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OH COUNTERPARTS FOR H_2O MASERS IN THE GALACTIC CENTER: EVOLVED STARS INSTEAD OF SIGNS OF RECENT STAR FORMATION

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ABSTRACT

We present the detection of OH maser emission associated with the H_2O masers recently found in the Galactic center by Levine et al. and by Yusef-Zadeh & Mehringer. The 1612 MHz OH masers were found in high-sensitivity maps created by combining 17 VLA observations taken by van Langevelde et al. as well as in new observations with the ATCA. Both Levine et al. and Yusef-Zadeh & Mehringer consider the H_2O emission to be clues for recent massive star formation, by associating it with a supergiant and an H II region. The newly found OH masers show the typical double-peaked spectra for evolved oxygen-rich stars and do not stand out among other OH/IR stars in this region, either in H_2O or OH maser characteristics. We conclude that the H_2O maser detections are associated with evolved, low- to intermediate-mass stars, and that these H_2O masers thus cannot be regarded as signposts for massive young stars or star-forming regions.

Subject headings: Galaxy: center — infrared: stars — masers — stars: AGB and post-AGB — stars: formation — surveys

1. INTRODUCTION

Claimed signs of recent massive star formation in the inner few parsecs of the Galactic center (GC) have resulted in an ongoing debate. The total mass and luminosity of young stars found until recently has been insufficient to power and drive the phenomena in the central few parsecs of our Galaxy, giving rise to searches for signs of a central engine, an accretion disk around a massive black hole. Recent reports on the detection of young and massive stars, which could provide the energy needed to explain the observations, undermine the necessity for a massive black hole located in the center (for a review, see Genzel, Hollenbach, & Townes 1994; Lacy et al. 1980; Krabbe et al. 1995; Zylka et al. 1995).

From the observations presented here, we cannot tell whether massive star formation has occurred in the past couple of hundred million years. We merely want to react upon Letters written by Levine et al. (1995, hereafter LFMM) and by Yusef-Zadeh & Mehringer (1995, hereafter Y-ZM), both of whom used an H_2O maser as evidence for recent or ongoing massive star formation in the central 10 pc of the GC.

LFMM associate the H_2O maser with a luminous and massive supergiant that could be physically connected to the circumnuclear disk and hence argue for recent star formation. The link to ongoing high-mass star formation by Y-ZM is based on the absent 1612 MHz OH maser emission and the coincidence of the H_2O maser with a possible shocked or pressurized molecular cloud.

However, in two surveys to find new OH masers for dynamical studies, we have found that both H_2O maser sources coincide with 1612 MHz OH maser sources, both with a double-peaked spectrum, which is typical for oxygen-rich stars undergoing spherical mass loss on the asymptotic giant branch (AGB). As the OH and H_2O maser emission characteristics seem to indicate that both objects are AGB stars (OH/IR stars or Mira variables), the two H_2O masers found by LFMM and Y-ZM cannot be used as proper indicators for star formation in the GC in the last couple of hundred million years.

In the following sections we describe the method of detection and present 1612 MHz OH spectra. The characteristics of the observed OH and H_2O maser emission will be discussed and compared to masers of previously known OH/IR stars in the GC. We discuss the near-infrared photometry available for the LFMM source in terms of an evolved AGB star. We argue that both objects are low- to intermediate-mass, evolved stars and therefore at least several hundred million years old (see Iben & Renzini 1983 for a review on AGB star evolution).

2. OBSERVATIONS

In a monitoring program with the VLA,[2] van Langevelde et al. (1993) observed the strongest OH/IR stars found by Lindqvist et al. (1992b) in a survey of the GC in the 1612 MHz maser line of the OH molecule (see van Langevelde et al. 1993 and Lindqvist et al. 1992b for details on the observations). We have combined 17 epochs of the monitor data into a high-sensitivity visibility data set. OH/IR stars can vary up to a factor of 2 in integrated 1612 MHz flux densities. The profile of OH/IR stars varies with periods in the range of 400–2000 days (e.g., van Langevelde et al. 1993). Finding weak OH/IR stars in this combined data set is therefore probably more efficient than searching each epoch separately or searching new high-sensitivity observations at one epoch. The data reduction techniques and our final results, including a com-

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[2] The Very Large Array (VLA), as part of the National Radio Astronomy Observatory, is operated by Associated Universities, Inc., under cooperative agreement with the National Science Foundation.

TABLE 1

H_2O AND OH DETECTIONS

Survey	Right Ascension (1950)	Declination (1950)		Radial Velocity[a] (km s^{-1}) Low	Mean	High	Resolution	Line Flux (mJy km s^{-1})
			LFMM Source: OH 359.956-0.050					
H_2O LFMM	17^{h}42^{m}32^s.00	−28°58′47″.8	(±0″.2)	···	45.3	55.8	(5.0)	···
H_2O Y-ZM	17 42 31.87	−28 58 46.8	···	···	44.7	···	(2.6)	603
OH VLA	17 42 31.95	−28 58 47.9	(±1.9)	34.3	48.5	62.7	(1.2)	610
OH ATCA	17 42 31.96	−28 58 50.0	(±3.3)	34.2	50.2	66.2	(1.5)	190
			Y-ZM Source: OH 359.980-0.077					
H_2O Y-ZM	17^{h}42^{m}41^s.65	−28°58′26″.78	···	86.1	···	···	(2.6)	112
OH VLA	17 42 41.71	−28 58 25.80	(±0.63)	85.4	104.7	124.0	(1.2)	360
OH ATCA	17 42 41.64	−28 58 27.15	(±0.73)	85.1	104.7	124.3	(1.5)	640

[a] With respect to LSR.

plete list of many weak and previously unknown OH masers in the GC, will be presented in a forthcoming paper.

In addition, we used the ATCA[3] in 1994 July to search for high-velocity OH/IR stars (Sjouwerman et al. 1996). Both OH data sets have comparable sensitivities and are about 4 times more sensitive than the original Lindqvist et al. (1992b) survey.

We give the OH counterpart detections and approximate integrated flux densities in Table 1. Allowing for resolution and possible systematic effects in the radio maps, the OH maser positions are consistent with the H_2O masers. Both sources are clearly variable in the OH maser line, but it is difficult to interpret the integrated flux density from the VLA data, since the flux density is an average over 17 epochs, taken in a time span of almost 3 years. The 1612 MHz spectra from the VLA data can be found in Figures 1*a* and 1*b*. In Figures 2*a* and 2*b* the spectra from our ATCA survey are displayed. Note that there are considerable difficulties when reaching such low noise levels in the GC area; residuals of the extended OH absorption, continuum subtraction, and very strong maser sources cause the poor baselines in both the VLA and ATCA data. The OH masers have expansion velocities of about 15 and 19.5 km s^{-1} centered on stellar radial velocities (line of sight, with respect to the LSR) of about 49 and 105 km s^{-1}, respectively, very well in agreement with the observations of LFMM and Y-ZM. We therefore believe the H_2O and OH masers are associated with the same object in both cases.

[3] The Australia Telescope Compact Array (ATCA) is operated by the Australia Telescope National Facility, CSIRO, as a National Research Facility.

3. DISCUSSION

Most of the previously unknown double-peaked OH masers found are seen in both the combined VLA monitor data and our new ATCA observations. So far we have only searched for OH emission exceeding 40 mJy, which is already a factor of 2.5

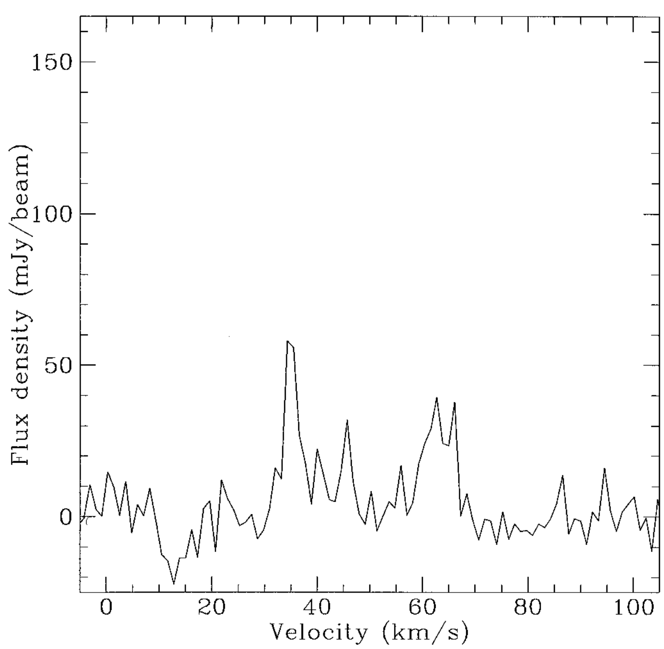

FIG. 1*a*

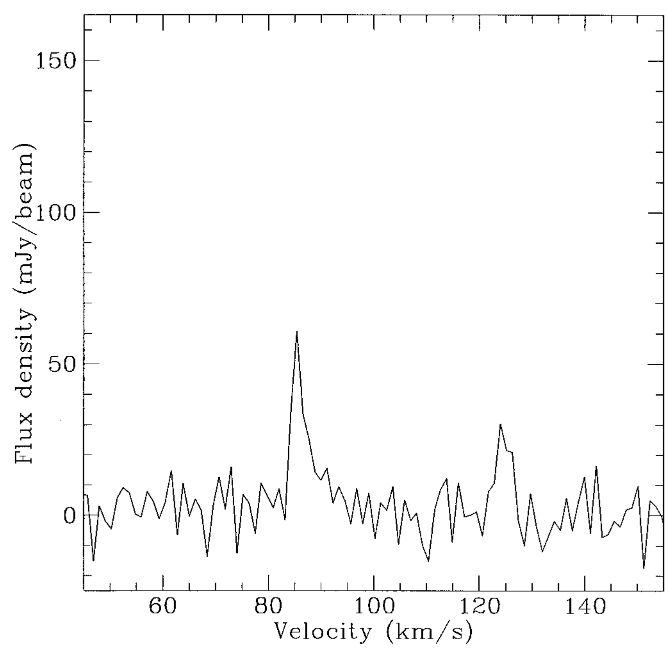

FIG. 1*b*

FIG. 1.—1612 MHz OH spectra from the VLA monitor: (*a*) OH 359.956−0.050, the counterpart for the H_2O maser found by LFMM, and (*b*) OH 359.980−0.077, the counterpart for the H_2O maser found by Y-ZM. Both spectra are an average over 17 epochs.

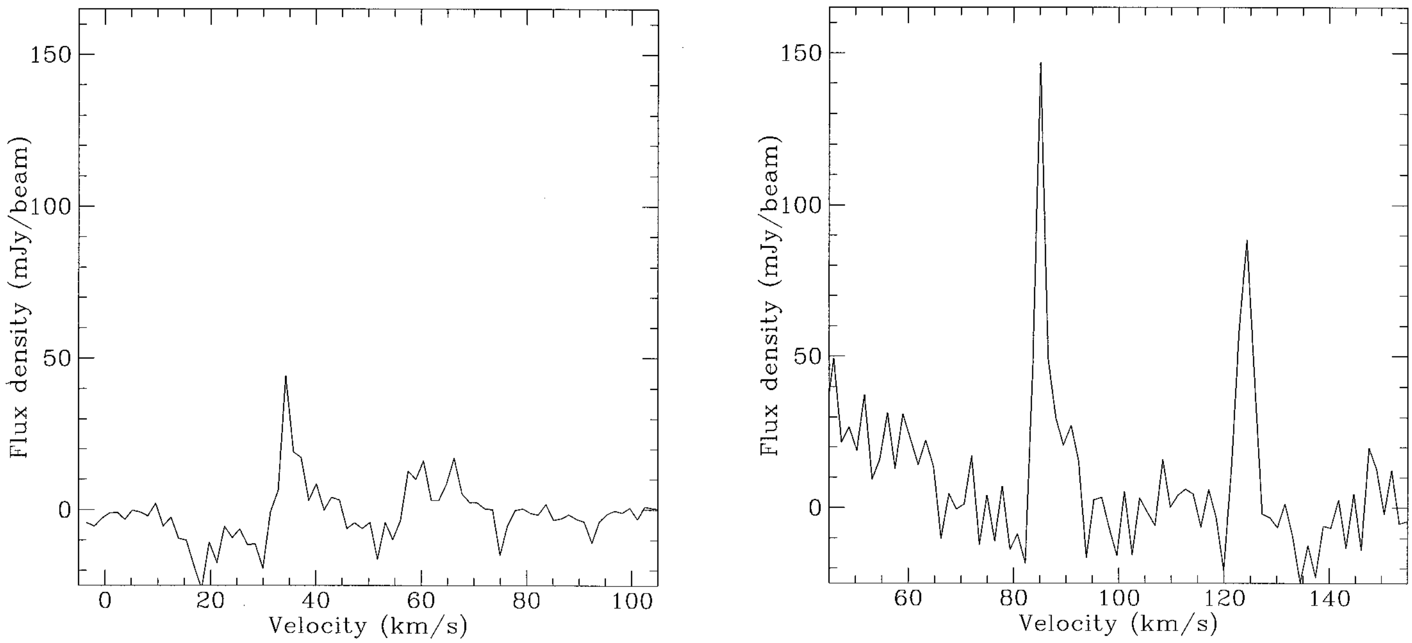

FIG. 2a

FIG. 2b

FIG. 2.—1612 MHz OH spectra from the ATCA survey: (*a*) OH 359.956−0.050 (LFMM) and (*b*) OH 359.980−0.077 (Y-ZM)

deeper than the Lindqvist et al. (1992b) survey. The weaker intrinsic OH emission explains why LFMM and Y-ZM unsuccessfully searched the survey of Lindqvist et al. (1992b) for a previous OH detection of their H_2O maser sources.

We assume that our new, double-peaked OH masers are associated with objects similar to the Lindqvist et al. (1992b) stars, i.e., low- to intermediate-mass, evolved AGB stars. We reach this conclusion by noting that our newly detected OH masers compare very well with the stronger OH masers detected by Lindqvist et al. (1992b) in all their properties (sky distribution, radial velocity distribution, expansion velocities, OH maser variability). Also, the expansion velocity distribution ranges from about 5 to 30 km s^{-1} and has a mean of 17 km s^{-1} for both the known and newly found OH/IR stars in the GC (see, e.g., Blommaert, van Langevelde, & Michiels 1994). Adopting the same metallicity, the distribution of the expansion velocities indicates a similar bolometric luminosity distribution for the weaker OH maser stars (Habing, Tignon, & Tielens 1994); they appear not to be different from the previously known OH/IR stars in any other respect than showing a weaker OH maser.

Parallel to the observations of LFMM and Y-ZM, our group has conducted a VLA survey for H_2O maser emission in the 150 OH/IR stars found previously near the GC. The detection rate for H_2O in OH/IR stars is low, partly because the H_2O masers are intrinsically weak. Also, in contrast to the OH masers, the H_2O maser emission varies strongly and irregularly. At the distance of the GC, as a consequence of sensitivity limits, one will find in most cases only one dominant H_2O peak near one of the OH maser peaks, a few km s^{-1} closer to the mean velocity, or H_2O emission at the mean velocity. The H_2O masers in the GC that we and Lindqvist, Winnberg, & Forster (1990) did detect in OH/IR stars, as well as the detections of LFMM and Y-ZM, all have similar H_2O maser characteristics: a double-peaked H_2O profile with the same mean (stellar) velocity as the OH maser or one single peak close to the mean velocity (e.g., Engels, Schmid-Burgk, & Walmsley 1986). The combination of the LFMM and Y-ZM H_2O masers and our OH detections fit the general OH/IR star maser picture as outlined above. For supergiants and star-forming regions, one finds in general much stronger H_2O masers with a complex spectral profile (see Engels, Schmid-Burgk, & Walmsley 1988; Reid et al. 1988).

In general, the OH maser luminosities for evolved, low- to intermediate-mass OH/IR stars are 1–100 times higher than the H_2O maser luminosities. Depending on the mass-loss rate, occasionally the opposite is also found for the thinner circumstellar shells of Mira and semiregular variables (e.g., Bowers & Hagen 1984). Of course, when working with variable sources one has to be careful to make comparisons between luminosities. Nevertheless, we think we can regard the H_2O luminosity for the Y-ZM source to be less than the OH luminosity, suggesting that this object is a regular OH/IR star, whereas the comparison of OH and H_2O for the LFMM maser indicates a thinner circumstellar shell (see Table 1).

Lindqvist, Habing, & Winnberg (1992a) discuss the kinematics of the OH/IR stars found in Lindqvist et al. (1992b). In good agreement with the results of McGinn et al. (1989), Sellgren et al. (1990), and Rieke & Rieke (1988) for K and M giants, the OH/IR stars show Galactic rotational behavior. The stars have a large dispersion in radial velocity (70 km s^{-1} or more), and the agreement of the radial velocity of the LFMM star with the circumnuclear disk is in our view accidental. The agreement is not strong evidence for such an object to be young, i.e., a couple of tens of million years.

The strongest argument by LFMM for a young age of the star associated with the H_2O maser is its very high luminosity (100,000 $L_\odot$). LFMM derive this from *H*-, *K*-, and *L*-band photometry by arguing that these observations are consistent with an M5 supergiant, seen at large visual extinction ($A_V \approx 37$) when applying a standard interstellar reddening law. With the knowledge that the star must have a considerable circumstellar shell, because it supports an OH 1612 MHz maser, the red colors of the object can be understood readily with less foreground extinction. Moreover, following the identification with a circumstellar shell, the near-infrared flux is produced mostly by this extended envelope. Hence the bolometric correction is much more moderate, resulting in a lower bolometric luminosity for the star.

The detailed calculation of a total luminosity or an accurate bolometric correction is quite uncertain because only near-infrared colors are available. Most of the luminosity is expected at the M band and beyond, where the extinction correction would be less steep as well. Correcting the photometry with a standard extinction law (Rieke & Lebovsky 1985) and a value of $A_V = 30$, which seems more appropriate for the location of this object (Catchpole, Whitelock, & Glass 1990), we find colors that are quite blue for OH/IR stars but still consistent with a circumstellar envelope. We estimate a bolometric correction in the L band of 4.9 mag in this case (see Jones et al. 1994). With these uncertainties, the total bolometric luminosity could be in the range 7000–10,000 $L_\odot$. In fact, the interstellar extinction law is a possible source of uncertainty, and we favor a reddening law based on extinction curve 15 of van de Hulst (1949) for the GC, which leads to an even lower bolometric luminosity of 5500 $L_\odot$ (Blommaert et al. 1996; Blommaert 1992, chap. 3; van Langevelde 1992, chap. 7).

The estimated luminosity, based on the identification as an AGB star, is comparable to the luminosity of the known OH/IR stars in the GC (Jones et al. 1994; Blommaert et al. 1992). This indicates a main-sequence mass of the star on the order of 2 $M_\odot$ and an age largely exceeding several hundred million years (e.g., van der Veen & Habing 1990). The near-infrared colors would then imply a $(K - L)_0$ as low as 0.56, corresponding to a mass-loss rate of about 3.5×10^{-6} $M_\odot$ yr^{-1} (Lepine, Ortiz, & Epchtein 1995). This mass-loss rate is sufficient to form an OH masering circumstellar shell (Bowers & Hagen 1984), but the low value of $(K - L)_0$ also indicates the circumstellar shell itself is optically thin in the near-infrared, such as in the optically visible Mira variables or proto–planetary nebulae (e.g., Lepine et al. 1995). The latter, however, normally have no H_2O masers (Lewis 1989). A thin circumstellar shell is also justified by the earlier remark that the H_2O luminosity might be higher than the OH luminosity. We therefore base our classification of the LFMM object as an evolved low-mass Mira-type OH/IR star on the OH maser profile and the OH and H_2O maser characteristics. This is entirely consistent with the near-infrared measurements taken by LFMM.

A final remark about the object found by LFMM concerns an article written by McGinn et al. (1989). They use integrated infrared starlight to determine mean stellar velocity and velocity dispersion in several 20″ diameter telescope apertures to probe the stellar kinematics and mass distribution in the GC. One of the telescope beams (45″ NE) is pointed toward the LFMM maser source, and McGinn et al. (1989) derive an average stellar velocity of 48 ($\pm$8) km s^{-1} for this beam. This is exactly the velocity of the LFMM maser source. It seems likely that the LFMM maser source has dominated the telescope beam. The observation of an increasing velocity dispersion toward the dynamical center seen by McGinn et al. (1989), and also by Sellgren et al. (1990), could differ from the constant velocity dispersion observed by Rieke & Rieke (1988), because of telescope beams being dominated by single stars instead of representing true stellar averages.

In summary, we conclude that the H_2O maser of Y-ZM is associated with an evolved OH/IR star. We think the H_2O maser found by LFMM, instead of being a massive supergiant, is more likely to be a Mira-type OH/IR star. We cannot rule out recent massive star formation in the GC, but we do conclude the H_2O masers found by LFMM and Y-ZM do not support the presence of a young population of massive stars.

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