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A SEARCH FOR RADIO CONTINUUM EMISSION FROM EVOLVED STARS WITH ASYMMETRIC OH MASER EMISSION

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RESUMEN

Durante la transición de supergigante roja a nebulosa planetaria es posible la coexistencia de gas ionizado en las partes centrales de la envolvente con máseres de OH en una cáscara exterior. En estas circunstancias la componente corrida al rojo de la emisión de maser de OH sería absorbida y aparecería al observador mucho más débil que la componente corrida al azul. Usando el *VLA* a 6 y 2-cm buscamos emisión de radio continuo en una lista de estrellas OH/IR con emisión de maser de OH asimétrica (componente corrida al azul más fuerte que componente corrida al rojo). No se detectó ninguna de las fuentes, concluyendo que ellas se encuentran aún en la etapa del superviento y que la asimetría en la emisión de maser de OH es debida probablemente a asimetrías en la envolvente y no a la presencia de una región interna ionizada.

Un modelaje sencillo de la transición de supergigante roja a nebulosa planetaria sugiere que la etapa de coexistencia de radio continuo con emisión de maser de OH dura sólo unas décadas. Puesto que la etapa de superviento dura unos miles de años, es necesario observar un gran número de estrellas OH/IR (10^2 o más) para tener una probabilidad significativa de detectar objetos en dicha etapa de transición.

ABSTRACT

The coexistence of ionized gas and OH maser emission is possible during the transition from red supergiant star to planetary nebula. Under these circumstances the redshifted OH complex emission may be absorbed by the ionized core and will appear weaker than the blueshifted OH maser emission. Using the *VLA* at 6 and 2-cm we searched for radio continuum emission in a list of OH/IR stars with such an asymmetric OH maser emission. No detections were made, and we conclude that these stars are still in the superwind phase and that the OH asymmetry is caused by envelope asymmetries and not by the presence of an ionized core.

A simple modeling of the transition from red supergiant star to planetary nebula suggests that the coexistence of radio continuum emission and OH maser emission lasts only a few tens of years. Since the superwind phase lasts a few thousand years, it is needed to survey a large sample (10^2 or more) of OH/IR stars to have a significant probability of detecting objects in the transition.

Key words: MASERS -- RADIO SOURCES–GENERAL -- STARS–SUPERGIANTS

I. INTRODUCTION

The transition from red supergiant to planetary nebula is an evolutionary stage that remains poorly studied, both observationally and theoretically. At present, it is believed that planetary nebulae form as a consequence of the massive wind that appears at the end of the evolution in the asymptotic giant branch (Renzini 1983; Baud and Habing 1983). This envelope is later ionized by the hot stellar nucleus. On these grounds, one would expect that a certain fraction of the evolved stars with massive winds could have the inner part of their envelopes ionized. Spergel, Giuliani and Knapp (1983) searched for 6-cm continuum emission from a sample of 31 evolved red giants with high mass loss rates. Only two tentative new detections were reported (IRC+10216 and *o* Ceti).

In this paper we present observations of radio continuum toward several evolved stars. To select them, we introduced the following main criterion. Many evolved stars are associated with OH maser emission usually dominated by the satellite-line transition at 1612 MHz. The OH spectra are characterized by two complexes of emission lines which are separated by 10 to 50 km s^{-1} in radial velocity (Reid and Moran 1981). The blueshifted and redshifted complexes are believed to be coming mainly from the front and back parts of the envelope, respectively. The OH maser-emitting regions are located relatively far from the star ($\sim 10^{15}$ cm). If ionized gas were present in the inner parts of the envelope, it would probably be optically thick at the relatively low frequency of 1612 MHz. Correspondingly, the emission from the redshifted 1612 MHz complex would be absorbed by the ionized gas and would appear much weaker, if at all, than the blueshifted emission. In §II we present the observations of a sample of OH star with these characteristics. Our interpretation of the data is

TABLE 1

WATER-VAPOR MASERS DETECTED

Source	α (1950)	δ	Peak Flux (Jy)	v_{LSR} (km s^{-1})	Δv (km s^{-1})
G5.9 – 0.4	$17^h57^m27^s$	– 24°03ʹ56″	172	20.6	0.6
G26.2 – 0.6	18 38 33	– 06 17 53	12	55.5	1.6

TABLE 2

FLUX UPPER LIMITS FOR THE OBSERVED STARS

Star	α (1950)	δ	Upper Limit[a] (mJy) 6-cm	Upper Limit[a] (mJy) 2-cm
G345.0 + 15.7	$16^h03^m00\overset{s}{.}0$	– 30°41′24″	0.3	1.0
G15.7 + 0.8	18 13 26.7	– 14 56 34	0.3	1.0
G20.7 + 0.1	18 25 44.3	– 10 52 51	0.4	0.9
G27.3 + 0.2	18 37 42.0	– 05 00 36	0.4	1.0
G35.6 – 0.3	18 54 56.0	+ 02 07 42	0.4	0.9
IRC + 10420	19 24 26.7	+ 11 15 10	0.3	0.8
G83.4 – 0.9	20 49 10.3	+ 42 36 54	0.4	0.7

a. Four-sigma upper limits.

given in §III and our conclusions are summarized in §IV.

II. OBSERVATIONS

From the catalog of Engels (1979) we selected 8 late-type stars having S_{1612} (blueshifted) > $2S_{1612}$ (redshifted). Here, S is the peak flux density of the emission complex. As a second discriminator these 8 stars were observed for H_2O maser emission from Haystack Observatory[1]. The observations were made with a digital autocorrelator covering a velocity range of about 90 km s^{-1} centered at the radial velocity of the star, as estimated from the OH data. Water-vapor maser emission was detected in two of the eight sources, G5.9–0.4 and G26.2–0.6. The parameters of the H_2O masers are given in Table 1. Since H_2O maser emission originates at distances ∿ 10^{14} cm from the center of the star, which correspond to the inner parts of the envelope, we considered unlikely that these two sources had ionized gas there, since dissociation of the H_2O would have occurred. We found during the preparation of this paper that G5.9–0.4 is a peculiar source that is associated with the H II region W28 (Genzel and Downes 1977) and could be an interstellar maser and not an OH/IR star. The remaining six stars plus IRC+10420 (Table 2) were observed with the *Very Large Array*[2] in 1985 March 12.

The observations were made at 6 and 2-cm, for which the *VLA*-A provides angular resolutions of ∿ 0″.3 and 0″.1, respectively. We used an effective bandwidth of 100 MHz. The amplitude calibrator was 3C286 and each source was observed at each frequency for two periods of 10 minutes, preceded and followed by observations of a convenient phase calibrator. The data were calibrated and edited following the *VLA* procedures. Maps of ∿ 26″ X 26″ (at 2-cm) and ∿ 78″ X 78″ (at 6-cm) did not reveal sources at the levels given in Table 2. Our upper limits are similar to those obtained by Herman, Baud, and Habing (1985) for another sample of OH/IR stars. Some of the 6-cm maps suggested, by the presence of sidelobe contamination, that sources could be present away from the phase center. Larger maps confirmed this possibility, and the parameters of the sources detected are given in Table 3. We will assume that these sources are unrelated to the stars studied, given the relatively large angular separation between the radio source and the star. The most interesting of these field sources is a relatively strong double source (Figure 1), most

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2. The *VLA* is part of the National Radio Astronomy Observatory, which is operated by Associated Universities, Inc., under contract with the National Science Foundation.

TABLE 3

FIELD SOURCES

α (1950)	δ	Peak Flux[a] (mJy)
$18^h25^m32^s.7$	$-10°48'58''$	8.7
18 37 55.6	− 05 00 36	72.5
18 55 05.8	+ 02 08 28	9.0

a. For a synthesized beam of ∿ 3″ and corrected for primary beam response.

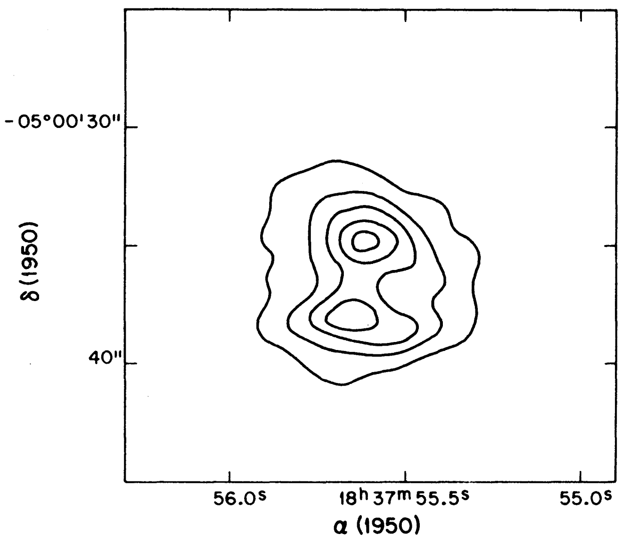

Fig. 1. *VLA* map at 6-cm of the double radio source detected in the field of G27.3+0.2. This source is far from the phase center of the observations and the map has significant radial smearing (mainly in the east-west direction) as a consequence of the finite bandwidth effect (Hjellming and Basart 1982). Contours are 0.1, 0.3, 0.5, 0.7 and 0.9 of the peak flux per beam, 72.5 mJy/beam.

probably a radio galaxy. From the amplitude versus (u,v) distance plot for this source, we estimate its total flux to be $\gtrsim 0.6$ Jy. This strong source is present in the 4.9 GHz galactic survey of Altenhoff *et al.* (1978). They measured a peak flux of 0.98 Jy for a beam of 2$'$.6.

III. INTERPRETATION

The upper limits obtained for the fluxes allow us to put upper limits on the parameters of any ionized gas present in the inner part of the stellar winds of the stars studied. If this ionized gas were optically thick at the observing frequencies, and assuming an electron temperature of 10^4 K, the typical upper limits ($\lesssim 0.4$ mJy at 6-cm and $\lesssim 0.9$ mJy at 2-cm) obtained in the continuum imply upper limits for the source angular diameter of $\Theta_s \lesssim 0''.04$ and $\Theta_s \lesssim 0''.02$, respectively. Distances to OH/IR stars are very poorly known. For the few cases where distance determinations have been given (Baud and Habing 1983), values are typically a few kpc. In their radio study of selected OH/IR stars, Herman *et al.* (1985) give a mean distance of 6.2 kpc. To continue our discussion, we will adopt a mean distance of 5 kpc to the stars observed. For this distance, the 2-cm upper limits imply a radius, $r \lesssim 10^{15}$ cm, for any ionized region at the center of the envelope.

Herman *et al.* (1985) proposed as an explanation to their lack of detections that the transition between the OH/IR phase and the planetary nebula stage is much shorter than the duration of the superwind. In what follows we will explore quantitatively this explanation. To estimate the time variation of the radio flux in a planetary nebula, we used a model similar to that described by Spergel, Giuliani and Knapp (1983). This model calculates numerically the position of the ionization front of a spherically symmetric, expanding shell. We used the dust parameters given by Spergel, Giuliani and Knapp, a mass loss of 5×10^{-5} $M_\odot$ yr^{-1} and a wind terminal velocity of 30 km s^{-1}. The ionizing flux of the central star was approximated by $N_*(t) = 1.0\times10^{48}$ s^{-1} for $0 < t < 3.1\times10^9$ s^{-1}, and $N_*(t) = 3.1\times10^{57}/t$ s^{-1} for $t > 3.1\times10^9$ s^{-1}. This analytical expression crudely approximates the ionizing flux of the model of Paczynski (1971) for a core star with mass of 1.2 $M_\odot$ At $t = 0$ the envelope is assumed to have an outer radius of 2×10^{17} cm. This implies a mass of 0.1 $M_\odot$ in the envelope. The slow velocity wind is assumed to cease at that time, while the shell keeps expanding at constant velocity, $v = 30$ km s^{-1}. The effects of a fast wind (e.g., Kahn 1983), posterior to the end of the superwind, are not considered. The radius of the ionization front, as function of time, is shown in Figure 2. Assuming $A_V = 10^{-21}$ N_H, where A_V is the visible extinction and N_H is the column density of hydrogen, it is possible to estimate A_V for the envelope. In Figure 2 we show the visible extinction obtained for a line of sight going from the surface of the envelope to the nucleus, for the cases when dust survives and when it is instantly destroyed in the ionized region. Finally, in Figure 2 we also show the 6-cm flux density as a function of time for the model, as well as the spectral index, defined as

$$\alpha = \frac{\log[S_{2\text{-cm}}\, S_{6\text{-cm}}]}{\log[6/2]} \quad .$$

For these calculations we used an ionized shell model similar to that described by Kwok (1977), and again adopted a distance of 5 kpc.

From this simple model we can conclude that there is a period of a few tens of years where the radio flux density is below present detectable values and the ionized gas is severely obscured by the dust. After this transition period the ionization front has run over the OH maser region, dissociating the molecule, and this type of emission will cease. The stars observed could be

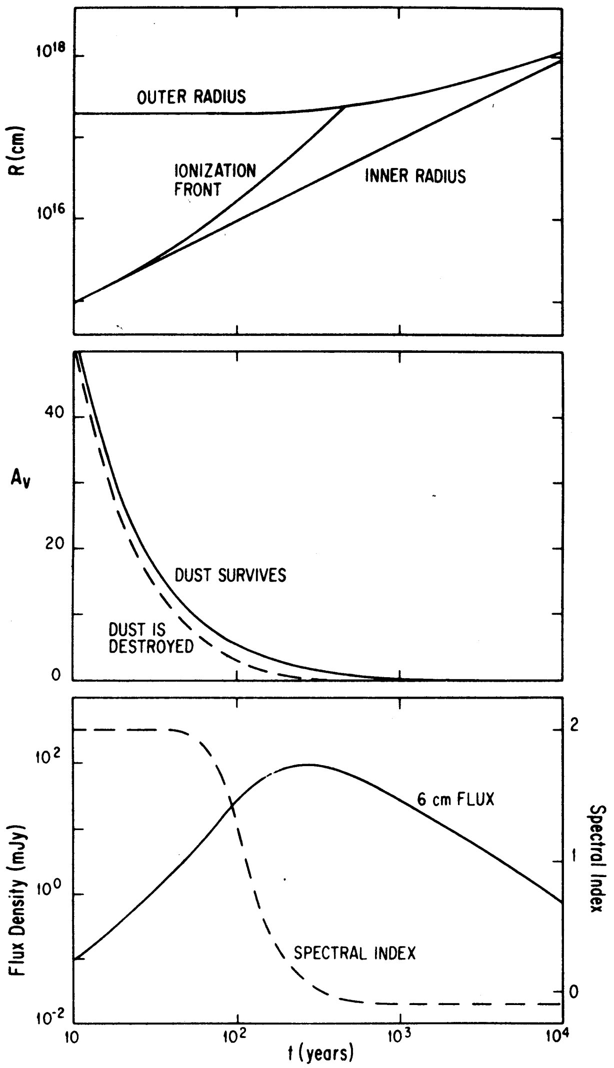

Fig. 2. Observational parameters as a function of time for the model planetary nebula described in the text. Top: inner radius, position of the ionization front and outer radius. Full ionization of the envelope is obtained at t $\simeq$ 500 years. Middle: extinction in the visible for a line of sight going from the outer surface of the envelope to the central star. The solid line is for the cáse of dust survival within the ionized gas and the dashed line is for instantaneous destruction of dust within the ionized volume. Bottom: flux density at 6-cm (solid line) and spectral index, as defined in the text (dashed line).

in this brief transition period. However, the superwind stage lasts a few thousand years and one expects that only about one in one hundred of a sample of supergiants would be in the transition to planetary nebula but still remain undetectable in the radio continuum. We suggest that the observed stars most likely do not have any ionized gas and are still in the superwind phase. The weak redshifted OH emission is probably due to an intrinsic asymmetry and not to an absorption effect. This conclusion is consistent with the existence of OH/IR stars in the catalog of Engels (1979) that have a stronger redshifted emission complex as compared with the blueshifted complex.

IV. CONCLUSIONS

1. We did not detect radio continuum emission at 6 or 2-cm in our sample of OH/IR stars. These stars are most probably still in the superwind phase and the asymmetry in their OH maser emission is caused by envelope asymmetries and not by absorption of the redshifted component by an ionized core.

2. A simple modeling of the stellar envelope for the transition from red supergiant to planetary nebula suggests that radio continuum and OH maser emission can coexist only for a few decades. Since the superwind phase is believed to last a few thousand years, large samples (10^2 or more) of OH/IR stars should be surveyed to have a significant probability to detect objects in the transition.

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