 symbiotic stars according to the detected SiO maser transitions and H_2O maser as shown in Table 2. In the case of the SiO maser, the ^{28}SiO $v = 1$ maser was detected from 10 stars, while the $v = 2$ maser was detected from 15 stars. In particular, the ^{28}SiO $v = 2$ maser emission without the $v = 1$ maser detection was detected from nine stars. The H_2O masers were detected from D-type symbiotic stars except for the S-type star, WRAY 15-1470. For two objects, WRAY 16-312 and NSV 11776, only the H_2O maser was detected, but no SiO maser was detected. The ^{29}SiO $v = 0$ maser emission was also detected from two stars, H 2-38 and BF Cyg together with the ^{28}SiO $v = 2$ maser. Negative results with upper limits are given toward 26 symbiotic stars in Table 3.

In Figure 1, whole spectra of 21 detected stars are shown. Spectra are arranged by the identification number of Table 1. Intensity is given in units of antenna temperature T_A^* (K) and the abscissa is $V_{\rm LSR}$ (km s^{-1}).

[5] http://www.aavso.org/

From the above observational results, we can find the different characteristics of SiO maser emission between isolated Miras/red giants and those in the symbiotic binaries. The ^{28}SiO $v = 2$ maser emission without the $v = 1$ maser is detected from as many as 9 symbiotic stars among 15 stars (60% among SiO $v = 2$ maser-detected sources) including six $v = 2$ maser-only detected sources without H_2O masers. In isolated Miras/red giants, the $v = 2$, $J = 1$–0 maser emission is ordinarily detected together with the $v = 1$ maser, which has a lower energy level than the $v = 2$. For example, in isolated Miras/red giants, 95% of the $v = 2$ maser emission was detected together with the $v = 1$ maser while the $v = 2$ maser emission without the $v = 1$ maser was detected only from 8 stars among 148 $v = 2$ detected sources with a detection rate of 5% (Kim et al. 2010). These results clearly suggest that physical environments of SiO maser emission in symbiotic stars are different from isolated Miras/red giants, and critical constraints for maser pumping between the $v = 1$ and $v = 2$ transitions are existent. It may be related with the presence of hot companions in symbiotic binary systems. The influences from a hot companion with an accretion disk (for example, hot ultraviolet radiation) can raise the temperature of the SiO maser region and can thermalize the $v = 1$ maser due to relatively lower excitation temperature compared with the $v = 2$ maser. In the case of SiO maser emission in Orion KL Source I, Goddi et al. (2009) showed that the $v = 2$ maser is optimized at higher temperatures and it is more strongly inverted in a strong, hot radiation field than the $v = 1$ maser. In particular, since the $v = 1$ maser occurs at larger radii from the central star of the cool companion compared with the $v = 2$ maser (Desmurs et al. 2000; Yi et al. 2005),

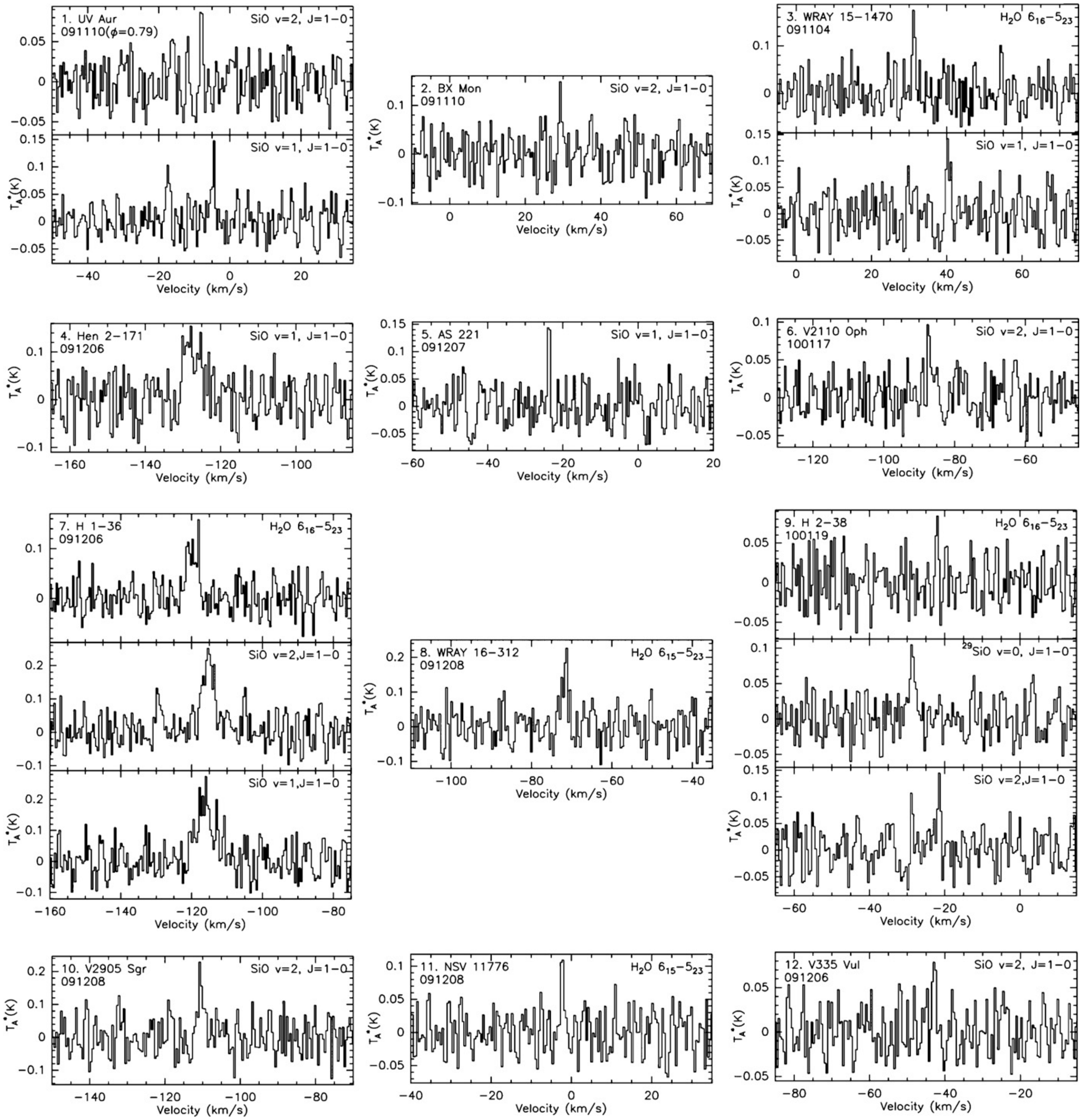

Figure 1. Whole spectra of 21 H_2O and SiO maser-detected stars. Spectra are arranged by the identification number of Table 1. Intensity is given in units of antenna temperature T_A^* (K) and the abscissa is $V_{\rm LSR}$ (km s^{-1}). The identification number, the source name, the molecule and its transitions, and the date of observation are given in the spectrum of each source.

it is much influenced by ultraviolet radiation from a hot companion and/or from an accretion disk. We also detected ^{29}SiO $v = 0$ maser emission from two symbiotic stars. The influence of the hot companion may play an important role even for the ^{29}SiO $v = 0$ maser emission. Therefore, a new pumping model considering the influence of the hot companion is required for the interpretation of these observational results.

In addition, D-type symbiotic stars have a more extended and dust-rich circumstellar envelope than S-type symbiotic stars. Therefore, the H_2O maser might be detected mainly from D-type symbiotic stars with a detection rate of 47% (7 detections from 15 stars) while the H_2O detection rate is 4% in S-type stars (1 detection from 28 stars). However, the first time detection of the H_2O maser from the S-type symbiotic star WRAY 15-1470 with T_A^*(peak) = 0.17 K, rms level ∼0.04 K at 22/43 GHz bands, may be of great importance. This is because the H_2O maser may be convincing evidence for mass loss to the hot companion white dwarf, which is required for accretion in an S-type symbiotic system.

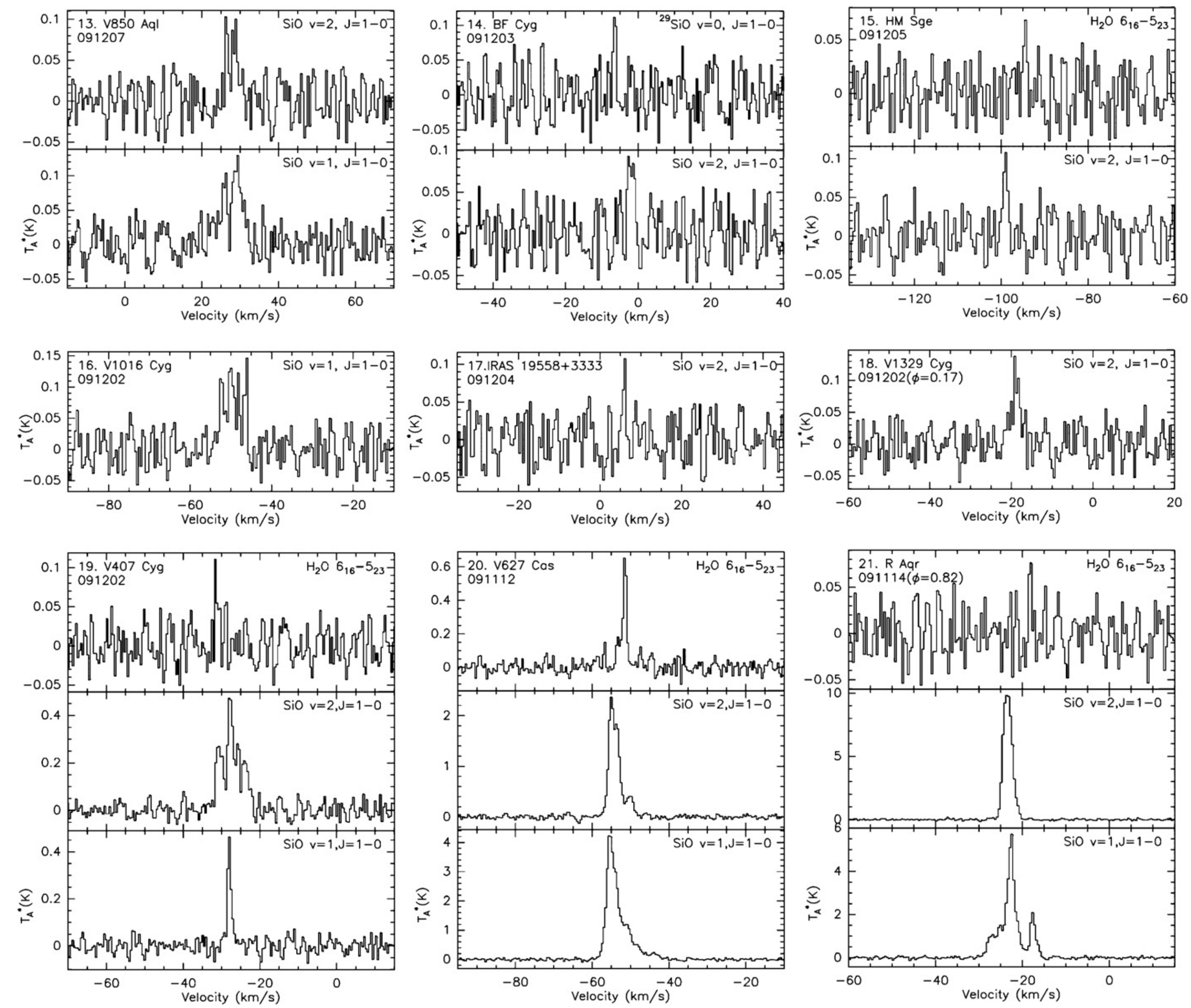

Figure 1. (Continued)

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REFERENCES

Allen, D. A., Hall, P. J., Norries, R. P., Troup, E. R., Wark, R. M., & Wright, A. E. 1989, MNRAS, 236, 363

Belczyński, K., Mikolajewska, J., Munari, U., Ivison, R., & Friedjung, 2000, A&AS, 146, 407

Cohen, N. L., & Ghigo, F. D. 1980, AJ, 85, 451

Deguchi, S., Nakashima, J., Miyata, T., & Ita, Y. 2005, PASJ, 57, 933

Desmurs, J. F., Bujarrabal, V., Colomer, F., & Alcolea, J. 2000, A&A, 360, 189

Goddi, C., Greenhill, L. J., Chandler, C. J., Humphreys, E. M. L., Matthews, L. D., & Gray, M. D. 2009, ApJ, 698, 1165

Hall, P. J., Wark, R. M., & Wright, A. E. 1987, Proc. Astron. Soc. Aust., 7, 50

Han, S.-T., et al. 2008, Int. J. Infrared Millim. Waves, 29, 69

Ivison, R. J., Seaquist, E. R., & Hall, P. J. 1994, MNRAS, 269, 218

Kenyon, S. 1986, The Symbiotic Stars (New York: Cambridge Univ. Press)

Kim, J., Cho, S.-H., Oh, C. S., & Byun, D.-Y. 2010, ApJS, 188, 209

Lepine, J. R. D., Le Squeren, A. M., & Scalise, E. 1978, ApJ, 225, 869

Yi, J., Booth, R. S., Conway, J. E., & Diamond, P. J. 2005, A&A, 432, 531