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DETECTION OF 6 CENTIMETER OH EMISSION FROM THE MIRA VARIABLE AU GEMINORUM

MARK J. CLAUSSEN AND JOHN D. FIX
Department of Physics and Astronomy, University of Iowa
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ABSTRACT

Fourteen stars which are known to emit ground-state OH maser radiation were examined for excited-state emission from the $^2\pi_{1/2}$, $J = \frac{1}{2}$ state at 6 cm. One star, AU Gem, was found to have such emission at the 4750 MHz transition, the only main line ($\Delta F = 0$) in the multiplet. We believe that AU Gem is the first star from which 6 cm OH emission has been observed.

Subject headings: masers — stars: long-period variables — stars: mass loss

I. INTRODUCTION

Ground-state OH maser emission has now been detected from many very cool giant and supergiant stars. Although many models for the production of maser emission in the envelopes of cool stars have been proposed, the most successful and widely accepted are those in which the masers are pumped by infrared radiation from warm circumstellar dust. For some combinations of parameters, these models can produce inversions not only of ground-state levels but also of excited levels, including the $^2\pi_{1/2}$, $J = \frac{1}{2}$ level within which the transitions at 4660, 4750, and 4765 MHz occur (Litvak, Zuckerman, and Dickinson 1969). Since it is apparent that the detection (or nondetection) of emission at these lines can provide meaningful information about the populations of excited levels of OH molecules in circumstellar shells, we examined a number of stars known to emit 18 cm ground-state OH radiation for emission in the 6 cm multiplet.

II. OBSERVATIONS

The observations were carried out using the 305 m telescope at the Arecibo Observatory[1] on 1981 April 12, 13, and 14. The surface was illuminated by a 16 foot flat line feed. The receiver was a one-channel cooled parametric amplifier which received linear polarization from the feed. The system temperature ranged from 90 to 110 K, and the sensitivity of the system was measured to be between 1.4 and 1.5 K Jy^{-1}.

On April 12 and 13, simultaneous observations of the 4750 and 4765 MHz lines were carried out. For each line the total velocity range was 80 km s^{-1} with a smoothed resolution of 0.6 km s^{-1}. Our list of sources was selected primarily on the basis of the strength of the 18 cm OH lines. When two stars competed for telescope time, we observed the one with stronger 18 cm OH emission. U Aur, however, was observed although it has been detected in water vapor but not OH. Many strong OH emitters could not be observed because they lie outside the range of declinations observable at Arecibo or because they could not be observed during the sidereal times (LST = $3^{\rm h} \rightarrow 10^{\rm h}, 15^{\rm h} \rightarrow 23^{\rm h}$) for which we were granted telescope time. On April 14 the strongest 18 cm OH emitters plus AU Gem were observed with the same velocity range and resolution, but at 4600 MHz. In all cases, the observations were carried out in a frequency switched mode.

III. RESULTS AND DISCUSSION

Table 1 lists the stars observed at Arecibo, the lines at which each star was observed, and the rms noise per channel. Of the fourteen stars observed, only one, AU Gem, was found to have detectable emission. For AU Gem a single feature was detected at the 4750 MHz line and at a velocity (LSR) of 3.5 km s^{-1}. The line was observed on both April 12 and April 13. The average of the spectra obtained on those days is shown in Figure 1.

AU Gem (IRC +30195) is a Mira variable with a spectral type of M10 and a period of 424 days (Kukarkin *et al.* 1969). Its $I - K$ color index is 5.6 mag (Neugebauer and Leighton 1969). The distance to AU Gem (Nguyen-Q-Rieu *et al.* 1979), calculated using a period-magnitude relation (Clayton and Feast 1969), is 2.4 kpc. Main-line OH emission at 1667 MHz was discovered by Nguyen-Q-Rieu *et al.* (1979) who reported two features at 0.0 and 12.9 km s^{-1} and having peak fluxes of 70 and 200 mJy, respectively. At the same time they searched unsuccessfully for emission at 1612 MHz. We reobserved AU Gem at 1667 MHz on 1981 May 11 using the 18.3 m telescope at the North Liberty Radio Observatory. At that time the 1667 MHz emission was less than 2.5 Jy, indicating that AU Gem had not undergone a dramatic increase in its 1667 MHz output since it was discovered to be a main-line maser.

[1]The Arecibo Observatory is part of the National Astronomy and Ionosphere Center, operated by Cornell University under contract with the National Science Foundation.

TABLE 1

STARS OBSERVED AT 6 CENTIMETERS

Source	RMS Noise (mJy) 4750, 4765 MHz	RMS Noise (mJy) 4660 MHz
IK Tau	20	50
U Aur...........	30	...
U Ori	20	30
AU Gem	20	20
R LMi	20	...
R Leo...........	20	...
U Her...........	10	...
R Aql...........	15	25
IRC +10420 ...	20	25
SY Aql	30	...
UX Cyg	20	...
UU Peg	20	...
RV Peg	20	...
R Peg...........	30	...

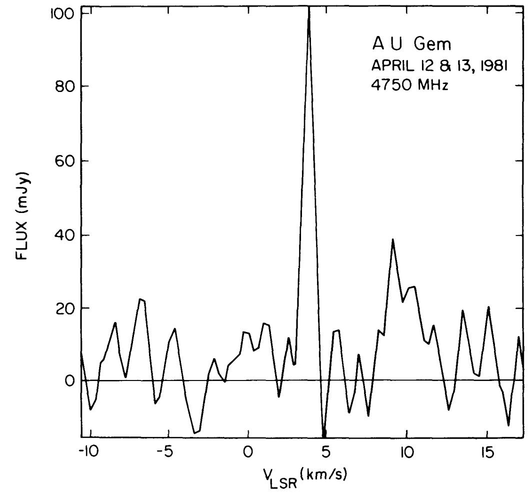

FIG. 1.—The 4750 MHz spectrum of AU Gem

AU Gem is the first star to be detected in the 6 cm multiplet, despite rather extensive searches by Baudry (1974) and Thacker, Wilson, and Barret (1970). Only one star, NML Cyg, detected at 5 cm in the $^2\pi_{3/2}$, $J = \frac{5}{2}$ multiplet by Zuckerman *et al.* (1972), has been detected at any excited-state OH line. For NML Cyg, the excited-state emission is much weaker than the ground-state emission. In AU Gem, however, this is not the case. The peak fluxes of the lines at 18 cm (200 mJy) and 6 cm (100 mJy) are comparable. The rough equality of the peak fluxes at 18 cm and 6 cm requires that the product of the fractional population inversion and the total coherent population of the masing column be similar for the lines. If the fractional inversions for different multiplets are comparable, as suggested by Litvak, Zuckerman, and Dickson (1969) and discussed by Baudry (1974), then the total populations of the ground and excited states must be comparable as well.

It is noteworthy that the velocity of the 6 cm peak in AU Gem does not correspond to either spectral feature in the 1667 MHz spectrum. However, a possible second feature at 9.1 km s^{-1} (2.3 σ) would complete a double-peaked structure within the 6 cm spectrum, with each 6 cm peak lying about 3.5 km s^{-1} nearer the central velocity (7 km s^{-1}) than do the 18 cm peaks. This could indicate that the expanding shell containing excited OH lies nearer the central star than does the shell within which the ground-state OH masers are produced. It seems plausible that the same region which produces the 6 cm OH masers could also yield detectable emission from other excited multiplets, especially the one at 5 cm. It is interesting that 6 cm OH emission can be found in AU Gem, an inconspicuous object in the 18 cm lines, but not from stars with ground-state OH peak fluxes hundreds of times larger than that of AU Gem. We speculate that there may be a class of cool stars with circumstellar shells within which conditions are favorable for the production of 6 cm (and other excited-state) masers, but not ground-state masers. Since the stars which have been examined for excited OH maser emission are generally those which have already been detected in the ground-state lines, there may be many detectable 6 cm maser objects which have gone unexamined.

IV. CONCLUSIONS

Fourteen stars have been examined for 6 cm OH emission, improving on upper limits for some sources and taking a first look at others. One star, AU Gem, was found to show 6 cm emission. It is possible that the 6 cm emission comes from an expanding shell lying closer to the central star than the region of 18 cm emission.

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MARK J. CLAUSSEN and JOHN D. FIX: Department of Physics and Astronomy, Physics Building, University of Iowa, Iowa City, IA 52242