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Citation

Te Lintel Hekkert, P., Habing, H. J., Caswell, J. L., Norris, R. P., & Haynes, R. F. (1988). Two IRAS sources with high velocity outflow similar to OH231.8 + 4.2. *Astronomy And Astrophysics*, 202, L19-L22. Retrieved from <https://hdl.handle.net/1887/7584>

Version: Not Applicable (or Unknown)

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Note: To cite this publication please use the final published version (if applicable).

Letter to the Editor

Two IRAS sources with high velocity outflow similar to OH 231.8 + 4.2

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Received May 31, accepted June 30, 1988

Summary. In a search for OH maser emission from IRAS point sources we found amongst 700 detections two objects with exceptionally broad maser lines, between 150 and 200 $\text{km} \cdot \text{s}^{-1}$. We present the OH line data, IRAS data and some additional visual and near infrared information. We suggest that the two objects, together with the well known object, OH231.8 + 4.2 constitute a small group of OH/IR stars showing bipolar mass loss.

Key words: OH/IR stars – Stars : circumstellar matter – Masers – Evolution of stars – Infrared radiation

1. Introduction.

We have been carrying out a survey for 1612MHz OH maser emission from IRAS point sources with colours similar to those of OH/IR stars, using the CSIRO 64 m telescope in Parkes, NSW, Australia. The main results will be published later. Among the more than 700 positive detections we found two sources, IRAS15405–4945 and IRAS16342–3814 to be quite exceptional in two respects. First the sources emit with comparable strength in three of the four ground state OH lines, 1612MHz, 1665MHz and 1667MHz, whereas other OH/IR stars have a strongly dominating 1612MHz line. Second the lines are very broad, about 150 to 200 $\text{km} \cdot \text{s}^{-1}$, which is a factor of at least 3 larger than the 1612MHz line in all other sources from our survey.

The maser line profiles of these two sources are similar to those of OH231.8 + 4.2, a well studied object, which is a late type giant losing mass at a high rate in a bipolar fashion (see Morris *et al.* 1987 and references therein). Outflows with gross deviations from spherical symmetry are rare among OH/IR stars. In the large scale surveys only about 5 % of the sources show irregular 1612MHz line profiles. Observations with the VLA and MERLIN arrays (*e.g.* Herman *et al.* 1985) and theoretical work (*e.g.* Reid *et al.* 1977) show that a regular profile is the signature of a spherical dust shell. Irregular spectra can be explained by a different geometry including a (thick) disk and/or bipolar outflow (*e.g.* Chapman 1988).

The nature of OH/IR stars and their role as progenitors of planetary nebulae have recently been discussed at several conferences (*e.g.* Kwok and Pottasch 1987; Torres–Peimbert 1988). It is now generally accepted that OH/IR stars are

highly evolved Asymptotic Giant Branch stars. The outflow during this evolution stage is predominantly spherical (at a rate of $\dot{M} = 10^{-5}$ to $10^{-4} M_{\odot} \text{yr}^{-1}$). Yet in the next evolutionary phase, that of the planetary nebulae, the shells usually have an axial symmetry or are clearly bipolar (*e.g.* Louise *et al.* 1987). When and how does the character of the outflow change so drastically ?

IRAS 15405–4945		stellar velocity : 55 – 65 $\text{km} \cdot \text{s}^{-1}$		
frequency [MHz]	vel. range [$\text{km} \cdot \text{s}^{-1}$]	typical flux [Jy]		polarization %
		red	blue	
1612	> 75.	0.2		< 25
1667	175.	0.9	0.3	< 5
1665	100.	2.0	0.5	25
1720		< 0.15		
IRAS 16342–3814		stellar velocity : 40 – 50 $\text{km} \cdot \text{s}^{-1}$		
frequency [MHz]	vel. range [$\text{km} \cdot \text{s}^{-1}$]	typical flux [Jy]		polarization %
		red	blue	
1612	140.	8.0	1.0	25 to 50
1667	140.	0.5	0.3	25
1665	80.	0.5	0.5	25 to 50
1720		< 0.15		
OH 231.8+4.2		stellar velocity : 20 $\text{km} \cdot \text{s}^{-1}$		
frequency [MHz]	vel. range [$\text{km} \cdot \text{s}^{-1}$]	typical flux [Jy]		polarization %
		red	blue	
1612	20.	0.1	1.0	
1667	80.	6.0	0.3	15
1665		< 0.15		
1720		< 0.15		

Table 1. Summary of the OH maser observations.

Objects like the ones discussed in this Letter may help to give an answer. After this paper had been written we received a preprint by Likkell and Morris (1988) that discusses OH measurements of IRAS16342–3814 and derives somewhat similar conclusions.

2. Observations.

2.1. Positions and optical counterparts.

We derived the maser position in the direction of IRAS15405–4945 to within 1 arcminute. However two differently labeled sources in the IRAS point source catalogue (PSC) approximately coincide with the maser : IRAS15405–4945 and IRAS15406–4946 ; for each source, data belonging to one source has been mixed with those of the other by the IRAS

data processing – see the individual entries in the IRAS Working Survey Database (WSDB) of the PSC (Chester, private communication). In the following we assume that IRAS15405–4945, which is the stronger source of the two, is the source with the OH maser lines and the near infrared data. Allen (private communication) found a faint star like image near the IRAS position for IRAS15405–4945.

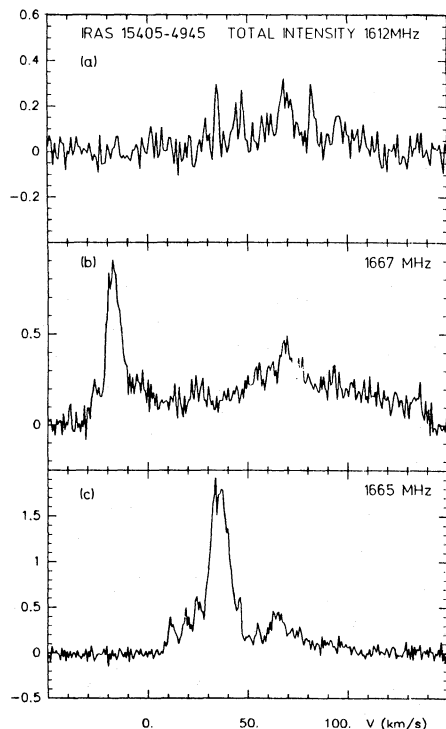


Figure 1. Averaged spectra of IRAS 15405 – 4945 at 1612 MHz (1^a), 1667 MHz (1^b) and 1665 MHz (1^c).

Near the IRAS position of IRAS16342–3814 we found a very red object, star or nebula. For OH231.8 + 4.2, a recent summary of all data known is given by Morris *et al.* (1987).

2.2. OH maser line measurements.

During April and May 1987 we observed with the Parkes 64 meter radiotelescope, using a dual-channel cooled FET receiver, with a typical system temperature of 38 K. The calibration is relative to Hydra A (PKS 0915-118) assuming an 18 cm flux of 36 Jy (18 Jy in each sense of circular polarization). The 1024 channel autocorrelator was split into two bands of 512 channels each, measuring the left and right circular polarization simultaneously. For some observations, two orthogonal linear polarizations were measured. We observed the three sources in all four 18 cm transitions of the OH radical: 1612, 1665, 1667 and 1720 MHz, using the total power technique. The observations of the 1612 MHz transition were seriously hampered by interference caused by the Soviet GLONASS satellite system (see also Carter 1986). The nature of the interference made it impossible to take high quality 1612 MHz spectra at the position of IRAS15405–4945. All velocities are with respect to the Local Standard of Rest. Owing to the use of new and not yet completely tested software, the absolute

velocities are uncertain up to $1 \text{ km} \cdot \text{s}^{-1}$. A summary of the results is given in table 1.

2.2.1. IRAS15405–4945 (OH329.14 + 3.92).

In figure 1 we give the total intensity spectra (sum of the two channels). In figure 2 we give the left minus the right hand circular polarization.

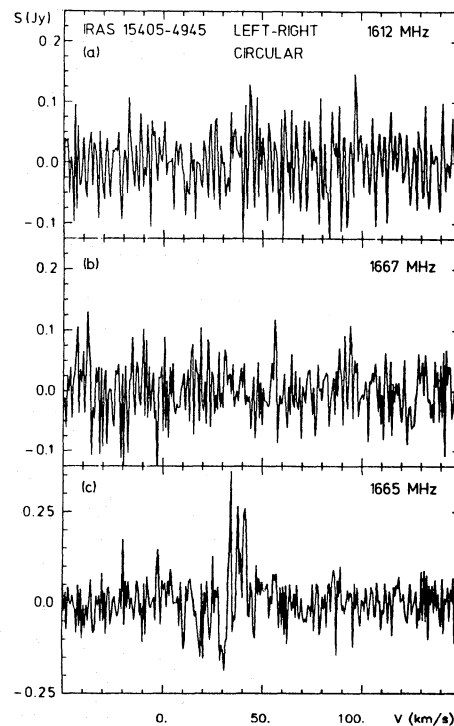


Figure 2. LEFT minus RIGHT hand circular polarization of IRAS 15405 – 4945 at 1612 MHz (2^a), 1667 MHz (2^b) and 1665 MHz (2^c).

Outside the velocity range shown in figure 1, no emission features at 1665 or 1667 MHz with flux larger than 0.1 Jy; at 1612 MHz the absence of other features is less certain, because of GLONASS interference at this frequency. Nevertheless we are confident that during our two months period of observations some features in the 1612 MHz spectrum varied drastically in intensity; further it seems that the spikes occur in pairs, centered near $61.5 \text{ km} \cdot \text{s}^{-1}$, and it is possible that the source has a weak plateau of emission (ranging from 25 to $100 \text{ km} \cdot \text{s}^{-1}$). In all three transitions the emission is centered between about 55 to $65 \text{ km} \cdot \text{s}^{-1}$, and this is probably close to the velocity of the central object. The emission at 1667 MHz can be thought of as a blue shifted spike on top of a broad emission feature. The shape of the spike is common for normal OH/IR stars and corresponds to the near side of the object on the assumption of outflow rather than inflow. Any red shifted peak from the far side may have been absorbed by ionised plasma around the central object, similar to the case assumed for planetary nebulae with OH emission (Payne 1987). Another possible explanation for the preferred blue shifted emission is the presence of a high intensity background (*e.g.* the star or lobes of high energy content) which

then is amplified by the maser; such an explanation has been proposed for OH231.8 + 4.2 (Morris *et al.* 1987). From figure 2 we deduce that there is hardly any polarized emission from this source at 1612MHz and 1667MHz. We estimate upper limits of 25 % and 5 %, respectively. The 1665MHz emission has some features with 25 % polarization.

2.2.2. IRAS16342–3814 (OH344.07 + 5.84).

In figure 3 the three 18 cm spectra of total emission are given. From these we estimate the velocity of the central object to be about 40 to 50 $\text{km} \cdot \text{s}^{-1}$.

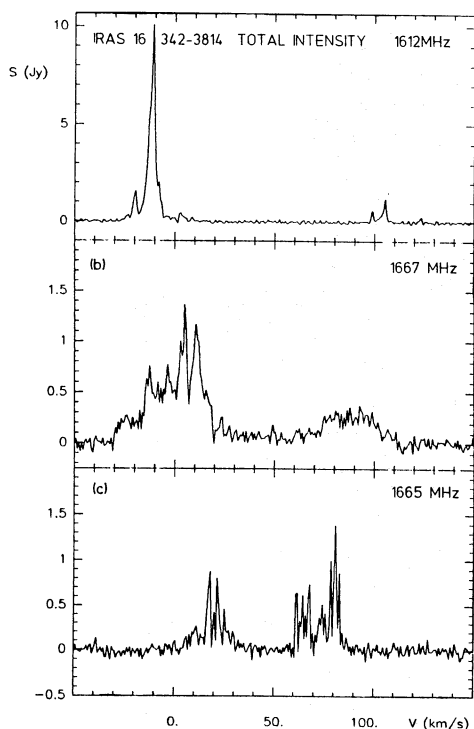


Figure 3. Averaged spectra of IRAS 16342 – 3814 at 1612 MHz (3^a), 1667 MHz (3^b) and 1665 MHz (3^c).

The emission at 1612MHz consists of two groups, one at $-15 \text{ km} \cdot \text{s}^{-1}$ and the other at $100 \text{ km} \cdot \text{s}^{-1}$ and a weak feature at $120 \text{ km} \cdot \text{s}^{-1}$. There is some indication of a weak plateau of emission between -20 and $10 \text{ km} \cdot \text{s}^{-1}$; GLONASS did not “allow” us to check the reality of this feature. The blue shifted peak is stronger than the corresponding red shifted peak, in this case by a factor of 8. The emission at 1665MHz and 1667MHz consists of two bunches of maser spikes. The difference between the velocity centroids of each group increases from $50 \text{ km} \cdot \text{s}^{-1}$ at 1665MHz, to $90 \text{ km} \cdot \text{s}^{-1}$ at 1667MHz, and to $115 \text{ km} \cdot \text{s}^{-1}$ at 1612MHz. In figure 4 we plot the difference of the right and left polarization. The degree of polarization is high, between 25 % and 50 %, for all three transitions. Polarization of 1612MHz emission is exceptional in OH/IR stars.

2.3. Infrared data.

In table 2 we give flux densities at near infrared and IRAS wavelengths; Colour correction factors were not applied to the IRAS fluxes. We find the infrared fluxes of each source can

be fitted adequately with two blackbodies at temperatures of about 100 K and 1000 K, some excess at the short wavelengths can be explained by assuming radiation from the photosphere of a central object hotter than 10,000 K. The ratio of the total fluxes of the cool (100 K) component over the warm (1000 K) component is 2.9, 150 and 1.7 for IRAS15405–4945, IRAS15405–4945 and OH231.8 + 4.2 respectively; this wide range may be partly due to variability since the short wavelengths observations were obtained more than 3 years after the IRAS data.

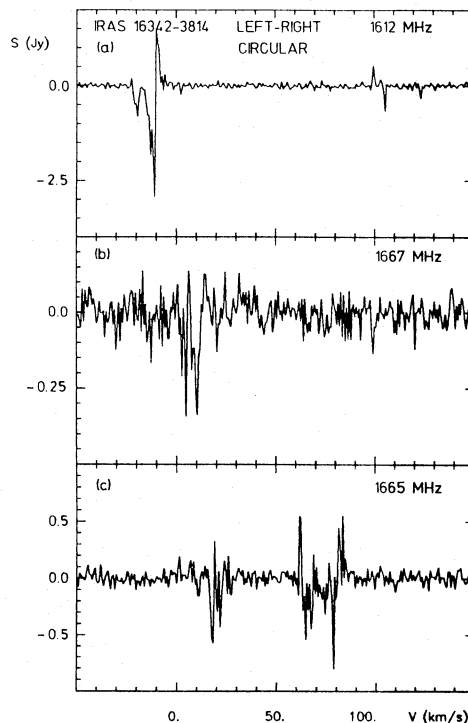


Figure 4. LEFT minus RIGHT hand circular polarization of IRAS 16342 – 3814 at 1612 MHz (4^a), 1667 MHz (4^b) and 1665 MHz (4^c).

During the IRAS mission low resolution spectra (LRS) were taken. The LRS spectrum of IRAS15405–4945 contains only noise. The LRS spectra of IRAS16342–3814 and OH231.8 + 4.2 are strikingly similar, except at wavelengths short of $10 \mu\text{m}$ where the spectrum of OH231.8 + 4.2 rises; this is probably due to a hot dust component. Emission lines are not seen.

2.4. H₂O maser emission.

IRAS16342–3814 was discovered by Zuckerman and Lo (1987) to have H₂O maser emission at about $140 \text{ km} \cdot \text{s}^{-1}$ with an intensity of 1.3 Jy. It is often assumed that H₂O masers are collisionally pumped and might originate from a shock front formed by the fast wind of the central object and the interstellar medium. Possibly Herbig–Harro objects are present, in the same way as near OH231.8 + 4.2 (Cohen *et al.* 1985). Winnberg (private communication) was unable to detect any H₂O line from IRAS15405–4945 or IRAS16342–3814 in October 1987, with an upper limit (3σ) of .09 Jy.

3. Discussion and conclusion.

The three sources in this paper have qualitatively very similar infrared spectra, each consisting of a cool (100 K) component and a warm (1000 K) component. For two of the sources an IRAS-LRS spectrum is available and these are rather similar as well. Also the maser properties, in spite of some differences, look rather similar, especially with respect to the broad velocity coverage (figures 1 and 3). We therefore suggest that the three sources have similar distributions of circumstellar matter and similar flow patterns. In OH231.8 + 4.2 this distribution and the flow pattern has been well established by Cohen *et al.* (1985) and confirmed by Reipurth (1987) and Morris *et al.* (1987). We take this as our basic model and ask whether we can explain the differences between the three sources by varying the orientation of the model.

The basic model consists of a thick disk, or highly flattened spheroid, with dust at a temperature of 100 K. Along the rotation axis, in each direction from the center of the disk emanates a "lobe" of gas containing warm (1000 K) dust. Each lobe forms a reflection nebula. The OH maser appears associated with the edge of the warm lobes, and not, as one could expect, with the cool disk. The rotation axis of the disk, and the symmetry axis of the lobes of OH231.8 + 4.2, has an inclination with the plane of the sky of 42° (Cohen *et al.* 1985).

Consider first the infrared spectra. The cold and the warm component are present in each source. In IRAS16342-3814 the ratio between cold and warm fluxes is a factor 50 to 100 larger than in the other two. Part of this discrepancy may perhaps be explained by variability. Part of it may be due to orientation: we suggest that in IRAS16342-3814 we see at the shorter wavelengths a significantly smaller projected area of the warm lobes, that is: our line of sight coincides with the rotation axis; the other two objects are seen much more edge on, with the rotation axis closer to the plane of the sky.

wavelength	IRAS15405-4945		IRAS16342-3814		OH231.8+4.2	
[μ m]	[Jy]	epoch	[Jy]	epoch	[Jy]	epoch
1.2	0.23	1987.6	0.022	1986.6	0.85	1986.1
1.6	0.63		0.055		2.18	
2.2	1.18		0.093		3.88	
3.8	1.88		0.17		12.3	
4.8			0.20		20.6	
12.	< 2.4	1983.	16.3	1983.	19.0	1983.
25.	26.6		199.8		226.0	
60.	82.5		290.1		548.0	
100.	33.7		138.2		292.0	
black body temperatures [K]						
	100.		115.		105.	
	1350.		1150.		775.	
$F_{\text{tot}}(\text{cool})/F_{\text{tot}}(\text{warm})$						
	2.9		150.		1.7	

Table 2. The near infrared data and IRAS fluxes.

The near infrared data for IRAS16342-3814 were provided by W. van der Veen (private communication), for IRAS15405-4945 from D. Allen (private communication) and OH231.8+4.2 from Reipurth (1987).

A similar conclusion is derived from the 1612MHz line profile, that is strong in IRAS16342-3814, weak in both IRAS15405-4945 and OH231.8 + 4.2. We assume that the single, strong component is produced by maser amplification of a background object (the star?) by the material flowing outward along the rotation axis. We see only the blue shifted component that approaches us - hence we look down on the system along the rotation axis. Because the maser amplification is limited to rays inside the lobe, the maser is highly beamed,

and we expect little 1612MHz emission in highly inclined objects.

It is not clear to us how the pattern of the main line emission fits into this description, nor how one explains the polarization of the three maser lines. We leave this to further investigations. For further understanding of these sources better infrared and OH positions are desired; infrared images and optical photographs should be made and optical spectroscopy should be done. Both IRAS sources are in crowded fields and a solid identification is absolutely necessary.

The "forbidden" system velocities of IRAS15405-4945 and IRAS16342-3814 suggest that these are old, low mass stars. This contrasts with the suggestion that OH231.8 + 4.2 is a star of considerable mass ($M > 3 M_{\odot}$, see Cohen *et al.* 1985).

Main line masers with line profiles superficially similar to IRAS16342-3814 and IRAS15405-4945 are also observed in Megamaser galaxies (*e.g.* Baan *et al.* 1982). But there the velocity extent is typically $500 \text{ km} \cdot \text{s}^{-1}$, almost a factor 4 larger than the velocity extent of the two IRAS sources. While we do not totally exclude the possibility that the two new sources are extragalactic objects, we find it highly unlikely in view of the low radial velocities of the systems.

Acknowledgements.

We thank David Allen for measuring the near infrared data of IRAS15405-4945 and Willy van der Veen for communicating data of IRAS16342-3814 prior to publication. Huub Röttgering and Sabine du Croo de Jongh are gratefully acknowledged for their support during the observations in Parkes. PLH received financial support to cover the travelling expenses to Australia from N.W.O., the Netherlands Foundation for the Advancement of Pure Research and from the Leids Kerkhoven - Bosscha Fonds (LKBF).

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Note added in proof. In June 1988 we found two more sources with 1667MHz profiles similar to the ones of OH231.8 + 4.2 and IRAS16342-3814: IRAS 17423-1755 and IRAS 18491-0207. The latter had a velocity coverage of $140 \text{ km} \cdot \text{s}^{-1}$.