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A LOW-DETECTION LIMIT SEARCH FOR OH EMISSION FROM INFRARED STARS

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ABSTRACT

We have used the 300 m telescope of the Arecibo Observatory to examine 154 cool luminous stars for 18 cm OH emission. Six of the stars (RU Ari, R Com, T Com, RX Oph, UU Peg, and RT Vir) were found to show OH emission. For the stars without OH emission, we have established detection limits several times smaller than those of previous surveys.

Subject headings: infrared: sources — radio sources: lines — stars: circumstellar shells — stars: long-period variables — stars: mass loss

I. INTRODUCTION

In the past 10 years it has become clear that many of the sources of 18 cm OH emission are associated with the mass flows originating in cool luminous stars (IR stars), many of which are long-period (Mira) variables. The OH emission, together with H_2O and SiO emission and IR radiation from solid particles, provides information about regions of the mass flows which are not easily observed in the visible part of the spectrum. The OH emission thus constitutes important data about the mass flows and the stars giving rise to them. Much of the available information about stellar OH sources has its origin in a number of surveys of IR stars. Surveys at 1612 MHz (all with 5 σ detection limits of about 0.5 Jy or greater) have been carried out by Caswell and Robinson (1970), Caswell, Robinson, and Dickel (1971), Wilson and Barrett (1972), Dickinson, Kollberg, and Yngvesson (1975), and Bowers and Kerr (1977). Surveys at 1665 MHz and/or 1667 MHz (all with 5 σ detection limits of about 0.4 Jy or greater) have been conducted by Wilson and Barrett (1972), Fillit *et al.* (1972), Fillit, Foy, and Gheudin (1973), Wilson and Riegel (1973), Bowers and Kerr (1977), and Kolena and Pataki (1977). In all, about 700 stars have been surveyed, and OH emission has been detected in approximately 60.

Although the apparent luminosity function of OH emission from IR stars is not very well determined (because of the relatively small number of known OH/IR stars as well as intentionally introduced selection effects in most surveys), the number-peak flux distribution estimated from previous surveys suggested that a considerable number of new OH/IR stars could be discovered in a survey having significantly lower detection limits. We have used the 18 cm spectral-line system of the Arecibo 300 m telescope to carry out such a survey.

II. THE OBSERVATIONS

A total of 154 stars were observed at the Arecibo Observatory during 1976 January and September. Most of the stars observed are Mira or semiregular variables, although a number of IRC objects with large $I - K$ indices or infrared variability were included in the survey. Since observations at 1612 MHz and at 1665/1667 MHz could not be carried out at the same time and since the allocated observing time did not permit identical sky coverage at 1612 MHz and at 1665/1667 MHz, it was not possible to observe each of the 154 stars at all three OH lines. Thus 89 stars were observed at both 1612 MHz and 1665/1667 MHz, 32 were observed only at 1612 MHz, and 33 were observed only at 1665/1667 MHz.

The 1612 MHz observations were made by using a 16 foot (5 m) linearly polarized line feed with a sensitivity of 2 K Jy^{-1}. The observations at 1665/1667 MHz were made with a 40 foot (12 m), linearly polarized line feed with a sensitivity of 4.7 K Jy^{-1} at the zenith. Typically, a star was observed in the frequency switching mode for 10 minutes using 252 autocorrelation channels covering 1.25 MHz. The spectra were subsequently smoothed to a resolution of 1.8 km s^{-1} and covered a velocity range of about 225 km s^{-1} centered at 0 km s^{-1} LSR. Typical 5 σ detection limits were about 0.15 Jy at 1612 MHz and 0.10 Jy at 1665/1667 MHz.

A number of stars which were observed in 1976 April had one or more velocity channels in which the flux was four or more sigma above the baseline. These were rechecked in September, and emission was confirmed in only a few. A few stars were observed for longer than 10 minutes and have correspondingly lower detection limits.

III. RESULTS

Six new stellar OH sources (RU Ari, R Com, T Com, RX Oph, UU Peg, and RT Vir) were discovered. The properties of these stars and their OH emission are summarized in Table 1. None of the new OH sources has properties which are extraordinary: The velocity separations of the OH components and the ratios of strengths of the velocity components fall well within the ranges delineated by previously known OH/IR stars. The spectral class of T Com (M3) is,

TABLE 1

NEW OH/IR STARS

	RU Ari	T Com	UU Peg	RT Vir	RX Oph	R Com
IRC	...	...	10498	10262	10314	20237
Spectral type	M10	M2	M7e	M8	...	M5e–M7e
Variable type	M	M	M	SR	M	M
P (days)	354	406	456	155	322	362
1612 MHz						
V_{LSR} (km s^{-1})	+24, +16	+23, +9	n.o.	...	n.o.	...
Peak flux (Jy)	0.90, 0.30	0.45, 0.15	n.o.	< 0.15	n.o.	< 0.15
Int. flux × 10^{-22} (W m^{-2})	0.85, 0.65	0.40, 0.20	n.o.	...	n.o.	...
1665 MHz						
V_{LSR}	n.o.	...	+23, +35	+24	−48, −52	...
Peak flux	n.o.	< 0.05	0.30, 0.25	0.06	0.15, 0.07	< 0.05
Int. flux	n.o.	...	0.65, 0.75	0.07	0.20, 0.08	...
1667 MHz						
V_{LSR}	n.o.	...	+23, +36	+24	−46, −53	−7, −1
Peak flux	n.o.	< 0.05	0.40, 0.20	0.30	0.20, 0.07	0.08, 0.06
Int. flux	n.o.	...	0.80, 0.65	0.30	0.50, 0.15	0.08, 0.06

however, very early for a star with maser emission. The 148 stars for which no OH emission could be detected are listed in Table 2. Many of these stars have been examined in previous surveys, but with detection limits several times higher than in the present case.

During the survey a number of known or suspected OH/IR stars were observed in order to be sure that the spectral-line system was functioning properly. These observations are summarized in Table 3. Two of the stars in Table 3, R Ari and R Leo, warrant further discussion. R Ari was described as a probable OH source by Dickinson and Chaisson (1973) and has been confirmed recently by Bowers (1977). We detected no OH emission from R Ari at or above a level of 0.1 Jy at 1665/1667 MHz.

Our measurements of R Leo demonstrate that its 1665/1667 MHz emission is highly variable, increasing in peak flux by over an order of magnitude between 1976 January and September. R Leo was first detected by Fillit, Foy, and Gheudin (1973) in 1972 September when it had a peak flux of 0.17 Jy at 1665 MHz and 0.3 Jy at 1667 MHz. We have subsequently measured its OH lines in 1977 April and found them to be about as strong as in 1976 September. When these measurements are combined with upper limits established by pre-1972 surveys, the variation of the main-line strengths of OH emission from R Leo appears to be roughly periodic and in phase with its optical variations, the lines being strongest near maximum visual light. The large variations in peak flux suggest that the main lines of R Leo are produced by an unsaturated maser.

IV. DISCUSSION

Using the absolute-magnitude–period relationship for Mira variables (Foy, Heck, and Mennessier 1975) and van Herk's (1965) model of interstellar extinction, we have calculated distances for the Mira variables examined in this survey as well as for those Mira variables which are known main-line OH emitters. These distances, plus either the detection limit for non–OH survey stars or peak main-line flux for known OH Mira variables, were used to calculate main-line peak luminosities for the various objects. The peak luminosities (or upper limits) for OH and non–OH Mira variables are shown against their periods in Figure 1. Several points are illustrated in Figure 1. First, as is well known, nearly all OH Mira variables have periods longer than 300 days. Second, the OH Mira variables exhibit a large range of main-line peak luminosities. Even among stars having similar periods, a range of over two orders of magnitude in main-line peak luminosity occurs. Third, the failure to detect some Mira variables as OH emitters is not a mere consequence of distance. Some of the stars examined in this survey have main-line peak luminosities which

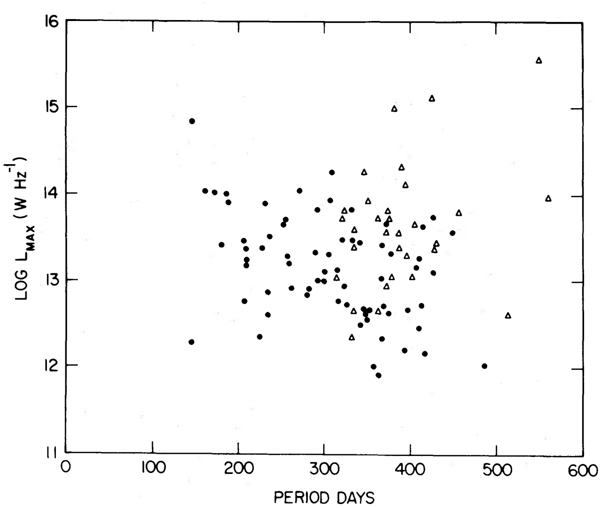

FIG. 1.—The logarithm of the main-line peak luminosity (W Hz^{-1}) for Mira variables. *Solid circles*, upper limits for Mira variables examined in this survey. *Open triangles*, known OH Mira variables.

TABLE 2

STARS NOT DETECTED AS OH EMITTERS

IRC	Name	Var. Type	P (days)	Lines Sought*	Comments†
30002.....	TT Peg	SR	153	1	
30006.....	...	...	...	3	
	UW And	M	236	1	
30009.....	T And	M	280	1	
	YZ And	M	208	1	
10005.....	T Psc	SR	258	1	
30012.....	TU And	M	316	1	
30015.....	RW And	M	429	1	
	V And	M	258	3	
	RR And	M	328	1	
	W Psc	M	189	1	
30021.....	...	...	...	1	
	UX Psc	SR	300	1	
	X Psc	M	353	1	
	VW Psc	SR	310	2	
10013.....	...	...	...	1	
	TZ Psc	M	376	1	
	U Psc	M	173	1	
	RX Psc	M	281	2	
	T Tri	M	322	1	
10025.....	...	...	...	2	
	Z Tri	M	216	2	
	S Ari	M	292	1	
20045.....	...	...	...	1	
20046.....	...	...	...	2	
30049.....	...	...	...	2	
20049.....	T Ari	M	324	2	
10034.....	...	...	...	2	
30055.....	...	...	...	2	
20052.....	...	...	...	2	
	RT Ari	M	264	2	
	Z Ari	M	345	2	
10040.....	U Ari	M	371	2	
	UU Tau	M	215	2	
	UY Tau	M	334	2	
	UV Tau	M	333	2	
	TZ Tau	M	269	2	
10061.....	S Tau	M	373	2	
20082.....	...	...	...	2	
10066.....	RX Tau	M	335	2	
10068.....	BZ Tau	SR	400	2	
	DG Ori	M	450	2	
10087.....	BK Ori	M	335	2	
30123.....	AW Aur	M	695	2	
	AW Tau	M	690	2	
	BE Tau	SR	500	2	
	BO Aur	SR	1000	2	
10153.....	V CMi	M	366	3	1
10162.....	ZZ CMi	SR	500	3	1
10167.....	S CMi	M	332	3	
	T CMi	M	319	3	
10171.....	U CMi	M	410	1	
	S Gem	M	294	1	
	BE Gem	M	404	1	
30195.....	AU Gem	M	421	1	
20192.....	XY Gem	M	340	1	
	SU Cnc	M	381	1	
	VW Cnc	M	366	1	
	RR Cnc	M	298	1	
20198.....	RX Cnc	SR	120	1	
10185.....	R Cnc	M	362	1	
	SZ Cnc	M	315	1	
	X Lyn	M	321	3	
	U Cnc	M	305	1	
10192.....	UY Cnc	M	229	1	
30208.....	W Cnc	M	393	3	1
	TW Leo	M	309	1	
	RS Leo	M	208	1	
10216.....	...	...	...	1	
	S LMi	M	234	1	1
40213.....	U LMi	SR	272	3	
	SV Leo	M	307	1	
20217.....	...	...	...	1	1
30219...	...	...	...	1	
10233.....	VV Leo	SR	181	1	
20225.....	...	...	...	3	
	YZ Leo	M?	...	1	
	TZ Leo	M	354	1	
20229.....	AF Leo	SR	107	1	
10241.....	...	...	...	1	
	AO Leo	M?	150	1	
10242.....	ZZ Leo	SR	148	1	
00210.....	...	...	...	1	
	SU Vir	M	210	1	
20239.....	SY Com	SR	176	1	
30239.....	T CVn	M	290	1	
	CV Vir	M	146	1	
30241.....	...	...	...	1	
10256.....	R Vir	M	146	1	
	U Vir	M	207	1	
20257.....	...	...	...	1	
10274.....	...	...	...	1	1
	WZ Vir	SR	130	1	
	RT CVn	M	254	1	1
	Z Boo	M	281	1	1
	AO Vir	M	256	1	
30257.....	RX Boo	SR	...	3	
	AP Vir	M?	330	1	1
30260.....	R Boo	M	223	3	
30261.....	RV Boo	SR	137	3	1
10290.....	S Ser	M	367	1	
00268.....	WW Ser	M	368	3	
	RU CrB	SR	436	3	2
20285.....	R Ser	M	357	3	
	U Ser	M	238	3	
30283.....	RU Her	M	485	3	2
10310.....	UV Her	M	342	3	1
	VX Her	M	300	3	
20314.....	BG Her	M	348	3	3
00298.....	UY Oph	M	332	3	
	Z Oph	M	348	3	
	V393 Oph	M	426	3	3
	V769 Oph	SR	400	3	
20328.....	MW Her	M	449	3	
	KU Oph	M	382	2	
10352.....	V454 Oph	SR	655	3	
10354.....	BC Oph	M	307	2	
	R Equ	M	260	1	1
	BH Vul	M	409	2	
20506.....	SW Peg	M	396	1	
20507.....	BM Peg	M	426	1	
	BL Vul	M	414	1	
20517.....	VX Peg	SR	934	1	1
10504.....	TU Peg	M	322	1	1
30479.....	CT Peg	SR	357	1	1
30481.....	TW Peg	SR	956	1	
10511.....	T Peg	M	374	1	1
10514.....	RS Peg	M	413	1	
10519.....	...	...	...	1	
30495.....	...	...	...	1	
20532.....	SS Peg	M	416	1	
20534.....	BC Peg	SR	125	1	1
30498.....	BD Peg	SR	78	1	
	EX Peg	SR	337	1	1
	SX Peg	M	307	2	
	GI Peg	M	222	3	
20542.....	BI Peg	SR	500	1	
30503.....	...	...	...	3	
	RW Peg	M	208	3	
30509.....	W Peg	M	344	1	
30514.....	...	...	...	3	
	FF Peg	M	252	1	
30515.....	...	...	...	1	
	DL Peg	M	180	1	1
30520.....	DU Peg	M	161	1	
30522.....	Z Peg	M	325	1	
	YY And	M	230	1	
	RR Psc	M	271	1	

* Lines sought: 1, 1612 MHz and 1665/1667 MHz. 2, 1612 MHz only. 3, 1665/1667 MHz only.

† Comments: 1. Also observed at 1665/1667 MHz during 1976 September. 5 σ detection limit 0.07 Jy; 2. 1665/1667 MHz detection limit 0.07 Jy; 3. Observed only at 1665/1667 MHz during 1976 September. Detection limit 0.07 Jy.

TABLE 3

SOME KNOWN OR SUSPECTED OH/IR STARS

			1612 MHz		1665 MHz		1667 MHz	
IRC	NAME	DATE	V_{LSR} (km s^{-1})	Peak Flux (Jy)	V_{LSR} (km s^{-1})	Peak Flux (Jy)	V_{LSR} (km s^{-1})	Peak Flux (Jy)
10011......	...	1/76	+26	4.9	+26	< 0.1	+26	1.6
			−10	6.4	−10	0.2	−10	1.3
	...	9/76	...	n.o.	+26	< 0.1	+26	2.2
					−10	0.2	−10	1.2
	R Ari	1/76	...	n.o.	...	< 0.1	...	< 0.1
20082......	...	1/76	...	< 0.1	...	n.o.	...	n.o.
30215......	R LMi	1/76	...	< 0.2	0	< 0.1	+4	0.4
					−4	0.6	−4	0.6
	...	9/76	...	n.o.	0	0.4	+4	0.4
					−4	0.7	−4	0.6
10215......	R Leo	1/76	...	< 0.2	...	< 0.1	...	< 0.1
	...	9/76	...	n.o.	+3	1.2	+4	1.5
10234......	W Leo	1/76	...	< 0.2	+53	0.05	+53	0.1
	...	9/76	...	n.o.	+54	0.1	+54	0.15
					+43	0.05	+43	0.10
00243......	RS Vir	1/76	−10	1.1	...	< 0.1	−10	0.3
			−18	0.3	...	...	−18	0.05
30272......	S CrB	1/76	...	n.o.	+3	2.4	+2	2.3
					−3	0.7	−3	1.2
20281......	WX Ser	1/76	...	n.o.	+12	0.15	+14	0.1
					0	0.9	−1	1.0
10342......	RT Oph	1/76	...	< 0.15	−15	0.1	−13	0.3
					−23	0.1	−23	0.1
10365......	...	1/76	−48	0.1	...	n.o.	...	n.o.
30492......	RV Peg	1/76	...	< 0.15	−21	0.15	−21	0.15
					−32	0.15	−30	0.15
10527......	R Peg	1/76	...	< 0.2	+28	0.4	+30	0.4
					+21	0.4	+20	0.7

must be significantly lower than any known OH Mira variable of similar period and at least three orders of magnitude lower than the brightest OH Mira variable of similar period. Of course, the phase dependence of OH flux from Mira variables should be kept in mind. Some of the non-OH Mira variables may be detectable if observed at different phases. The mingling of OH and non–OH stars is not, of course, confined to the luminosity-period diagram. At the present time there does not seem to be any very successful means of distinguishing OH and non–OH IR stars on the basis of their optical characteristics, although weak criteria based on light-curve shape (Bowers and Kerr 1977) and infrared color (Fillit, Foy, and Gheudin 1973) have been developed.

Although the detection limit of this survey was considerably lower than the detection limits of previous surveys, only six of 154, or 4%, of the stars examined showed OH emission. This suggests that more complete surveys of IR stars are unlikely to discover large numbers of new OH sources. Although the stars selected for observation in this survey tended, as in previous surveys, to be the ones most likely to be OH emitters (that is, long-period late spectral type), most of the known Mira and semiregular variables located between 0° and 38° in declination and in the ranges of right ascension $7^h\!.5$ to $15^h\!.5$ and 21^h to $1^h\!.5$ were examined. When the list of stars observed in this survey is added to those of previous surveys, it is found that in those two regions nearly 90% of the known Mira and semiregular variables which are brighter than about 12th visual magnitude at maximum light have now been examined. Of these, only 12 (R Com, T Com, S CrB, R Leo, W Leo, R LMi, R Peg, RV Peg, UU Peg, WX Ser, RS Vir, and RT Vir), or about 10%, have been found to show OH emission. The distribution in minimum magnitude for the stars surveyed and for those found to be OH emitters in the two regions are given in Table 4. The fraction of OH emitters seems to be nearly constant for stars brighter than 12th mag. The failure to detect

TABLE 4

OH AND NON–OH STARS BETWEEN 0° AND 30° DECLINATION AND IN THE RIGHT ASCENSION RANGES $7^h\!.5$ TO $15^h\!.5$ AND 21^h to $1^h\!.5$

Apparent Magnitude at Maximum Light	Number of Stars Surveyed	Number of OH Emitters	Percentage of OH Emitters
4–6..........	3	1	33
6–8..........	26	3	12
8–10.........	48	5	10
10–12.........	28	3	11
12–14.........	13	0	0
14–16.........	2	0	0
Total.......	120	12	

OH emission from fainter stars may be, in part, a consequence of the distribution of main-line peak luminosities among (nonsupergiant) IR stars. For example, a Mira variable with $m_v = 12$ would require a main-line peak luminosity of about 10^{14} W Hz^{-1} to have been detected in this survey. As seen in Figure 1, only about 20% of the known OH Mira variables have main-line peak luminosities of 10^{14} W Hz^{-1} or greater. In contrast, all of the known main-line OH Mira variables would have been detected if they lay at distances which would make them 8th mag stars in the visual at maximum light.

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