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Water maser emission from southern *IRAS* sources

Shuji Deguchi *Nobeyama Radio Observatory, National Astronomical Observatory, Minamimaki, Minamisaku, Nagano 384-13, Japan*

Yoshikazu Nakada *Department of Astronomy, University of Tokyo, Bunkyo-ku, Tokyo 113, Japan*

J. R. Forster *Division of Radiophysics, CSIRO, Australia Telescope, Paul Wild Observatory, PO Box 94, Narrabri, NSW 2390, Australia*

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Summary. We have searched for water maser emission in 112 bright, southern *IRAS* sources and have detected it in 27 cases. These sources include M-type stars and previously unidentified *IRAS* objects. The detection rate is discussed with reference to *IRAS* low-resolution spectral (LRS) class and the (60–25) μm colour index. Water maser emission was detected in three sources which have LRS class 4n, indicating the presence of 11-μm SiC emission. The oxygen/carbon-richness of the circumstellar envelopes of these sources is discussed, and it is concluded that these sources are probably M-type stars whose LRS class is misassigned.

1 Introduction

Emission from molecules at radio frequencies provides a useful probe into the chemical composition of the circumstellar envelopes surrounding late-type stars. A number of *IRAS* sources have been identified as being oxygen-rich stars from the detection of H_2O maser emission at 22 235 MHz and from OH emission at 1612 MHz (Engels *et al.* 1984; Zuckerman & Lo 1987; Eder, Lewis & Terzian 1988). Such studies are helped by the fact that the far-infrared colours are a useful indicator of the likelihood of detecting OH and H_2O maser emission (Lewis & Engels 1988). Carbon-rich stars have been identified in the radio by the detection of thermal emission from HCN and CO (Leahy, Kwok & Arquilla 1987; Nguyen-Q-Rieu *et al.* 1988). For *IRAS* sources in which low-resolution spectra have been obtained at 8–23 μm, band features at 10, 11 and 18 μm are used for determining the carbon or oxygen richness of the objects (*IRAS* Science team 1986). The type of star inferred from *IRAS* spectra, however, is not always consistent with other classifications. Some stars which had been identified optically as carbon stars exhibit the 10 and 18 μm silicate features, characteristic of an oxygen-rich envelope (Willems & de Jong 1986). The detection of H_2O emission at 22 235 MHz has confirmed that the circumstellar envelopes of some of these carbon stars are indeed oxygen-rich (Benson & Little-Marenin 1987; Nakada *et al.* 1987).

Searches for OH maser emission at 1612 MHz have been made towards southern infrared objects by Caswell *et al.* (1981), and Dollery, Gaylard & Cohen (1987). An extensive OH survey was recently undertaken by te Lintel-Hekkert *et al.* (private communication) which includes about 800 *IRAS* sources. A near-infrared survey of southern stellar sources has been performed by Epchtein *et al.* (1987). The aim of our search for H_2O maser emission towards southern infrared objects is to explore different classes of *IRAS* sources, and to look for chemically peculiar objects. A related survey for H_2O emission from carbon stars with silicate features has been recently published (Nakada, Deguchi & Forster 1988). Some of the objects in the current study have been searched for OH emission, and some are optically identified stars not previously observed at radio wavelengths. We find that H_2O emission occasionally occurs in stars with A or K types, and also in *IRAS* sources with class 4n, neither of which are expected to have water in their envelopes. These sources may have been misclassified in previous catalogues, or they may be inherently chemically peculiar. In this paper we present the results of the survey and discuss individually some of the sources toward which we have detected water emission.

2 Observations and results

Observations of the 6_{16}–5_{23} transition of H_2O at 22235.08 MHz were made on 1987 November 9–12, with the 64-m Parkes radio telescope. Only the inner 44-m section of the dish was illuminated, resulting in a FWHM beamwidth of about 80 arcsec. A single-channel maser receiver was used, and the system temperature was between 75 and 120 K depending on the weather and elevation angle. The Parkes 1024-channel digital autocorrelator was configured to provide three overlapping bands of 10 MHz each, covering a total of 24 MHz (320 km s^{-1}). The velocity resolution of the central 10-MHz section was 0.5 km s^{-1} after Hanning smoothing.

The observations were made by switching between the source position and reference position (7 arcmin offset) every 2 s. The on-source integration time was typically 15 min. The maximum pointing error is about 35 arcsec, based on observations of masers with accurately known positions. The amplitude scale was calibrated assuming a peak flux density of 20 Jy for Virgo A, and the amplitudes have been corrected for atmospheric extinction and antenna efficiency as a function of zenith angle.

Measurements were made at the positions of *IRAS* point sources with declination below 0°, and whose 12-μm flux in the LRS is above 10^{-12} W m^{-2}. In addition we have included RV Tau variables, and M stars with LRS class 4n (Othman *et al.* 1988). The results are summarized in Tables 1 and 2, and the spectra for detected sources are shown in Figs 1–25 (except for carbon stars, MC79-11 and C2123, which are in Nakada *et al.* 1988). The characteristics of a few individual sources for which other information is available are discussed below.

IRC-30023: The H_2O spectrum from this source is shown in Fig. 1. It exhibits double peaks at $V_{lsr} = -16$ and -4 km s^{-1}, typical of maser emission from expanding circumstellar envelopes. The near-infrared spectrum of this source has been obtained by Bouchet & Le Bertre (1985) and it is consistent with the *IRAS* LRS class of 29. An SiO maser has been detected in this source (Ukita, private communication). The visual magnitude of this star is about 10 mag at the maximum, with a period of 500 d. The total luminosity is 7×10^3 $L_\odot$ and the mass loss rate of grains is 1.7×10^{-7} $M_\odot$ yr^{-1} (Bouchet & Le Bertre 1985).

W Hor = HD 17271: The H_2O spectrum is shown in Fig. 2. The spectrum exhibits triple peaks centred at $V_{lsr} = 3$ km s^{-1}. According to the *General Catalogue of Variable Stars* (Kukarkin *et al.* 1969), this star is a semi-regular variable with period 137 d and spectral type M.

Table 1. Sources with H_2O maser emission.

Source Name	LRS-class	R. A. (1950)	Decl.	V_{1sr}	H_2O Flux Density peak	integrated
		h m s	° ' "	(km s^{-1})	(Jy)	(Jy km s^{-1})
IRC-30023	29	02 35 11.4	-27 11 37	-4	43	147
W Hor	22	02 42 42.0	-54 30 44	3	55	100
IRAS03074-8732	27	03 07 24.7	-87 32 09	0	14	66.5
U Men	24	04 14 00.8	-81 58 53	18	48	87.6
SVS01835	27	05 05 17.6	-84 20 21	-6	1.5	1.3
AFGL5201	32	06 31 58.3	-05 01 13	-61	9.7	17.7
SVS03731	27	07 44 38.5	-32 10 54	28	51	185
HU Pup	28	07 53 38.6	-28 30 55	44	44	142
MC79-11	65	08 57 45.6	-60 35 54	42	25	39.9
SVS04485	28	09 23 35.7	-23 47 37	13	2.5	3.7
C2123	27	13 44 17.7	-61 09 30	-63	61	463
IRAS13527-6117	43	13 52 45.5	-61 17 28	-58	18	19.3
IRAS14582-5926	42	14 58 17.2	-59 26 28	-55	16	143
IRAS15027-5959	27	15 02 46.2	-59 59 10	-56	18	84
IRAS15099-5509	26	15 09 56.8	-55 09 29	-19	2.7	4.5
IRAS15287-5811	27	15 28 47.7	-58 11 02	-62	64	136
IRAS15568-4513	29	15 56 50.6	-45 13 52	8	7.6	7.3
IRAS16222-4738	27	16 22 16.8	-47 38 19	-13	8	11.2
IRAS16292-5004	28	16 29 12.6	-50 04 37	1	18	44.0
IRAS16460-4022	36	16 46 05.9	-40 22 28	-42	5.7	18.3
IRAS17187-3750	26	17 18 46.2	-37 50 21	-26	9.3	45.9
OCL1021	29	17 32 53.5	-33 27 50	-14	5.2	4.7
IRC+00363	27	18 38 46.2	-04 23 30	42	55	364
IRAS18467-4802	22	18 46 42.9	-48 02 42	-56	6.6	9.0
AFGL5552	26	18 59 34.5	-39 47 22	22	5.4	33.0
FQ Sgr	41	19 04 43.1	-17 06 05	7	2.5	7.1
IRAS20541-6549	29	20 54 07.9	-65 49 54	-18	5.0	27.8

IRAS *03074-8732:* This source lies near the south celestial pole. The spectrum (Fig. 3) is composed of broad emission covering about 5 km s^{-1} centred at $V_{1sr}=2$ km s^{-1}, and a weak narrow peak at $V_{1sr}=18$ km s^{-1}.

U Men: The spectrum is shown in Fig. 4. A broad feature is seen from $V_{1sr}=11$ to 21 km s^{-1}.

Table 2. Sources without detectable H_2O emission.

Source Name	LRS-class	R. A. (1950)	Decl.	R.M.S.
		h m s	° ' "	(Jy)
IRAS00193-4033	28	00 19 19.3	-40 33 51	0.4
R Scl		01 24 40.0	-32 48 07	0.2
o Cet		02 16 49.0	-03 12 13	0.6
V Eri		04 02 01.6	-15 51 38	0.2
V535 Ori	43	05 20 52.3	-04 36 58	0.4
IC418	91	05 25 09.5	-12 44 18	0.4
V883 Ori	71	05 35 53.3	-07 04 07	0.4
17 Lep	25	06 02 45.0	-16 28 48	0.4
S Lep	26	06 03 41.9	-24 11 24	0.5
IRC-20101	23	06 39 08.3	-22 13 47	0.2
CN CMa	14	06 40 16.3	-18 57 51	0.5
Z CMa	31	07 01 22.0	-11 28 35	0.3
HN Mon	29	07 02 07.6	-08 52 40	0.6
AFGL 1099	29	07 15 15.8	-34 44 12	0.5
U Mon	26	07 28 24.2	-09 40 14	0.4
IRAS07376-2827	29	07 37 40.8	-28 27 18	0.4
HR3017	22	07 43 28.3	-37 50 46	0.5
C1003	27	08 00 17.0	-38 03 30	0.2
AR Pup	23	08 01 09.2	-36 26 46	0.4
IRAS08074-3615	22	08 07 28.1	-36 15 35	0.6
RX Pup	45	08 12 28.2	-41 33 18	0.5
AFGL5250	22	08 17 06.9	-21 34 47	0.4
EP Vel	26	08 40 04.5	-47 55 58	0.3
IRAS08571-5901	25	08 57 08.5	-59 01 28	0.7
IRAS09003-5437	26	09 00 23.4	-54 37 10	1.6
WY Vel	28	09 20 21.0	-52 20 58	0.7
IRAS09425-6040	50	09 42 35.2	-60 40 34	0.3
IRC-20197	28	09 42 58.3	-21 48 05	1.5
IRAS09448-4748	04	09 44 51.0	-47 48 00	0.3
IRAS09593-5540	42	09 59 20.2	-55 40 55	0.6
AFGL4767	64	10 02 49.6	-58 25 13	0.6
C1633	22	10 09 06.4	-70 49 25	0.3
HR4049	80	10 15 50.1	-28 44 32	0.3
EV Car	29	10 18 38.0	-60 12 09	0.8
IRAS10323-5735	28	10 32 22.4	-57 35 51	0.3
IRAS10323-4611	24	10 32 22.9	-46 11 57	0.4
IRAS10359-5955	29	10 35 55.6	-59 55 58	0.6

Table 2 – continued.

Source Name	LRS-class	R. A. (1950)	Decl.	R.M.S.
		h m s	° ' "	(Jy)
IRAS10379-5817	25	10 37 58.2	-58 17 23	0.6
IRAS10394-5747	26	10 39 27.9	-57 47 44	0.6
V Hya		10 49 11.3	-20 59 05	0.4
IRAS11113-5949	26	11 11 20.5	-59 49 10	0.6
IRAS11179-6458	29	11 17 58.0	-64 58 38	0.6
IRAS11438-6330	38	11 43 48.8	-63 30 32	0.6
AFGL4136	22	11 46 07.8	-35 42 32	0.3
RU Cen		12 06 47.5	-45 08 51	0.4
SX Cen		12 18 32.2	-48 56 00	0.5
IRAS12384-4536	24	12 38 29.9	-45 36 58	0.3
HR5171		13 43 40.3	-62 20 25	0.4
IRAS13517-6515	24	13 51 47.6	-65 15 55	0.6
IRAS13581-5930	34	13 58 08.9	-59 30 06	0.5
IRAS14251-6256	26	14 25 07.0	-62 56 03	0.4
IRAS14531-5337	27	14 53 08.7	-53 37 38	0.4
IRAS14591-4438	26	14 59 12.0	-44 38 26	0.6
IRAS15408-5413	71	15 40 49.3	-54 13 40	0.4
HD143183	27	15 57 40.8	-54 00 12	0.6
IRAS16079-4812	42	16 07 54.9	-48 12 09	0.7
IRAS16105-4205	35	16 10 34.9	-42 05 29	0.4
IRAS16219-5048	27	16 21 54.8	-50 48 54	0.5
IRAS16327-4848	32	16 32 47.0	-48 48 34	0.8
KW Sgr	29	17 48 51.4	-28 00 40	0.3
AI Sco		17 53 00.1	-33 48 20	0.5
FJF272	22	18 00 37.1	-32 13 10	0.5
FX Ser	44	18 04 05.1	-09 41 40	0.6
Gometz's Hamberger		18 05 57.5	-32 11 20	0.7
IRC-20445	42	18 09 21.5	-21 07 19	0.8
IRC-20455	41	18 13 30.8	-17 40 08	0.7
IRC-20461	43	18 15 34.2	-15 19 26	0.7
IRAS18248-0839	43	18 24 49.7	-08 39 19	0.9
R Sct	19	18 44 48.5	-05 45 39	0.8
IRC-30398	27	18 56 02.9	-29 54 29	0.3
W Aql	22	19 12 40.5	-07 08 14	0.3
AFGL2370	26	19 17 51.4	-26 20 16	0.5
SAO163075	05	19 50 01.5	-17 09 38	0.7
S Pav	07	19 51 01.5	-59 19 38	0.7

Table 2 – continued.

Source Name	LRS-class	R. A. (1950)	Decl.	R.M.S.
		h m s	° ' "	(Jy)
RR Tel	26	20 00 20.2	-55 52 04	0.3
V2234 Sgr	28	20 04 15.7	-42 41 05	0.3
IRAS20484-7202	29	20 48 29.3	-72 02 48	0.5
RS Cap	27	21 04 28.8	-16 37 23	0.4
AFGL5592	29	21 06 57.0	-38 43 18	0.5
SAO145652	23	21 43 56.8	-02 26 39	0.3
SAO258927	23	22 14 14.8	-84 54 59	0.5
161 Gru	42	22 19 40.8	-46 12 06	0.4
IRAS22231-4529	29	22 23 09.4	-45 29 30	0.7
AFGL4293	22	22 54 03.4	-57 40 02	0.5
AFGL4296	28	23 21 22.2	-45 21 29	0.5

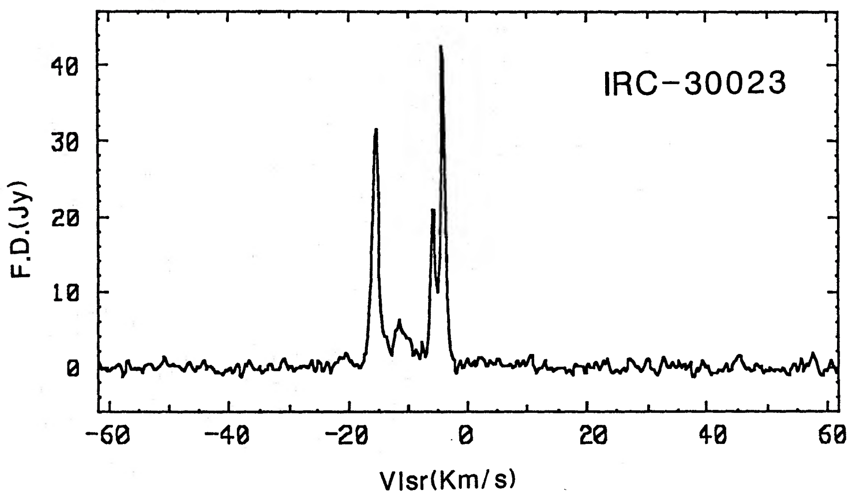

Figure 1. H_2O spectrum for IRC-30023.

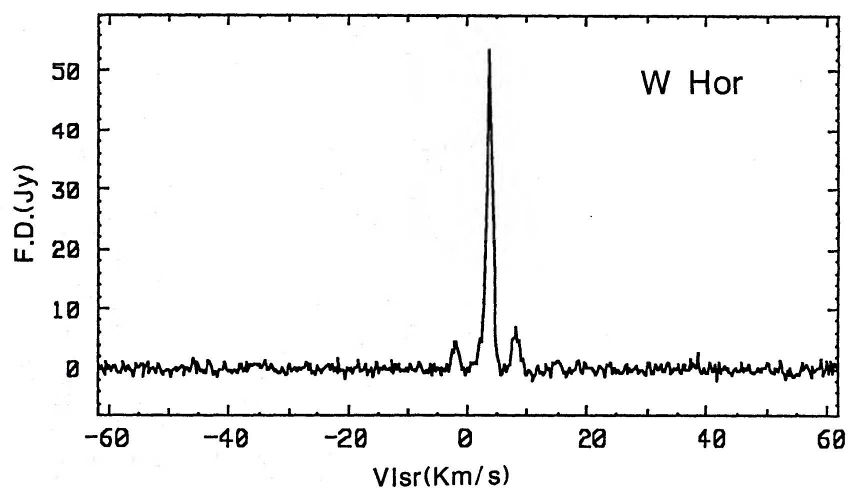

Figure 2. H_2O spectrum for W Hor.

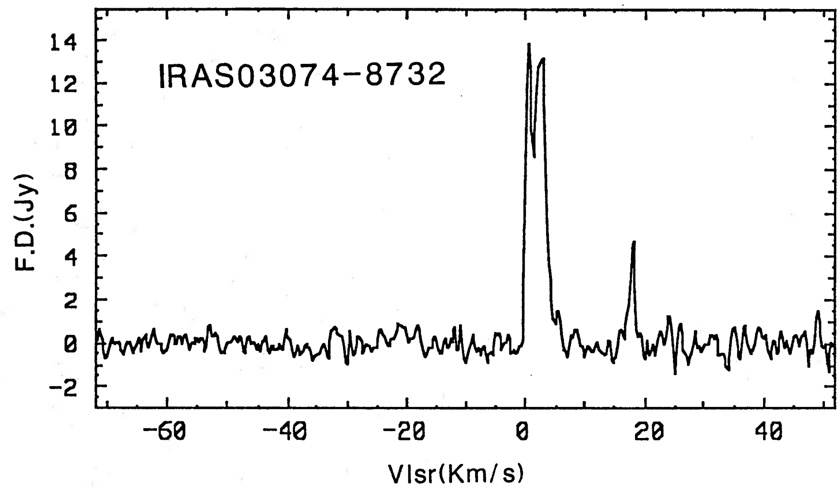

Figure 3. H_2O spectrum for *IRAS* 03074-8732.

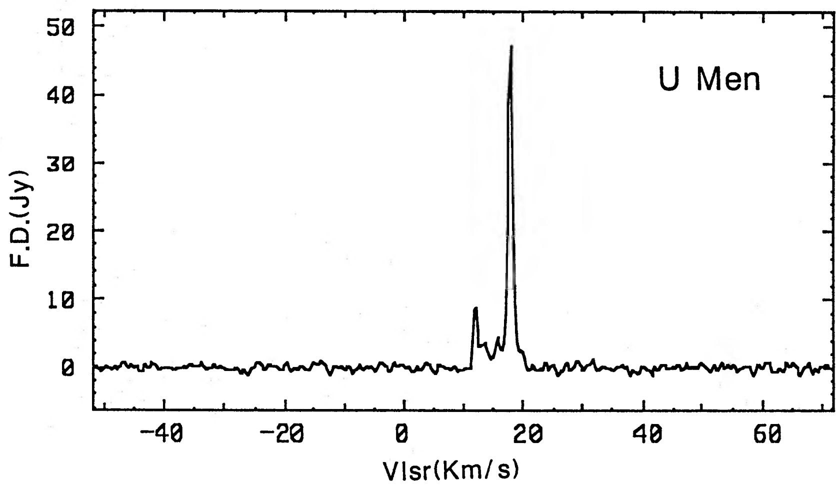

Figure 4. H_2O spectrum for U Men.

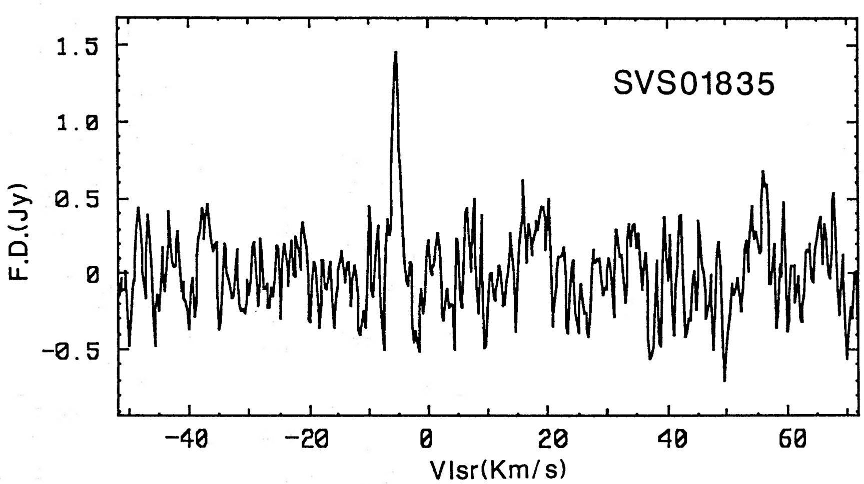

Figure 5. H_2O spectrum for SVS01835.

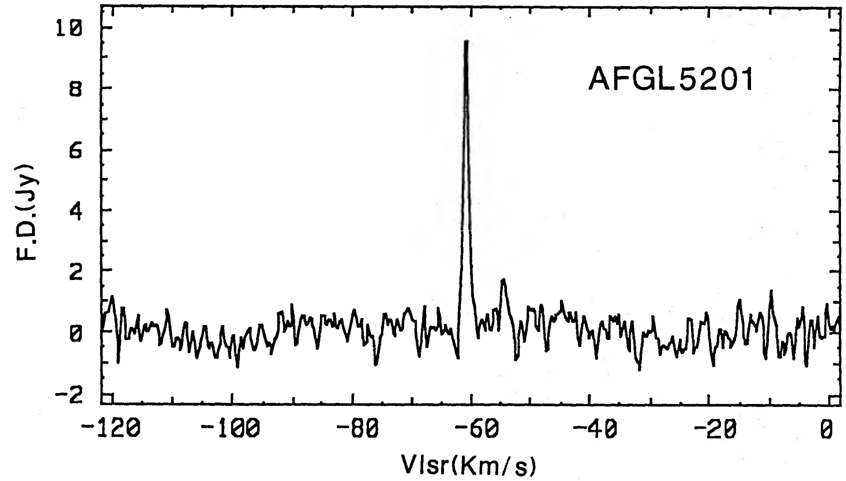

Figure 6. H_2O spectrum for AFGL5201.

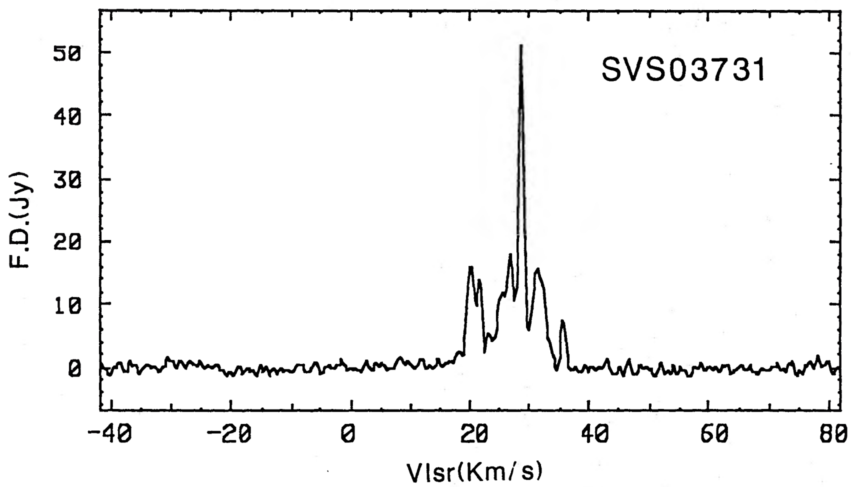

Figure 7. H_2O spectrum for SVS03731.

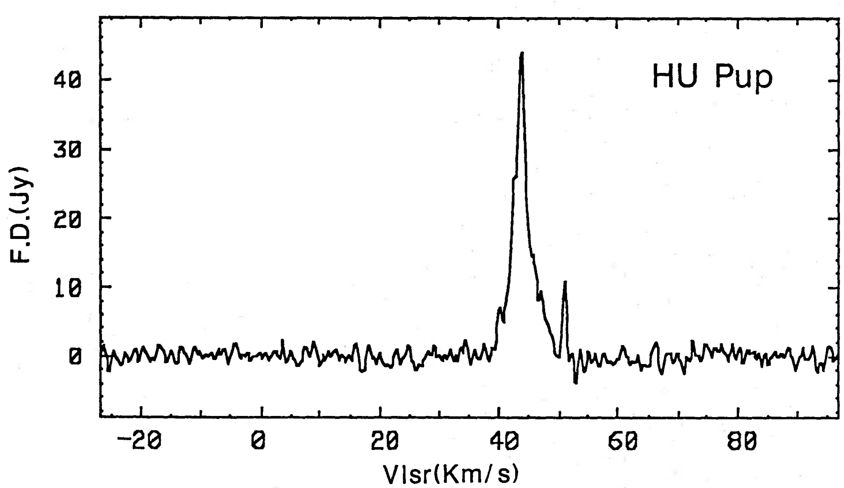

Figure 8. H_2O spectrum for HU Pup.

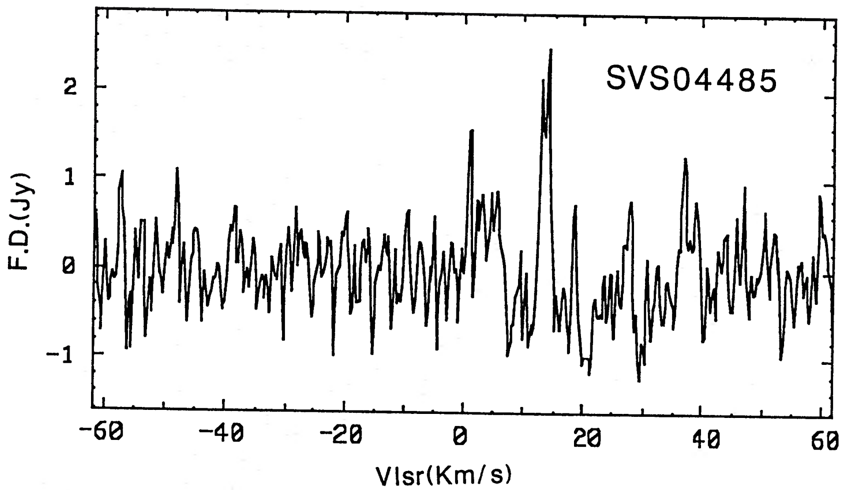

Figure 9. H_2O spectrum for SVS04485.

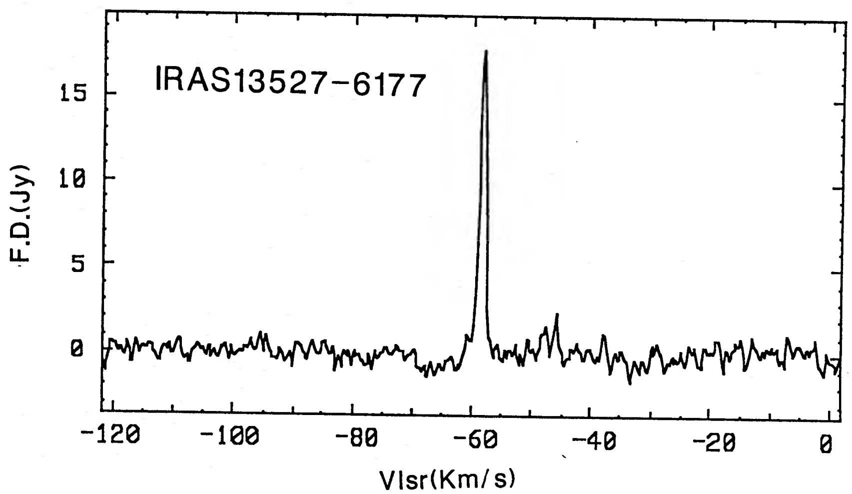

Figure 10. H_2O spectrum for *IRAS* 13527-6117.

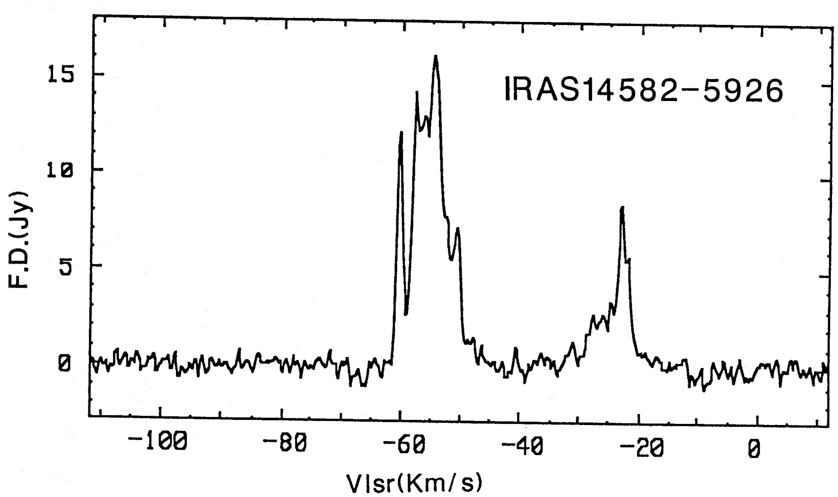

Figure 11. H_2O spectrum for *IRAS* 14582-5926.

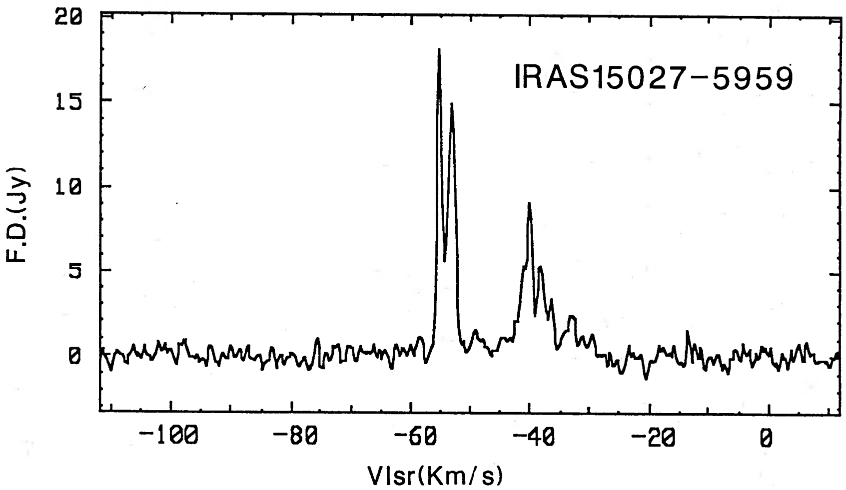

Figure 12. H_2O spectrum for *IRAS* 15027-5959.

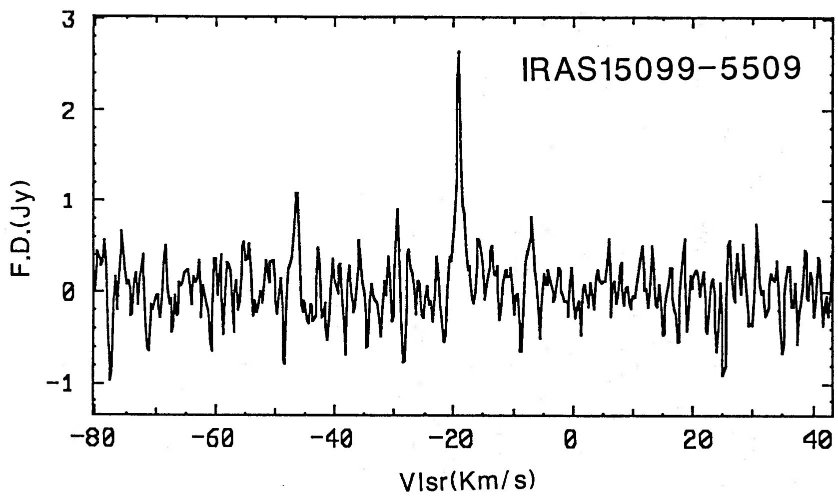

Figure 13. H_2O spectrum for *IRAS* 15099-5509.

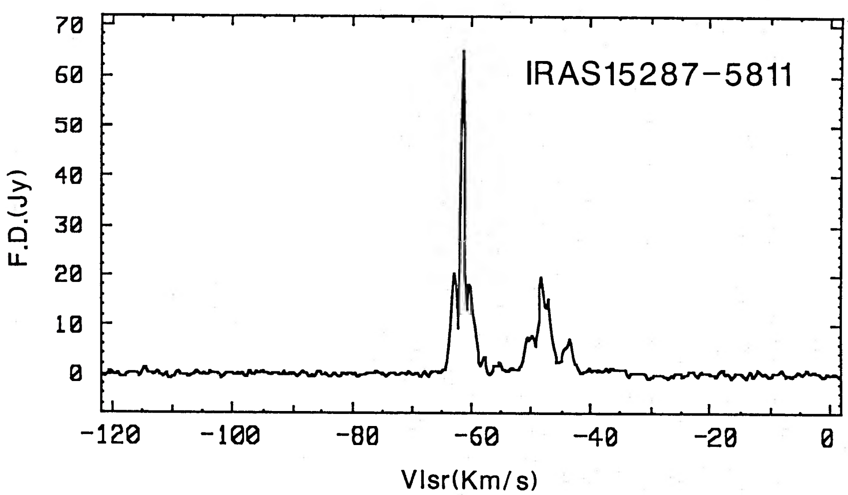

Figure 14. H_2O spectrum for *IRAS* 15287-5811.

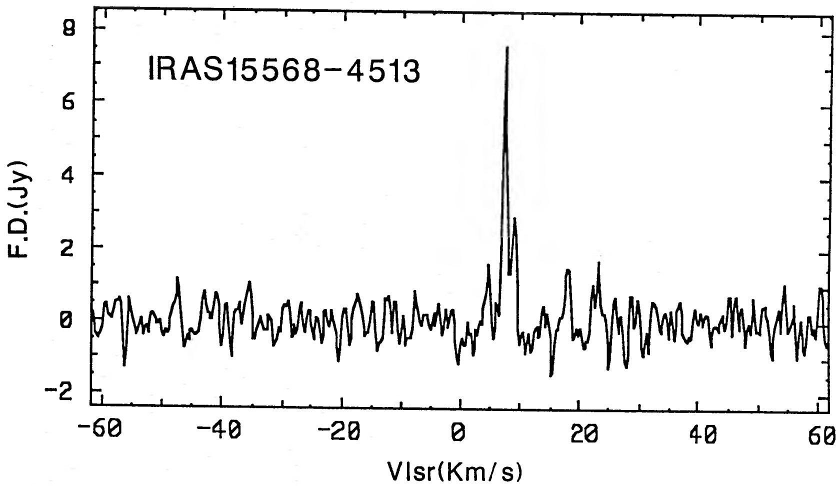

Figure 15. H_2O spectrum for *IRAS* 15568-4513.

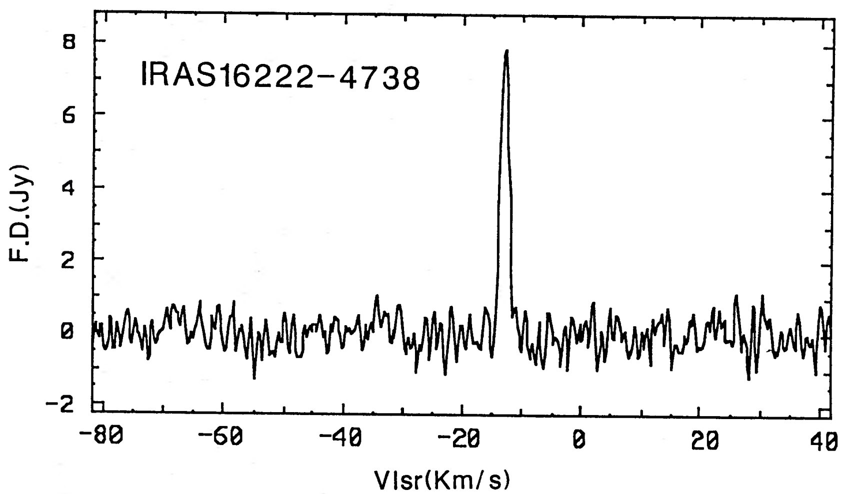

Figure 16. H_2O spectrum for *IRAS* 16222-4783.

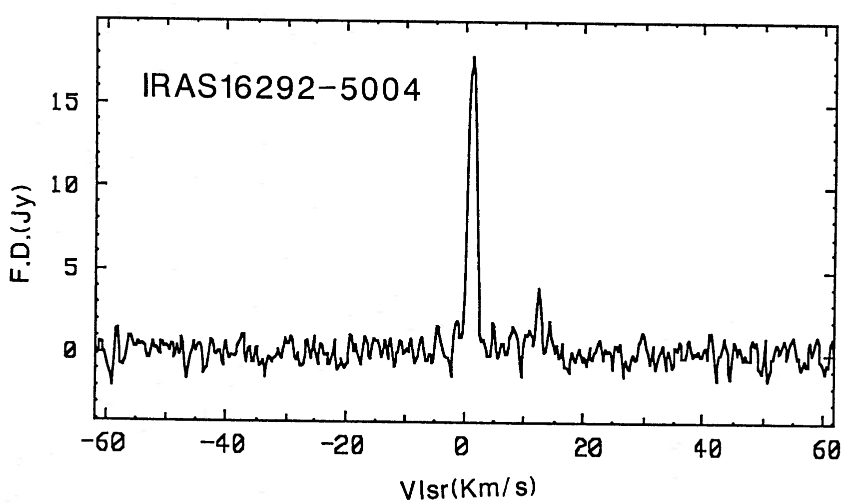

Figure 17. H_2O spectrum for *IRAS* 16292-5004.

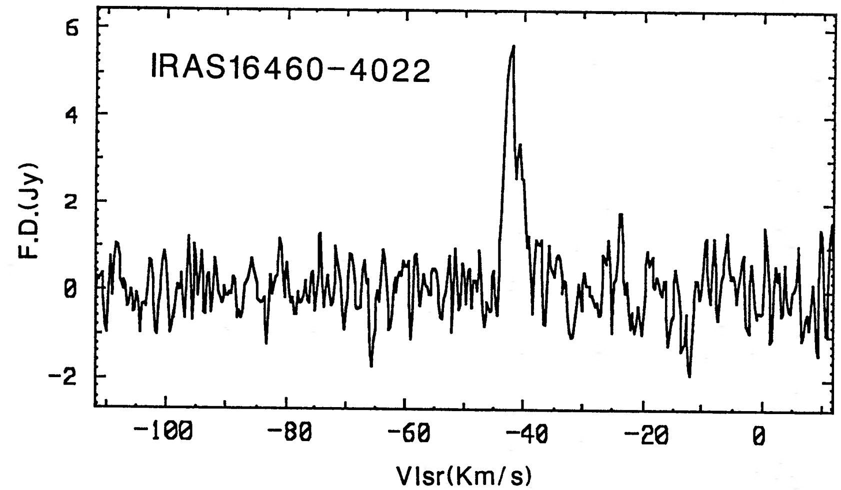

Figure 18. H_2O spectrum for *IRAS* 16460-4022.

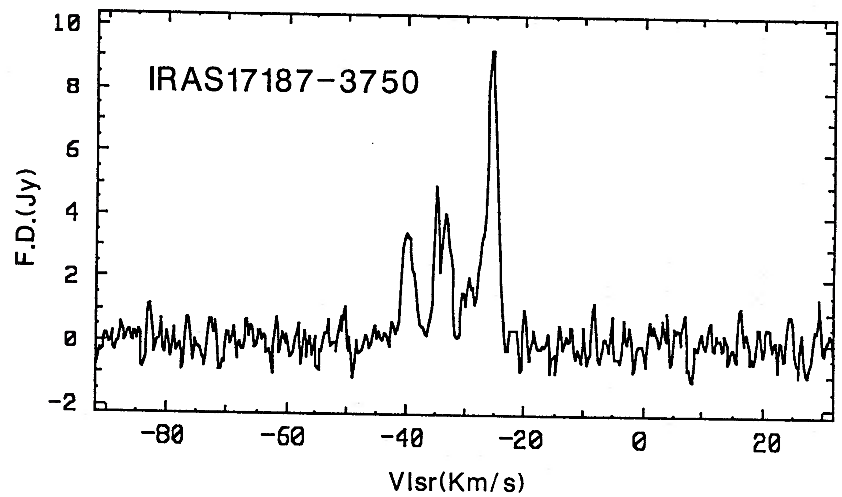

Figure 19. H_2O spectrum for *IRAS* 17187-3750.

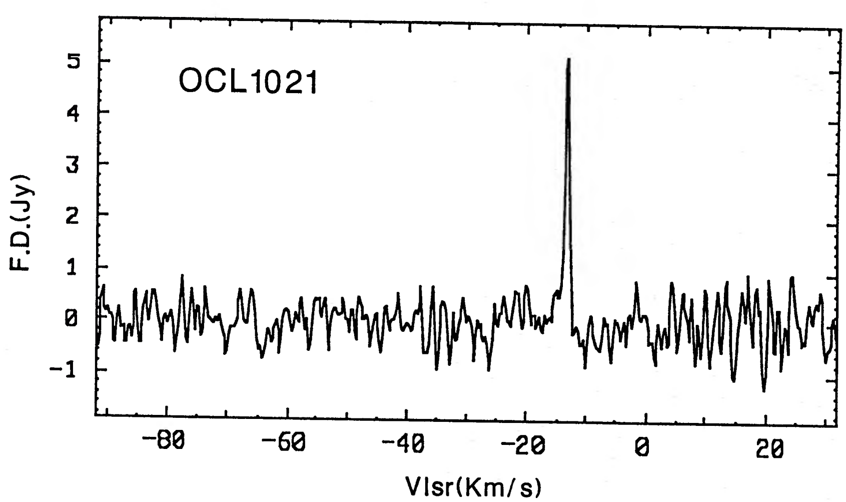

Figure 20. H_2O spectrum for OCL1021.

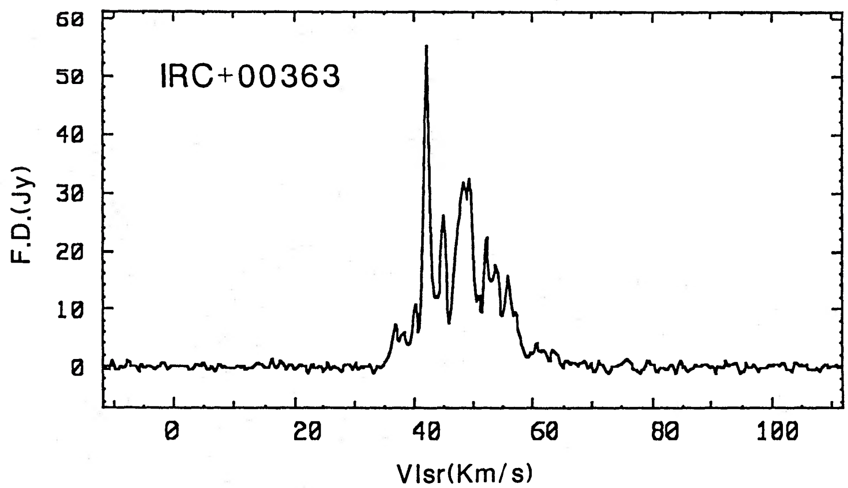

Figure 21. H_2O spectrum for IRC + 00363.

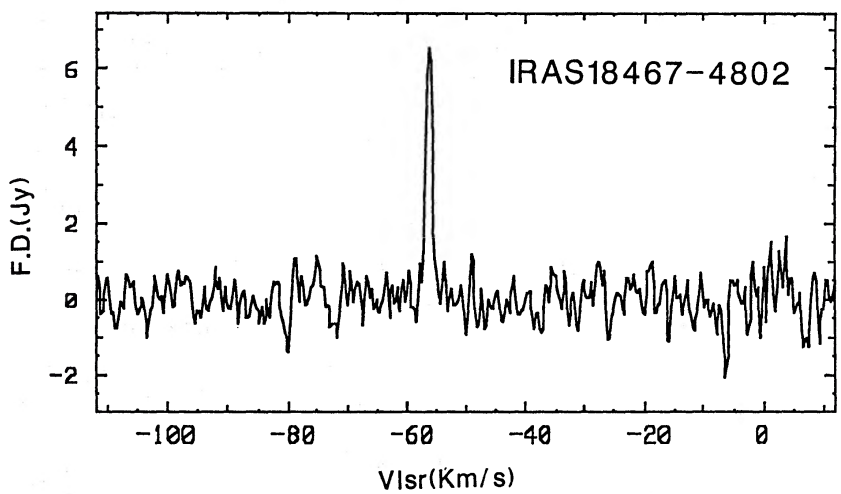

Figure 22. H_2O spectrum for *IRAS* 18467-4802.

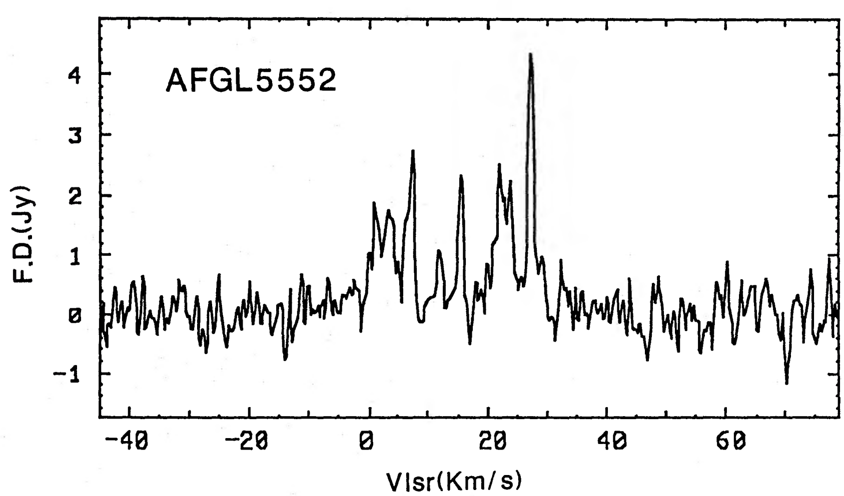

Figure 23. H_2O spectrum for AFGL5552.

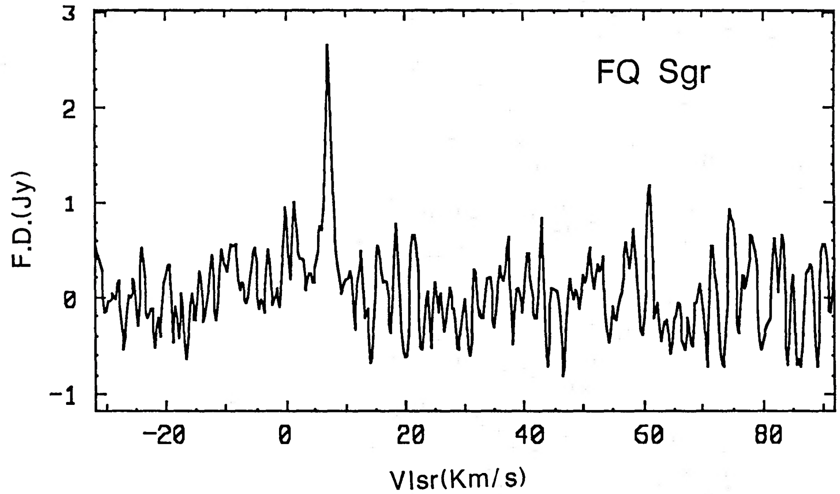

Figure 24. H_2O spectrum for FQ Sgr.

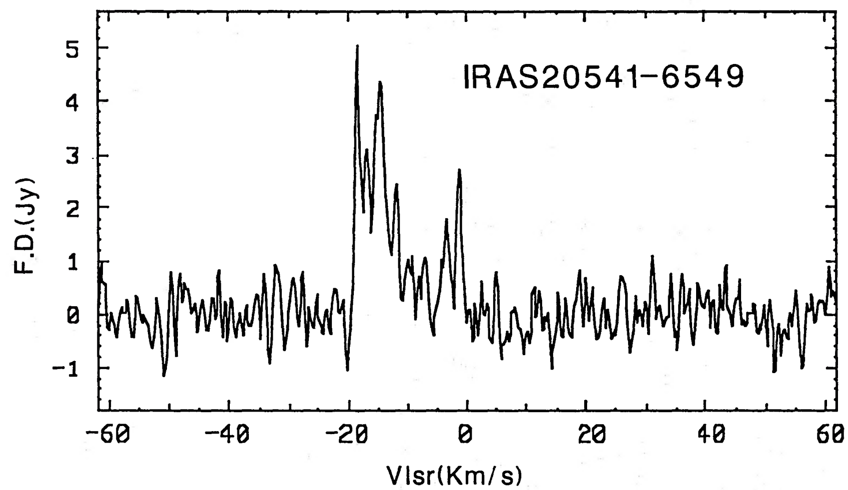

Figure 25. H_2O spectrum for *IRAS* 20541-6549.

The spectral type of this star is M3 (Kukarkin *et al.* 1969). The radial velocity of this star is measured ($V_{1sr}=16$ km s^{-1}, Feast, Woolley & Yilmas 1972). An SiO maser has been detected (Allen *et al.* 1988).

SVS01835: The H_2O spectrum is shown in Fig. 5. The optical spectral type of this star is unknown. The visual magnitude varies from 12.3 to 19.0 mag (Kholopov 1982). The detection of water maser emission suggests that it is an M-type Mira.

AFGL 5201: The spectrum is shown in Fig. 6. The *IRAS* LRS class of this star is 32, indicating silicate absorption at 10 μm. Zuckerman & Lo (1987) detected H_2O maser emission previously at $V_{1sr}=-59$ km s^{-1} in this source.

SVS03731 = IRC − 30100 = SAO 198422: The spectrum is shown in Fig. 7. It exhibits H_2O emission over 20 km s^{-1} and a strong peak at 29 km s^{-1}. The *General Catalogue of Variable Stars* (Kukarkin *et al.* 1969) assigns the spectral type as M1, but the SAO catalogue assigns the type as A0 with visual magnitude 8.7. An SiO maser has been detected (Ukita, private communication).

HU Pup = IRC − 30105 = SAO 174817 (Fig. 8): According to Kukarkin *et al.* (1969), this is a semi-regular variable with a period of 238 d and spectral type M. The SAO catalogue classifies it as K5. An SiO maser is also present (Ukita, private communication).

SVS04485 = IRC − 20188: The spectrum is shown in Fig. 9. A 2–11 μm infrared spectrum has been obtained by Merrill & Stein (1976). This star is classified as M9 (Kholopov 1982) and an SiO maser has been detected (Ukita, private communication).

OCL 1021: The spectrum (Fig. 20) exhibits a single peak at $V_{1sr} = -24$ km s^{-1}. OCL is the catalogue of open clusters and associations (Alter, Ruprecht & Vanysek 1970). The radio continuum sources (probably H II regions) G355.06-0.7 and G355.-0.71 are about 1 arcmin south of this source. The detected H_2O emission could be contamination from a source associated with an H II region. The *IRAS* LRS class of this source is 29, which suggests that it is a late-type star. Star No. 1 in the star cluster Tr 27 (in table 12 of Thé & Stokes 1970) is known to be extremely red. It is identified as CD-33°12241 and the spectral type is classified as M0Ia by Imhoff & Keenan (1976). The position of this star coincides with the *IRAS* position within 5 arcsec in right ascension and 3 arcsec in declination, and this is probably the water maser source.

IRC + 00363 = DO 16914: The spectrum is shown in Fig. 21. It shows a very symmetrical profile centred at $V_{1sr} = 48$ km s^{-1}, except for the sharp feature at $V_{1sr} = 42$ km s^{-1}. The infrared spectrum of this source (Merrill & Stein 1976) shows silicate emission at 10 μm, which is consistent with the LRS classification. An SiO maser has also been detected (Ukita, private communication).

AFGL 5552 = RS CrA: The H_2O spectrum (Fig. 23) shows a forest of weak emission from $V_{1sr} = 0$ to 30 km s^{-1}. Zuckerman & Dyck (1986) detected CO emission centred at $V_{1sr} = 17.4$ km s^{-1}, which is near the central velocity of H_2O emission from this source.

FQ Sgr: The H_2O spectrum (Fig. 24) exhibits a weak single peak at $V_{1sr} = 7$ km s^{-1}. This star is classified as M and the variability period is not known (Kukarkin *et al.* 1969). It should be noted that the *IRAS* LRS class of this star is 41 (11-μm SiC emission).

We have also detected water masers from *IRAS* 13527-6117 (Fig. 10) and *IRAS* 14582-05926 (Fig. 11) which have LRS classes of 43 and 42, respectively (11-μm SiC emission). For these sources, and for FQ Sgr, the stellar type inferred from radio and from infrared observations are contradictory.

1612-MHz OH emission has also been detected in several *IRAS* sources for which we found H_2O emission. Radial velocities in the double-peaked spectra for OH are −57 and −18 km s^{-1} for *IRAS* 14582-5926, −47 and −12 km s^{-1} for *IRAS* 16460-4022, and −59.6 and −35.4 km s^{-1} for *IRAS* 18467-4802 (Dollery *et al.* 1987). The radial velocities of H_2O emission for these sources (Figs 11, 18 and 22) are generally between the two peak velocities of OH emission. This is consistent with models of the expanding circumstellar envelopes of late-type stars (e.g. Deguchi 1977; Cooke & Elitzur 1985). 1665- and 1667-MHz OH emission has been detected in *IRAS* 16327-4848 (Cohen, Baart & Jonas 1988); we did not detect H_2O emission in this source.

We have also searched for water emission in five RV Tau variables. These stars have characteristic light curves with alternate deep and shallow minima, periods in the range 30–150 d, and spectral types F, G and K (Lloyd-Evans 1985; Goldsmith *et al.* 1987). Many of these stars have an infrared excess. The RV Tau stars in which we searched for water masers were U Mon, R Pup, RU Cen, SX Cen and AI Sco. No H_2O emission was detected towards these stars. A detection of 1612-MHz OH emission in RV Tau was reported by Fix &

Claussen (1984). The RV Tau variables are considered to be post-asymptotic giant branch stars (Jura 1986). The non-detection of H_2O from these stars may be due to a relatively small mass-loss rate, and possibly also to dissociation of H_2O by UV radiation from the warmer central stars (F, G and K type).

The other group of stars we searched are the M stars with *IRAS* LRS class 4n. These sources (taken from Othman *et al.* 1988) were V535 Ori, CN CMa, FX Ser, IRC-20445, IRC-20455, IRC-20461 and FQ Sgr. We have detected H_2O maser emission in FQ Sgr. The implications of this result will be discussed in the next section.

3 Discussion

3.1 DETECTION RATE

Table 3 summarizes the detection rate of H_2O emission according to *IRAS* LRS class. Unfortunately, the derived detection rates cannot be directly compared, due to the small number of sources observed in some classes. Nevertheless, the higher detection rates recorded for classes 2–6 suggest a preference for water emission from *IRAS* sources in this range. For *IRAS* class 2n (10-μm silicate emission) a higher number for subclass n clearly favours detection (subclass n is a measure of strength of the features). For the 21 class 2n objects in the range 21–25, the detection rate is 14 per cent; for the remaining 50 objects in the range 26–29 the detection rate is 37 per cent.

It is recognized that the colour index calculated from 60- and 25-μm fluxes is a good indicator for detecting OH/H_2O masers from *IRAS* sources (Eder *et al.* 1988). The colour indices used here are corrected for the energy distribution similar to a blackbody at 300 K, but the correction is small (about -0.035; see Eder *et al.* 1988). A colour–colour diagram for the observed sources is shown in Fig. 26. A preference for H_2O maser emission from sources with (60–25)-μm colours < -0.9 is suggested in the survey by Lewis & Engels (1988). In order to check this, we have tabulated the detection rate for colours above and below -0.9 in Table 4. We find that the detection rate is about twice as high for sources with (60–25)-μm colours

Table 3. H_2O detection rate for *IRAS* classes.

Class	Detected	Observed	Detection Rate(%)
0n	0	3	0
1n	0	2	0
2n	21	71	30
3n	2	7	29
4n	3	13	23
5n	0	1	0
6n	1	2	50
7n	0	2	0
8n	0	1	0
9n	0	1	0

< -0.9 as for those with colours > -0.9. The three sources with (60–25)-μm colours > -0.9 exhibiting H_2O emission have colours of -0.81, -0.87 and -0.87.

It is somewhat surprising that water masers are rare for sources with high colour index since it is believed that higher colour indices indicate higher mass-loss rates and the water masers are pumped by collisions. Lewis & Engels (1988) suggest that H_2O maser emission is quenched by collisional de-excitation at mass-loss rates exceeding about $10^{-5}\ M_\odot\ yr^{-1}$). Since H_2O masers are located at a radius of 10^{15} cm (Lane *et al.* 1987) and OH masers at 10^{16} cm (Chapman *et al.* 1984), OH masers may still be detected in stars whose H_2O emission has been quenched. Bedjin (1987) has suggested that the central stars of non-variable OH/IR sources are post-asymptotic giant branch stars with high surface temperatures. The inner part of the dusty envelope around these stars is sufficiently hot that water molecules are dissociated. One or both of these effects might explain the non-occurrence of water masers in high-colour-index sources.

3.2 CLASS 4n OBJECTS

IRAS objects in LRS class 4n exhibit 11-μm emission, which is thought to be due to SiC grains originating in a carbon-rich atmosphere (e.g. Baron *et al.* 1987; Gal *et al.* 1987). Objects in this

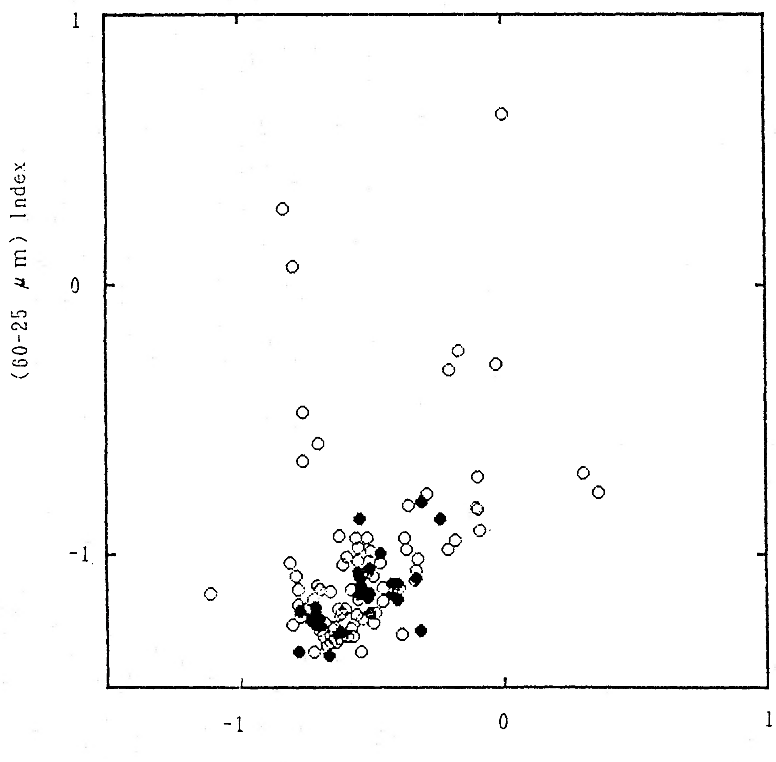

Figure 26. Colour–colour diagram for the sources with (filled circle) and without (open circle) H_2O emission.

Table 4. Detection rate for the colour index (60–25) μm.

Index (60–25) μm.	Detected	Observed	Detection Rate (%)
-0.9	3	19	16
-0.9	24	92	26

class include carbon stars and S stars. We have detected water emission in three sources with class 4n: *IRAS* 13527-6117, *IRAS* 14582-5926 and FQ Sgr. FQ Sgr is a star with optical spectral type M8e. It has been recognized that the *IRAS* class 4n objects include M-type stars (Othman *et al.* 1988; Popular 1988). Additionally, Lewis (1988) found that 1612-MHz OH emission also occurs in class 4n objects. Our detection of H_2O masers in some class 4n objects supports the contention that the circumstellar envelopes of these stars are in fact oxygen-rich. This apparently contradicts the *IRAS* LRS classification.

The *IRAS* LRS class is determined 'automatically' from low-resolution spectra. The *IRAS* Science team (1986) noted that "for the spectra with emission band just above 10 percent level the choice between main classes 2n and 4n is quite arbitrary". The *IRAS* team further noted that "spectra with self-absorption in the 9.8-micron band look very much like class 4n spectra". This is true for the spectrum of FQ Sgr (class 41) in which the 11-μm emission is just above the noise, and the apparent emission at 11 μm may be due to self-absorption of silicate grains at 9.8 μm. The feature at 18 μm due to silicate grains is not clear in FQ Sgr. For *IRAS* 13527-6117 (Class 43) and *IRAS* 14582-5926 (class 42), the emission feature at 11 μm seems stronger, but a close inspection of the spectra for these two sources leads one to recognize a weak hump at 18 μm in their low-resolution spectra. This suggests that the 11-μm emission for these sources is spurious, and the LRS classes are misassigned.

While our detection of H_2O in these class 4n sources supports the contention that oxygen-rich envelopes are present, we cannot exclude the possibility of confusion in our search for water masers towards *IRAS* sources. The Parkes telescope beam at 22 GHz is approximately 80 arcsec FWHM, and there is substantial sidelobe structure over large angles. There is thus a small probability of detecting an H_2O maser which is not associated with the *IRAS* source under investigation, particularly for sources located near the galactic plane. On the other hand, if the detected masers are associated with the *IRAS* sources, and the 11-μm features are real, these objects could be binary systems composed of a carbon star and an M star. Little-Marenin, Benson & Dickinson (1988) have discussed the possibility that carbon stars with silicate features are binary systems composed of a carbon and an M star. Water maser emission has been found toward a number of carbon stars (Benson & Little-Marenin 1987; Nakada *et al.* 1988) and the position of one water maser source in V778 Cyg is confirmed to coincide with the optical position of the star within 0.5 arcsec (Deguchi *et al.* 1988). Clearly, more observations of these chemically peculiar objects are needed to distinguish between the possibilities.

4 Conclusions

We have detected H_2O maser emission in 27 out of a sample of 112 bright, southern *IRAS* sources. The H_2O detection rate is greatest for sources with (60–25)-μm colour index -0.9, and whose LRS class is in the range 2n–6n. For sources in class 2n, the detection rate increases with the strength of the 9.8-μm silicate feature. H_2O emission was detected in three class 4n objects, which are generally held to be stars with carbon-rich envelopes. These objects may have been misclassified on the basis of their *IRAS* spectra. Alternatively, they may be binary systems containing both C and M stars, or inherently chemically peculiar objects.

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References

Allen, D. A., Hall, P. J., Norris, R. P., Troup, E. R., Wark, R. M. & Wright, A. E., 1988. Preprint.

Alter, G., Ruprecht, J. & Vanysek, V., 1970. *Catalogue of Star Clusters and Associations,* Akademiai Kaido, Budapest.

Baron, Y., de Muizon, M., Papoular, R. & Pégourié, B., 1987. *Astr. Astrophys.,* **186,** 271.

Bedjin, P. J., 1987. *Astr. Astrophys.,* **186,** 271.

Benson, P. J. & Little-Marenin, I. R., 1987. *Astrophys. J.,* **316,** L37.

Bouchet, P. & Le Bertre, T., 1985. *Messenger,* **40,** 17.

Caswell, J. L., Haynes, R. F., Goss, W. M. & Mebold, U., 1981. *Aust. J. Phys.,* **34,** 333.

Chapman, J., Cohen, R. J., Norris, R. P., Diamond, P. J. & Booth, R. S., 1984. *Mon. Not. R. astr. Soc.,* **207,** 149.

Cohen, R. J., Baart, E. E. & Jonas, J. L., 1988. *Mon. Not. R. astr. Soc.,* **231,** 205.

Cooke, B. & Elitzur, M., 1985. *Astrophys. J.,* **295,** 175.

Deguchi, S., 1977. *Publs astr. Soc. Japan,* **29,** 669.

Deguchi, S., Kawabe, R., Ukita, N., Nakada, Y., Onaka, T., Izumiura, H. & Okamura, S., 1988. *Astrophys. J.,* **325,** 795.

Dollery, M. E., Gaylard, M. J. & Cohen, R. J., 1987. *IAU Symp. No. 122,* p. 215, eds Appenzeller, I. & Jordon, C., Reidel, Dordrecht.

Eder, J., Lewis, B. M. & Terzian, Y., 1988. *Astrophys. J. Suppl.,* **66,** 183.

Engels, D., Habing, H. J., Olnon, F. M., Schmit-Burgk, J. & Walmsley, C. M., 1984. *Astr. Astrophys.,* **140,** L9.

Epchtein, N., Le Bertre, T., Lepine, J. R. D., Marques dos Santos, P., Matsuura, O. T. & Picazzio, E., 1987. *Astr. Astrophys. Suppl.,* **71,** 39.

Feast, M. W., Woolley, R. & Yilmas, N., 1972. *Mon. Not. R. astr. Soc.,* **158,** 23.

Fix, J. D. & Claussen, M. J., 1984. *Astrophys. J.,* **287,** L35.

Gal, O., de Muizon, M., Papoular, R. & Pégourié, B., 1987. *Astr. Astrophys.,* **183,** 29.

Goldsmith, M. J., Evans, A., Albinson, J. S. & Bode, M. F., 1987. *Mon. Not. R. astr. Soc.,* **227,** 143.

Imhoff, C. L. & Keenan, P. C., 1976. *Astrophys. J.,* **205,** 455.

IRAS Science Team, 1986. *Astr. Astrophys. Suppl.,* **65,** 607.

Jura, M., 1986. *Astrophys. J.,* **309,** 732.

Khopolov, P. N., 1982. *New Catalogue of Suspected Variable Stars,* Nauka, Moscow.

Kukarkin, B. V., Khopolov, P. N., Efremov, U. N., Kukarkina, N. P., Kurochkin, N. E., Medveda, G. I., Perova, N. B., Fedorovich, V. P. & Frolov, M. S., 1969. *General Catalogue of Variable Stars,* 3rd Edn, Nauka, Moscow.

Lane, A. P., Johnston, K. J., Bowers, P. F., Spencer, J. H. & Diamond, P. J., 1987. *Astrophys. J.,* **323,** 756.

Leahy, D. A., Kwok, S. & Arquilla, R. A., 1987. *Astrophys. J.,* **320,**825.

Lewis, B. M., 1988. Preprint.

Lewis, B. M. & Engels, D., 1988. *Nature,* **332,** 49.

Little-Marenin, I. R., Benson, P. J. & Dickinson, D. F., 1988. *Astrophys. J.,* **330,** 28.

Lloyd-Evans, T., 1985. *Mon. Not. R. astr. Soc.,* **217,** 493.

Merrill, K. M. & Stein, W. A., 1976. *Publs astr. Soc. Pacif.,* **88,** 294.

Nakada, Y., Izumiura, H., Onaka, T., Hashimoto, O., Ukita, N., Deguchi, S. & Tanabe, T., 1987. *Astrophys. J.,* **323,** L77.

Nakada, Y., Deguchi, S. & Forster, J. R., 1988. *Astr. Astrophys.,* **193,** L13.

Nguyen-Q-Rieu, Epchtein, N., Truong-bach & Cohen, M., 1988. *Astr. Astrophys.,* Preprint.

Othman, M., Ishida, K., Okamura, S. & Nishimura, S., 1988. *Astrophys. Space Sci.,* **148,** 191.

Papoular, R., 1988. *Astr. Astrophys.,* **204,** 138.

Thé, P. S. & Stokes, N., 1970. *Astr. Astrophys.,* **5,** 298.

Willems, F. J. & de Jong, T., 1986. *Astr. Astrophys.,* **309,** L39.

Zuckerman, B. & Dyck, H. M., 1986. *Astrophys. J.,* **311,** 345.

Zuckerman, B. & Lo, K. Y., 1987. *Astr. Astrophys.,* **173,** 263.