1990A&A...237..153P

Astron. Astrophys. 237, 153–158 (1990)

ASTRONOMY
AND
ASTROPHYSICS

Infrared photometry up to 34 μm of the type II OH/IR sources OH 127.8 − 0.0 and OH 345.0 + 15.7*

P. Persi[1], **M. Ferrari-Toniolo**[1], **K. Shivanandan**[2], **M. Ranieri**[1], **and A. Marenzi**[1]

[1] Istituto Astrofisica Spaziale, CNR, CP. 67, I-00044 Frascati, Italy
[2] E.O. Hulbert, Center for Space Research, Naval Research Laboratory, Washington, D.C., USA

Received October 24, 1989; accepted March 15, 1990

Abstract. We present ground-based infrared photometry between 2.2 and 34 μm, and IRAS observations of two OH/IR stars, OH 127.8 − 0.0 (GL 230) and OH 345.0 + 15.7 (GL 1822). From a study of the infrared flux distributions we have derived several physical parameters of the sources, and, in particular, their mass loss rates.

The values of $\dot{M}$ of 2.7 10^{-4} $M_{\odot}$ yr^{-1} and 1.4 10^{-4} $M_{\odot}$ yr^{-1} for OH 127.8 − 0.0 and OH 345.0 + 15.7 respectively, imply that the two stars are in a superwind phase at the tip of the Asymptotic Giant Branch (AGB).

Our direct 34 μm observations compared with the OH flux densities, strongly reinforce the hyphothesis that the 1612 MHz OH emission is radiatively pumped by 35 μm photons.

Finally, the infrared observations of OH 127.8 − 0.0, obtained on a time scale of a few years confirm the OH periodicity of 1994 *d*.

Key words: OH/IR stars – infrared photometry – IRAS sources

1. Introduction

OH 127.8 − 0.0 and OH 345.0 + 15.7 are two strong 1612 MHz OH line emitters discovered by Kerr and Bowers (1974) and Allen et al. (1977), and identified with the very red AFGL objects GL 230 and GL 1822, respectively. These optically unidentified AFGL sources were classified by Kleinmann et al. (1981), according to the presence of the CO first overtone band near 2.3 μm, as late M-type stars with a very dense dusty circumstellar envelope (Gehrz et al., 1985).

The observed high OH luminosity of these two sources, suggests a large value of mass loss rate (> 10^{-5} $M_{\odot}$ yr^{-1}) typical of evolved stars approaching the end of the Asympotic Giant Branch (AGB), and assumed to be progenitors of planetary nebulae.

Two IR pumping schemes were proposed for 1612 MHz OH masers, one involving vibrational excitation at 2.8 μm (Litvak, 1969) and the other involving rotational excitation at 35 μm (Elitzur et al., 1976). This last hypothesis is supported by a direct comparison of maser and IR emission from a sample of OH/IR stars (Evans and Beckwith, 1977; Werner et al., 1980). Evans and Beckwith (1977), assumed the flux at 35 μm equal to that observed at 12.5 μm, while Werner et al. (1980) obtained the 35 μm flux by interpolation between the measured 30 μm and 50 μm flux densities.

Although ground-based observations at 35 μm are very difficult, a direct measurement at this wavelength of OH/IR stars is very important to confirm definitively the pump mechanism proposed by Elitzur et al. (1976).

For this purpose, we collected new and more accurate photometry from 2.2 to 34 μm of the OH/IR stars OH 127.8 − 0.0 and OH 345.0 + 15.7. Our IR data were compared with the IRAS broad-band photometry and with the IRAS low resolution spectra (LRS) in order to estimate some physical parameters of the two OH maser sources such as the bolometric luminosity, the mass loss rate and the dust temperature.

2. Instrument and observations

The IR photometry was obtained with the multifilter helium-cooled Ge bolometer system of the Istituto Astrofisica Spaziale, CNR (IAS), attached in different epochs between 1983 and 1988 at the high mountain (3200 m.s.l.) f/20 1.5 m Italian Infrared Telescope (T.IR.GO) located at the Gornergrat (Switzerland).

The IAS bolometer system includes nine broad and narrow-band filters, and a circular variable filter (CVF) with an intrinsic spectral resolution $R = 50$. The photometric characteristics of this system, are reported in Table 1. The effective wavelengths (λ_{eff}) and $\Delta\lambda$ (FHWD) were computed including the transmission curves of the filters at 4 K, and a standard atmospheric transmission. The effective wavelengths specially in *M*, *Q*, and *P*(34 μm) bands depend strongly on the water vapour content of the atmosphere.

Taking the photometric response of Table 1, and the Kurucz (1979) atmospheric model for α Lyr with log $g = 3.94$ and $T_{\mathrm{eff}} = 9400$ K, we derived the 0.0 mag flux density for the IAS bolometer system, reported in the last column of the table.

The 34 μm filter here used is an OCLI filter blocked at shorter wavelengths. At this wavelength we estimated a very low efficiency (< 10%) including the atmosphere, telescope, and photometric system responses.

The AOV star α Lyr was taken as primary standard star in the *K*, *L*, and *M* bands, while the K2 III star α Boo was chosen as primary standard star in the *N*, *Q*, and *P*(34 μm) broad-bands.

Send offprint requests to: P. Persi

* Based on observations collected at the Gornergrat Observatory (T.IR.GO)

We assumed 0.0 mag in the K, L, and M bands for α Lyr, and $N = -3.15$ mag, $Q = -3.19$ mag, and $P(34\ \mu m) = -3.24$ mag for α Boo, respectively.

The observations of our sources were relative to a system of standard stars reported in Table 2. These stars were calibrated with respect to the primary standard stars, during twelve observing runs. Their magnitudes are given in Table 2, together with the number of observations for each standard star. All the observations were taken with a diaphragm of 14″ and chopping throw of 20″ in RA direction at small air masses to reduce the corrections.

Typical errors in deriving these magnitudes are less than 5% up to 10 μm and 10–20% in Q bands, depending on the number of observations. At 34 μm, where the band is not well defined, the error could be greater than 20%.

Our photometric system at 10 and 20 μm is in good agreement with that of Tokunaga (1984). This can be deduced by comparing the magnitudes of Table 2 with that observed by Tokunaga (1984) in the same bands.

The IR magnitudes corrected for air mass, of the OH maser sources OH 127.8−0.0 and OH 345.0+15.7 are reported in Table 3. The 1σ statistical errors are also indicated when greater than ±0.04 mag. The observations relative to OH 345.0+15.7 were taken with the same instrument mounted at the 2.1 m telescope of the Mexican National Observatory (S. Pedro Martir, B.C., Mexico). Due to the different atmospheric conditions of the two sites, the 34 μm observation of S. Pedro Martir, could be affected by a different calibration and $\lambda_{\rm eff}$.

The two sources were identified with point-like IRAS sources from the Point Source Catalogue (PSC). The IRAS flux densities corrected according to the prescription given in the Explanatory Supplement (Beichman et al., 1985), are reported in Table 4.

Table 1. IAS bolometer system

Filter	$\Delta\lambda$ (FHWD)	$\lambda_{\rm eff}$ (μ)	Flux 0^m (Jy)
K	0.6	2.2	680.0
L	0.9	3.6	269.0
M	0.6	4.9	151.0
N	5.0	10.6	35.6
$N1$	0.9	8.7	49.2
$N2$	1.5	9.8	40.0
$N3$	2.5	11.2	30.4
Q	4.6	20.3	9.3
P	12.0	34.0	3.7

3. Discussion

We discuss here the properties of the two OH/IR sources, combining the IR observations and radio data taken in literature and summarized in Table 5. S_ν(OH) in the table represents the geometric averages of the peak fluxes in the two OH velocity peaks; V_0 is the stellar radial velocity; $V_{\rm exp}$ the circumstellar expansion velocity, and ΔV is the velocity separation of the two peaks.

3.1. *OH 127.8−0.0*

This sources was identified with the AFGL object GL 230 and with the point-like IRAS source 01 304+6211.

OH variability at 1612 MHz with a period of 1994 d was found by Herman and Habing (1985). The L, M, and N light curves obtained by combining our IR photometry with the IR data by Grasdalen et al. (1983), and Gehrz et al. (1985) (Fig. 1), suggest a similar variability in IR. The amplitude of this variation is reduced from 1.9 mag at 3.6 μm to 1.1 mag at 10 μm. The fact that IR and OH emission vary in phase, confirms the OH emission is radiatively pumped.

We may provide a direct quantitative test of the rotational pump model, comparing the number of OH photons emitted per second n(OH), with the number of IR photons available to be absorbed per second in the 35 μm rotational transition, n(IR). Besides the observed peak OH and 35 μm flux density and, according to Eq. 1 of Evans and Beckwith (1977), the pump efficiency $\varepsilon = n({\rm OH})/n({\rm IR})$ is related to the following factors including the solid angle into which the observed flux is emitted, and the bandwidth in km s^{-1} for microwave emission or IR absorption by OH molecules. In the first approximation, following Werner et al. (1980), it is plausible to relate the pump efficiency to the observed quantities only, i.e. $\varepsilon = S_\nu({\rm OH})/S_\nu(35\ \mu{\rm m})$. Using our 34 μm photometry, and S_ν(OH) obtained approximately at the same phase as the IR observations (Herman and Habing, 1985) (see Table 5), we derived $\varepsilon = 0.36$. Since $\varepsilon < 1$, we conclude that 35 μm pumping is feasible for this OH/IR star.

Water vapour maser emission at 22 GHz was detected by Engels et al. (1986) at the 0.01 OH phase. Comparing the H_2O photon luminosity with the photon luminosity at 6.3 μm obtained from the M band observed at the same phase, and using Eq. 1 of Engels et al. (1986), we obtained $L^{6.3}/L^{\rm H_2O} = 1267$. This ratio indicates that in OH 127.8−0.0 there are sufficient 6.3 μm photons to sustain the H_2O maser emission.

The IR flux distribution of this OH/IR star is reported for different epochs in Fig. 2. The ground-based IR observations

Table 2. IAS standard star magnitudes

Name	SP	K	L	M	N	$N1$	$N2$	$N3$	Q	P	$N_{\rm ob}$
α Tau	K5 III	−2.96	−3.06	−2.88	−3.00				−3.04	−3.04	4
β Peg	M2 II	−2.25	−2.45	−2.27	−2.50	−2.43	−2.49	−2.53	−2.59	−2.69	10
β And	MO III	−1.95	−2.11	−1.92	−2.09				−2.14	−2.17	4
β Gem	KO III	−1.17	−1.22	−1.13	−1.18				−1.25		4
μ UMa	MO III	−0.84	−0.97	−0.78	−1.02				−1.12		6
α Boo	K2 III	−2.99	−3.09	−2.94	−3.17	−3.14	−3.09	−3.08	−3.19	−3.20	6
α Aur	G8 III	−1.83	−1.89	−1.95	−1.93				−2.03		3

Table 3. IR photometry of the two OH/IR stars

OH/IR	Date	K	L	M	N	$N1$	$N2$	$N3$	Q	$P(34)$
OH 127.8−0.0	Sep. 23, 1983	6.50(.11)	1.57	0.11	−1.71	−1.84	−0.88	−1.64	−4.16(.18)	
OH 127.8−0.0	Nov. 27, 1988	7.25(.08)	3.02(.05)	0.98(.08)	−1.17(.06)		0.02(.14)	−1.02(.05)	−3.90(.10)	−3.70(.20)
OH 345.0+15.7	Jun. 07, 1985	6.82(.18)	2.27	1.11	−1.37(.06)	−0.88	−0.72	−1.90	−3.06(.11)	−3.47(.15)

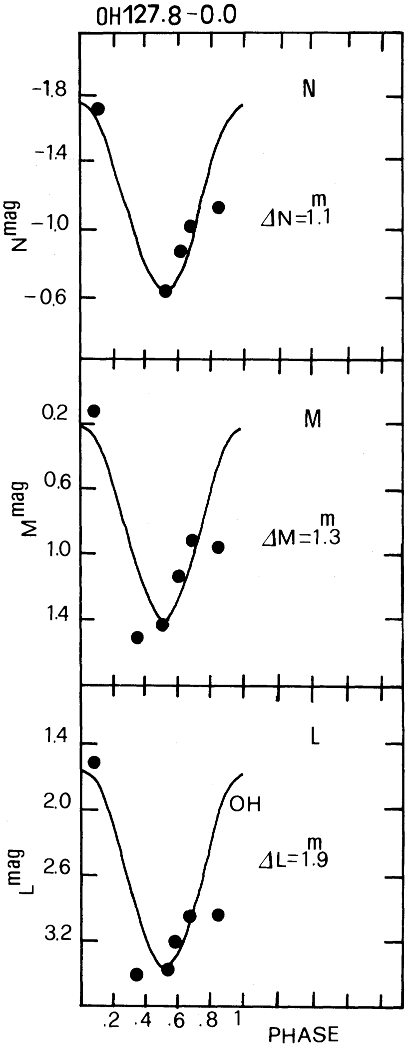

Fig. 1. Variation of the IR emission of OH 127.8−0.0; $P = 1994$ d. The solid line represents the OH light curve found by Herman and Habing (1985)

relative to September 23, 1983 (0.08 OH phase), agrees with the IRAS fluxes collected at approximately the same time. Integrating the 2–100 μm spectrum relative to the maximum IR emission, and applying the bolometric correction beyond 100 μm, we derived the bolometric luminosity $L(\mathrm{bol}) = 1.7\ 10^5\ L_\odot$ ($M(\mathrm{bol}) = -8.3$), assuming a kinematic distance of $D = 5.6$ kpc (Engels et al., 1986). This luminosity is consistent with the period $P = 1994$ d observed in OH, according to the period-luminosity relation found for the OH/IR stars by Engels et al. (1983).

An evaluation of the mass loss rate was obtained, considering that the observed expansion of the shell is driven by radiation pressure on the dust. Following the relationship given by Engels et al. (1983):

$$\dot{M} = (\beta_d / c\ V_{\mathrm{exp}})\, L(\mathrm{bol}) \qquad (1)$$

where c is the velocity of the light, V_{exp} the expansion velocity, and β_d the ratio of stellar photon momentum needed to accelerate the shell to the total photon momentum, we derived from the observed $L(\mathrm{bol})$, V_{exp}, and $\beta_d = 1$, $\dot{M} = 2.7\ 10^{-4}\ M_\odot\ \mathrm{yr}^{-1}$. This

Table 4. Corrected IRAS flux densities

OH/IR	IRAS	[12] Jy	[25] Jy	[60] Jy	[100] Jy
OH 127.8 − 0.0	01 304 + 6211	324.6 + 13.0	406.0 + 16.0	154.8 + 14.0	45.2 + 5.4
OH 345.0 + 15.7	16 029 − 3041	163.3 + 18.0	232.2 + 9.3	64.8 + 6.5	21.5 + 1.9

Table 5. OH data

Source	V_0 (km s^{-1})	$V_{\rm exp}$ (km s^{-1})	ΔV km s^{-1}	S_ν(OH) (Jy)	Ref.
OH 127.8 − 0.0	−55	12.7	24.5	40.6	1
OH 345.0 + 15.7	−2.7	12.9	25.8	18.8	2

References: (1) Herman and Habing (1985) $\phi = 0.87$; (2) Allen et al. (1977)

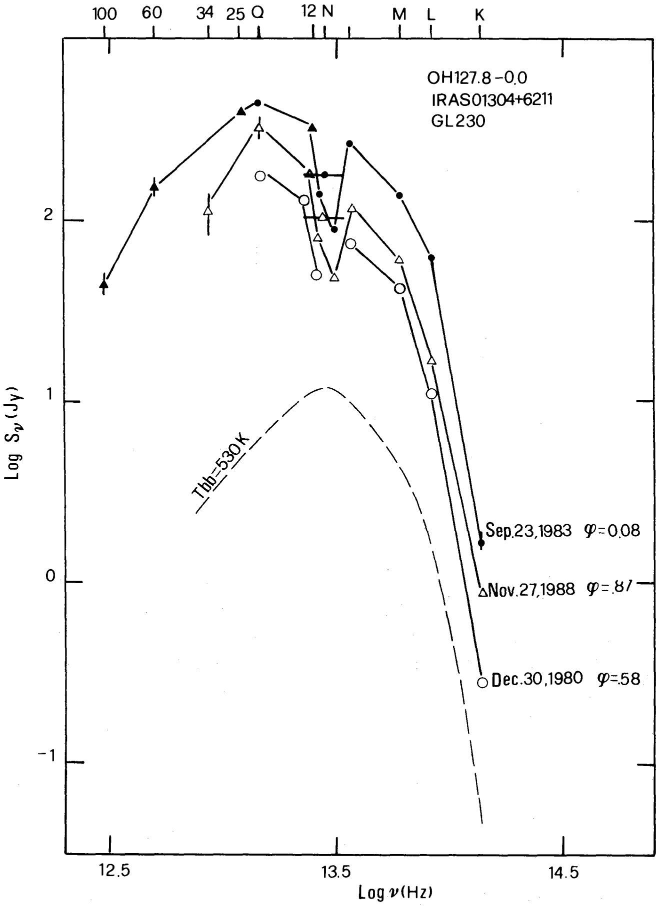

Fig. 2. Infrared flux distribution of OH 127.8 − 0.0 taken at different epochs. (▲) IRAS data. (---) blackbody at $T = 530$ K

value consistent with that independently obtained by Nyman et al. (1986) using the OH luminosity, is one of the largest known for such stars.

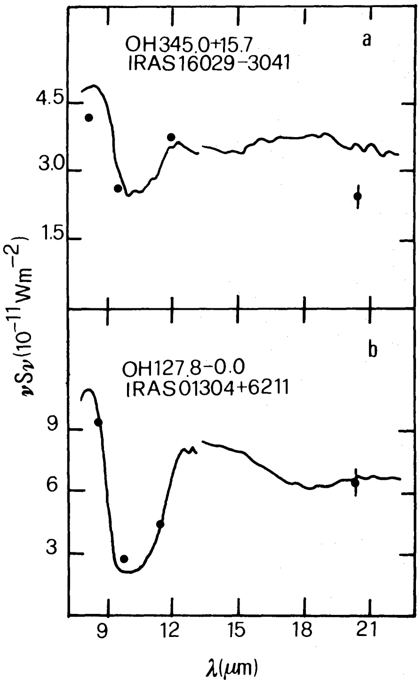

Fig. 3. a IRAS LRS of OH 345.0 + 15.7. **b** IRAS LRS of OH 127.8 − 0.0. (○) Narrow-band and *Q* photometry of Table 3

Colour temperature respectively of 530 K and 280 K were found from the observed near-IR colour *K–M* and the [25–60] IRAS colour indices. This indicates that dust at different temperatures is present in the shell of OH 127.8 − 0.0. From a comparison of the 530 K blackbody reported in Fig. 2 (dashed line) with the near IR-fluxes, we deduced that the OH/IR star radiates beyond 10 μm as a blackbody.

The narrow-band photometry around 10 μm at different phases, shows the presence of the 9.7 μm silicate absorption band (Fig. 2). This deep feature together with a weak absorption band at 18 μm is observable in the IRAS Low Resolution Spectrum (LRS, IRAS Team, 1986) (Fig. 3b). The 18 μm absorption band was detected in the OH/IR AFGL source GL 2205 (OH 26.5 + 0.6) (Forrest et al., 1978) and in the Galactic Center (McCarthy et al., 1980), and requires the presence of cold silicate grains. From the IRAS LRS of Fig. 3b, we derived the optical depth at 9.7 and 18 μm; $\tau_{9.7} = 1.5$, and $\tau_{18} = 0.17$. It results that the observed ratio $\tau_{9.7}/\tau_{18} = 8.8$ is greater than those observed in GL 2205 and in the Galactic Center by a factor 2–3. This could indicate that the dust absorbing at 10 μm is warm enough to radiate significantly at 18 μm.

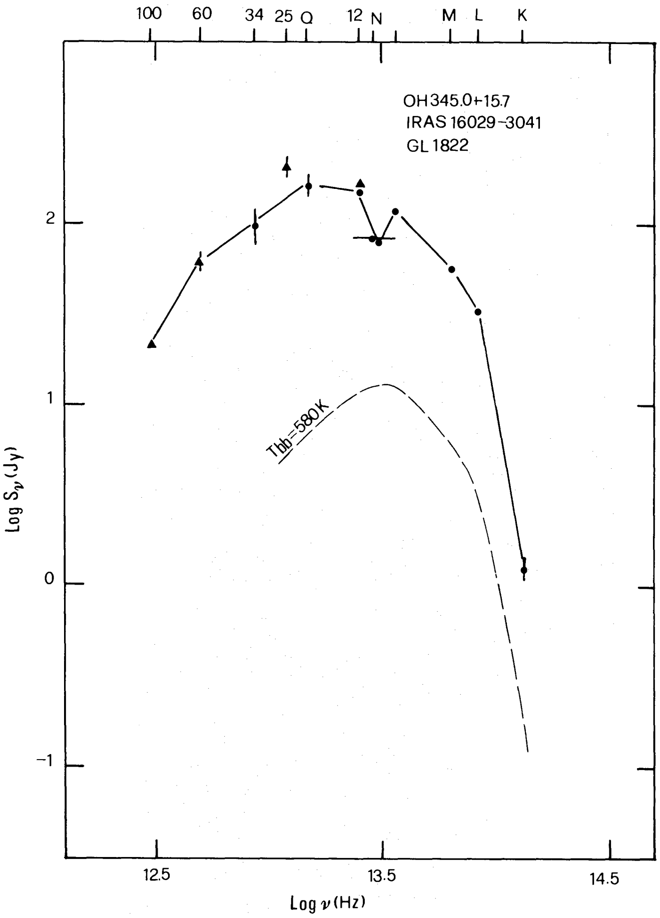

Fig. 4. Infrared flux distribution of OH 345.0+15.7. (▲) IRAS data. (- - -) blackbody at $T=580$ K

3.2. *OH 345.0+15.7*

This type II OH/IR source was discovered by Allen et al. (1977) during a survey at 1612 MHz of AFGL objects, and identified with GL 1822. The source is reported in the IRAS PSC with the name 16029-3041.

The characteristics of this OH maser source and of OH 127.8−0.0 are very similar, but no monitoring was made in order to study a possible OH periodicity. Even the IR observations of OH 345.0+15.7 are insufficient to bring out an IR variability.

Although IR observations and OH measurements were taken at different time, we derived the pump efficiency ratio following the considerations made in Sect. 3.1. From our observed 34 μm flux densities and S_ν(OH) of Table 5, we got $\varepsilon=0.19$ in agreement with the model of Elitzur et al. (1976) that predict a value of $\varepsilon=0.25$.

Figure 4 gives the IR flux distribution of this source, including the photometry of Table 3 and the IRAS data of Table 4. Except for the 25 μm, our data agree well with IRAS flux densities. The continuum spectrum could be fitted by a combination of two blackbody curves at $T(K\text{–}M)=580$ K and at $T(25\text{–}60)=420$ K, respectively in order to explain the far-IR emission.

Table 6. Physical parameters derived from IR observations

	OH 127.8−0.0	OH 345.0+15.7
L(bol)	$1.7\,10^5\,L_\odot$	$8.7\,10^4\,L_\odot$
F(IR)	$1.8\,10^{-10}$ W m^{-2}	$7.8\,10^{-11}$ W m^{-2}
$F(\lambda>12)/F(\mathrm{IR})$	0.4	0.4
$T(K\text{–}M)$	530 K	580 K
T(25–60)	280 K	420 K
$\tau_{(9.7\mu\mathrm{m})}$	1.5	0.6
$\tau_{(18\mu\mathrm{m})}$	0.17	—
$\dot{M}(M_\odot\,\mathrm{yr}^{-1})$	$2.7\,10^{-4}$	$1.4\,10^{-4}$
ε	0.36	0.19

The derived bolometric luminosity, obtained after integrating the 2–100 μm spectrum of Fig. 4, and correcting for emission beyond 100 μm, is $L(\mathrm{bol})=8.7\,10^4\,L_\odot$ assuming a distance $D=6$ kpc (Allen, 1977). Supposing that the OH shell in OH 345.0+15.7 is expanding at a velocity $V_{\mathrm{exp}}=\Delta V/2=12.9$ km s^{-1} (Allen et al., 1977) (Table 4) we got from Eq. (1), $\dot{M}=1.4\,10^{-4}\,M_\odot\,\mathrm{yr}^{-1}$.

The 9.7 μm silicate absorption band is also observed in OH 345.0+15.7 with an optical depth $\tau_{9.7}=0.6$ as illustrated in Fig. 4 and in the IRAS LRS of Fig. 3a. The 18 μm feature is probably lacking because in this OH/IR star the dust which absorbs at 10 μm is warmer than in OH 127.8−0.0.

Finally, the physical parameters of the two OH/IR stars OH 127.8−0.0 and OH 345.0+15.7, deduced from the IR observations are given in Table 6. The bolometric luminosities and the mass loss rates here computed, could be affected by systematic errors due to the rather uncertain kinematic distances used.

4. Conclusions

The main results of our IR photometry of the two OH/IR stars OH 127.8−0.0 and OH 345.0+15.7 can be summarized as follows:

1. The derived pump efficiency ratios of the two sources, given in Table 6, are in the range of those observed by Werner et al. (1980) and Evans and Beckwith (1977) in five OH/IR stars. This fact reinforces the hypothesis that the 1612 MHz maser emission is pumped by 35 μm photons.

2. The ratio between the flux emitted longward of $\lambda=12$ μm and the total IR flux is 0.4 for both the sources (Table 6), indicating that the bulk of luminosity is not emitted in the far-IR. Therefore, ground-based measurements in the near and mid-IR are important in the determination of the bolometric luminosity and mass loss rate.

The derived value of $\dot{M}\sim10^{-4}\,M_\odot\,\mathrm{yr}^{-1}$ for the sources here analyzed (Table 6), indicates the presence of a superwind. This superwind places the two OH/IR stars at the tip of the Asymptotic Giant Branch (AGB) according to Renzini (1981).

3. OH 127.8−0.0 shows an IR variability probably in phase with the OH emission ($P=1994$ d).

Finally, the two OH/IR stars fall in a region (IIIb) of the IRAS colour diagram studied by van der Veen and Habing (1988), where variable stars with thick O-rich circumstellar shells are found.

Acknowledgements. The authors are grateful to the infrared staff of the Gornergrat Observatory (T.IR.GO) and to Drs. M. Tapia and M. Roth in participating to the IR observations of S. Pedro Martir. We thank in particular the referee Dr. N. Epchtein for his helpful comments and suggestions.

References

Allen, D.A., Hyland, A.R., Longmore, A.J., Caswell, J.L., Goss, W.M., Haynes, R.F.: 1977, *Astrophys. J.* **217**, 109

Beichman, C.A., Neugebauer, G., Habing, H.J., Clegg, P.E., Chester, T.J.: 1985, *IRAS Catalogs and Atlases Explanatory Supplement*, U.S. GPO, Washington, D.C.

Elitzur, M., Goldreich, P., Scoville, N.: 1976, *Astrophys. J.* **205**, 384

Engels, D., Kreysa, E., Schultz, G.V., Sherwood, W.A.: 1983, *Astron. Astrophys.* **124**, 123

Engels, D., Schmidt-Burk, J., Walmsley, C.M.: 1986, *Astron. Astrophys.* **167**, 129

Evans, N.J., Beckwith, S.: 1977, *Astrophys. J.* **217**, 729

Forrest, W.J., Gillett, F.G., Houck, J.R., McCarthy, J.F., Merrill, K.M., Pipher, J.L., Puetter, R.C., Russell, R.W., Soifer, B.T., Willner, S.P: 1978, *Astrophys. J.* **219**, 114

Gehrz, R.D., Kleinmann, S.G., Mason, S., Hackwell, J.A., Grasdalen, G.L.: 1985, *Astrophys. J.* **290**, 296

Grasdalen, G.L., Gehrz, R.D., Hackwell, J.A., Castelaz, M., Gullixson, C.: 1983, *Astrophys. J. Suppl.* **53**, 413

Herman, J., Habing, H.J.: 1985, *Astron. Astrophys. Suppl.* **59**, 523

Kerr, F.J., Bowers, P.F.: 1974, *Astron. Astrophys.* **36**, 225

Kleinmann, S.G., Gillett, F.G., Joyce, R.R.: 1981, *Annu. Rev. Astron. Astrophys.* **19**, 411

Kurucz, R.L.: 1979, *Astrophys. J. Suppl.* **40**, 1

IRAS Science Team: 1986, *Astron. Astrophys. Suppl.* **65**, 607

Litvak, M.M.: 1969, *Astrophys. J.* **156**, 471

McCarthy, J.F., Forrest, W.J., Briotta, D.A., Houck, J.R.: 1980, *Astrophys. J.* **242**, 965

Nyman, L.A., Johansson, L.E.B., Booth, R.S.: 1986, *Astron. Astrophys.* **160**, 352

Renzini, A.: 1981, in *Physical Processes in Red Giants*, eds. I. Iben Jr., A. Renzini, Reidel, Dordrecht, p. 165

Tokunaga, A.T.: 1984, *Astron. J.* **89**, 172

van der Veen, W.E.C.J., Habing, H.J.: 1988, *Astron. Astrophys.* **194**, 125

Werner, M.W., Beckwith, S., Gatley, I., Sellgren, K., Berriman, G.: 1980, *Astrophys. J.* **239**, 540