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VLBI OBSERVATIONS OF THE WATER VAPOR MASERS IN CEPHEUS A, S252A, GL 2789, GL 2139, CO 59.79+0.04, W33B, AND U ORIONIS

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ABSTRACT

We report VLBI observations with angular resolution of 0".003 of H_2O maser sources associated with Cepheus A, S252A, GL 2789/V645 Cyg, GL 2139, CO 59.79+0.04, W33B, and U Ori. The absolute positions of the masers were measured to an accuracy of 0".3. Positional coincidences were found between two groups of maser spots and two very compact H II regions in Cep A, and between the maser spots and a stellar-like optical image in GL 2789. In the case of Cep A, we found that the line widths of individual maser components varied as the $\frac{1}{3}$ power of the flux densities.

Subject headings: interferometry — interstellar: molecules — masers

I. INTRODUCTION

The association of H_2O masers with regions of recent star formation has been extensively documented (e.g., Habing and Israel 1979, and references therein). However, the detailed structure of the maser emitting regions and the physical nature of their association with the star formation process is poorly understood. In order to acquire a better understanding of the relationship between the appearance of maser spots and the process of star formation, we conducted a VLBI experiment on selected galactic H_2O maser sources. The 845 km baseline provided typical angular resolutions of $\sim$0".003 and enabled us to construct detailed maps of small-scale source structure. Numerous observations of extragalactic continuum sources enabled us to determine absolute positions accurate to about 0".2. Thus we accurately located the maser positions relative to compact radio, infrared, and optical objects in those sources where high-resolution observations at other wavelengths existed (i.e., Cep A, S252A, and GL 2789). Close positional coincidences were found between the H_2O maser spots and the compact continuum sources in Cep A and between the H_2O maser spots and a stellar-like optical knot in GL 2789. The masers in S252A have no detected compact radio continuum counterparts. We also obtained accurate maps and positions for H_2O masers associated with the young regions W33B, GL 2139, CO 59.79+0.04, and the evolved star U Ori. A detailed understanding of the relation of these masers to star formation requires high-angular-resolution studies of related objects at other wavelengths.

II. OBSERVATIONS

The interferometer elements used for these observations were the 43 m antenna of the National Radio Astronomy Observatory (NRAO) and the 37 m antenna of the Haystack Observatory. The baseline was 845 km, and the maximum fringe rate sensitivity was 20 mHz arcsec^{-1}. Both antennas were equipped with receivers having maser preamplifiers and hydrogen maser frequency standards. The data were recorded on the standard Mark II VLBI system and processed at NRAO with fringe rate analysis programs (see Moran 1976; Giuffrida 1978; Walker *et al.* 1981). Our analysis included the use of the multiple fringe rate mapping programs whereby many features at the same velocity that are separated by more than the fringe rate beam of $\sim$0".05 can be distinguished and mapped.

The experiment was conducted in a 72 hour period in the interval 1979 January 12–15. Weather conditions at both sites included periods of clear sky, snow, freezing rain, and fog. Each maser source had associated with it one or more calibrator source. The basic observing sequence consisted of a 15 minute observation of a calibrator source followed by a 45 minute observation of the maser. This sequence was followed for each maser source over a full track from horizon to horizon at the observing telescopes. The frequent calibration allowed us to make good estimates of maser source positions.

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III. RESULTS

a) *Absolute Positions*

The absolute positions of the masers were determined from the fringe rate data. Each maser observation was divided into three sections of 10 minute duration each (approximately the coherence time of the interferometer), and the fringe rate of a reference feature was measured for each section. There were 99 fringe rate measurements among the seven maser sources. A single fringe rate measurement was made for each observation of a calibrator. The calibration sources were 3C 345(7), 3C 120(2), 3C 84(5), NRAO 150(3), 4C 39.25(5), BL Lac(2), 3C 545.3(6), 3C 273(5), NRAO 530(3), and PKS 2134+004(3), where the number of observations of each calibrator is given in parentheses after its name. The position of each calibrator was estimated as the weighted mean of the positions given by Wade and Johnston (1977), Rogers *et al.* (1973), Clark *et al.* (1976), and Elsmore and Ryle (1976). From the consistency among observations, these calibrator positions appear to be accurate to about 0ʺ.03. A least mean square analysis was performed on the entire data set of 137 fringe rate measurements, and 18 parameters were estimated: the 14 coordinate parameters for the seven masers, the two equatorial baseline coordinates, the excess propagation delay in the zenith direction, and the frequency difference between the maser frequency standards. The maser positions are listed in Table 1 along with the positions of nearby objects of interest. We estimate that the systematic error in our position determinations is about 0ʺ.2, and this error has been added in quadrature to the formal errors to give the errors listed in Table 1.

b) *Source Spectra and Maps*

i) *Cep A*

Figure 1 shows the total-power and cross-power spectra for the Cep A maser. The ratio of the cross-power and the total-power spectrum at any velocity is the normalized fringe visibility. Figure 2 shows the cross-power spectrum for Cep A on a logarithmic scale. We identified 10 individual maser components labeled A–J in Figure 2. The relative positions of these components are listed in Table 2.

In Figure 3 the maser components are shown relative to the 6 cm continuum emission observed with the VLA (Rodriguez *et al.* 1980). The maser spots are clustered into two groups separated by approximately 4ʺ or 4×10^{16} cm assuming a distance of 700 pc (Blaauw, Hiltner, and Johnston 1959). These two groups are examples of "centers of activity," discussed by Genzel *et al.* (1978), and each group is associated with a compact continuum source. The northern group consists of components A, D, E, F, G, I, and J which lie within a region having approximate dimensions of 0ʺ.7 × 0ʺ.3 (7×10^{15} by 3×10^{15} cm). The three components of the southern group, B, C, and H, are clustered within an area ~0ʺ.1 or 10^{15} cm in diameter. Blitz and Lada (1979) found several high-velocity spectral features which would have been outside the passband of the VLBI experiment. The spot map may, therefore, be incomplete with regard to the high-velocity maser emission.

ii) *S252A*

The H_2O spectra for the S252A maser are shown in Figure 4. Comparison of the total-power and cross-power spectra suggests that most of the H_2O emission originates

TABLE 1

POSITIONS OF MASERS AND OTHER COMPACT OBJECTS

Source	Object	α(1950)[a]	δ(1950)	Ref[b]
Cep A	H_2O(−5.29 km s^{-1})	22ʰ54ᵐ19ˢ.23 ± 0ˢ.03	61°45′44ʺ.1 ± 0ʺ.2	1
	H II	22 54 19.21 ± 0.07	61 45 44.1 ± 0.5	2
S252A	H_2O(1.5 km s^{-1})	06 05 36.52 ± 0.015	20 39 34.3 ± 0.3	1
	H II(A3)	06 05 33.7	20 39 47	3
GL 2789	H_2O(−50.2 km s^{-1})	21 38 10.62 ± 0.03	50 0 42.7 ± 0.2	1
	Optical (N0)	21 38 10.61 ± 0.03	50 0 42.6 ± 0.2	4
	IR (4.6 μm)	21 38 10.4 ± 0.6	50 0 44 ± 5.0	5
CO 59.79+0.04	H_2O(12.0 km s^{-1})	19 41 4.23 ± 0.03	23 36 42.4 ± 0.5	1
W33B	H_2O(58.8 km s^{-1})	18 10 59.24 ± 0.02	−18 02 40.9 ± 0.3	1
	OH(61–65 km s^{-1})	18 10 59.6 ± 0.4	−18 02 47 ± 3	7
	H II	18 11 01.0 ± 0.7	−18 01 42 ± 10	8
	IR (169 μm)	18 10 58.6 ± 2	−18 01 20 ± 30	9
GL 2139	H_2O(43.5 km s^{-1})	18 20 27.88 ± 0.02	−13 44 22.5 ± 0.3	1
	IR	18 20 25	−13 42 54	6
U Ori	H_2O(−41.3 km s^{-1})	05 52 50.91 ± 0.02	20 10 6.2 ± 0.3	1
	Optical[c] (SAO 7457V)	05 52 51.01 ± 0.05	20 10 5.8 ± 0.7	10

[a] 1σ error including a contribution of 0ʺ.2 for systematic effects.

[b] Ref. (1) This paper; (2) Rodriguez *et al.* 1980; (3) Felli, Habing, and Israel 1977; (4) Cohen 1980; (5) Joyce *et al.* 1977; (6) Walker and Price 1976; (7) Wynn-Williams, Werner, and Wilson 1974; (8) Bieging, Pankonin, and Smith 1978; (9) Stier 1979; (10) SAO Catalog 1966.

[c] Proper motion from 1950 to 1979.1 included.

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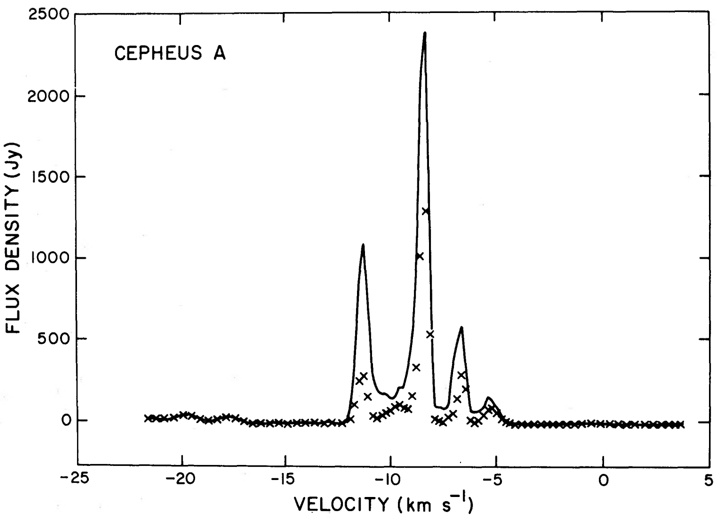

FIG. 1.—The total-power spectrum and a cross-power spectrum of the Cep A maser obtained during our VLBI experiment. The cross-power spectrum represents only one 15 minute scan and was constructed using standard fringe rate analysis. The velocity axis is referred to the local standard of rest and a rest frequency of 22235.080 MHz. The ratio of the cross-power and total-power spectra at any velocity is the normalized fringe visibility.

in a few spots. From multiple fringe rate analysis we identify five individual maser components whose relative positions are listed in Table 2. The maser emission originates from four locations within a region having a diameter of approximately 2″3 ($\sim 2.8 \times 10^{16}$ cm), comparable to the largest scale size in Cep A.

The S252A maser was first detected by Lada and Wooden (1979), who made detailed CO observations of this region of young star formation, and also observed by Genzel and Downes (1979). The maser is located near a strong peak in the CO emission but does not appear associated with any structures in the 6 cm continuum map made by Felli, Habing, and Israel (1977).

iii) *GL 2789*

The H_2O maser in GL 2789, also designated V645 Cyg, was first observed by Sargent (1979). Figure 5 shows the total-power and the cross-power spectra for the object. We mapped three individual components in the cross-power spectrum: two originate from the same position on the sky and the third is $\sim$0″2 away. All three spots are coincident with a stellar-like optical image in the V645 Cyg complex, and the complex itself is coincident with a CO bright spot within the large molecular cloud associated with the H II region S124.

iv) *CO 59.79+0.04*

Spectra for the H_2O maser associated with CO 59.79+0.04 are shown in Figure 6. We identified three spectral components whose velocities and positions are listed in Table 2. The three spots are clustered with an area of diameter 0″1. The CO cloud and H_2O maser were first observed by Blitz, Cohen, and Lada (1981) who found the H_2O maser to be near the position of both a CO

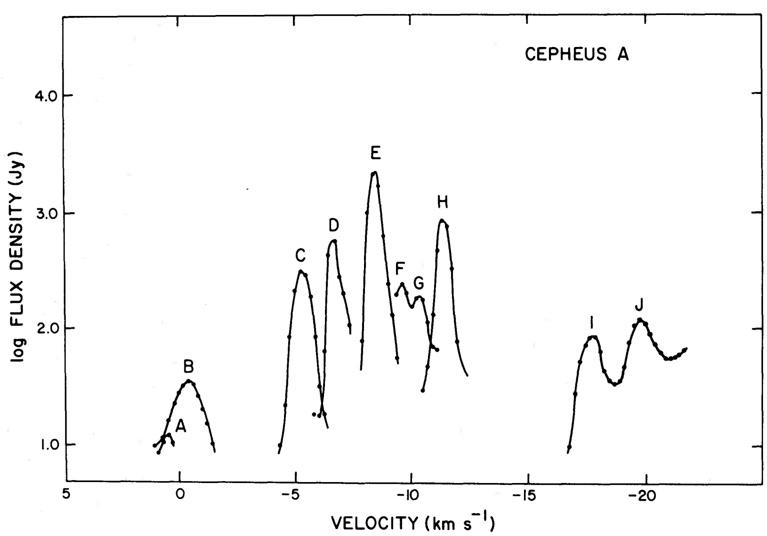

FIG. 2.—Cross-power spectrum of Cep A derived using the multiple fringe rate analysis technique and plotted on a log scale. These data are the average of all the scans obtained during our observing run.

TABLE 2

RELATIVE POSITIONS OF H_2O MASER FEATURES

Source		Velocity (km s^{-1})	ΔX[a] (″)	ΔY[a] (″)
Cep A	(A)	+0.57	−1.533 ± 0.004	3.280 ± 0.004
	(B)	−0.36	0.097 ± 0.001	−0.068 ± 0.001
	(C)	−5.29	0	0
	(D)	−6.64	−1.267 ± 0.002	2.923 ± 0.002
	(E)	−8.42	−1.265 ± 0.005	2.957 ± 0.005
	(F)	−9.65	−1.309 ± 0.007	3.714 ± 0.007
	(G)	−10.36	−1.315 ± 0.001	3.714 ± 0.001
	(H)	−11.37	0.046 ± 0.001	0.004 ± 0.001
	(I)	−17.69	−1.306 ± 0.001	3.316 ± 0.001
	(J)	−19.76	−1.306 ± 0.001	3.316 ± 0.001
S252	(A)	+10.9	1.139 ± 0.003	2.968 ± 0.006
	(B)	+9.8	−1.844 ± 0.003	6.19 ± 0.01
	(C)	+8.8	−2.014 ± 0.005	6.34 ± 0.015
	(D)	+8.2	−1.904 ± 0.002	3.800 ± 0.004
	(E)	+1.5	0	0
GL 2789	(A)	−50.2	0	0
	(B)	−48.9	0.000 ± 0.001	0.000 ± 0.001
	(C)	−44.5	0.049 ± 0.001	0.182 ± 0.002
H_2O 59.79+0.04	(A)	+20.6	−0.064 ± 0.002	−0.02 ± 0.01
	(B)	+18.7	−0.094 ± 0.004	−0.04 ± 0.01
	(C)	+12.0	0	0
W33B	(A)	+60.5	0.013 ± 0.001	0.015 ± 0.003
	(B)	+58.8	0	0
	(C)	+56.9	0.013 ± 0.002	−0.040 ± 0.004
	(D)	+56.1	0.016 ± 0.001	−0.042 ± 0.004
GL 2132	(A)	+44.3	−0.01 ± 0.02	0.01 ± 0.02
	(B)	+43.5	0	0
	(C)	+41.8	0.04 ± 0.01	−0.06 ± 0.01
	(D)	+40.1	−0.01 ± 0.01	−0.01 ± 0.01
	(E)	+32.5	0.00 ± 0.01	−0.03 ± 0.02
U Ori	(A)	−41.3	0	0
	(B)	−40.0	−0.012 ± 0.001	0.002 ± 0.003
	(C)	−38.8	−0.014 ± 0.001	0.007 ± 0.004
	(D)	−35.8	0.013 ± 0.002	−0.005 ± 0.01

[a] Position with respect to reference features. Absolute positions of the reference features are given in Table 1.

bright spot and radio H II region. However, other than the water maser, no observations of this source have been made at a resolution less than 2′.5. The strongest component of the maser is blueshifted by 9 km s^{-1} with respect to the velocity centroid of the molecular complex, but the two weaker features are closer to the CO velocity.

v) *W33 B*

Figure 7 shows the spectra we obtained for the W33 B H_2O maser. We identified four individual components, all of which are clustered within an area having a diameter of 0″.05. The maser appears to be associated with a distant, cool H II region (Bieging, Pankonin, and Smith 1978) and possibly with a far-infrared source (Stier 1979). CO and radio recombination-line emission and H_2CO absorption were detected at the velocity of the maser (Wilson and Bieging 1977; Blitz, Cohen, and Lada 1981). However, unlike most young H_2O masers, there is no significant increase in the CO emission on any size scale from 1′–30′ at the position of the W33 B maser (Cohen 1980; Blitz, Cohen, and Lada 1981; Ho 1981). It is curious that this apparent protostellar or neostellar source has not heated its placental cloud sufficiently to be detectable as enhanced CO emission. However, contrary to the CO and H_2CO results, Ho, Martin, and Barret (1980) found the emission in the $(J, K) = (1, 1)$ transition of NH_3 to have a strong maximum at the position of the H_2O maser. The difference between these observations could be explained if there were a foreground cloud at nearly the same velocity as W33 (the entire region is obscured optically) with optically thick CO and H_2CO lines but optically thin NH_3 emission. The CO and H_2CO lines from the protostellar source would then suffer absorption, while the NH_3 lines would be little affected. This situation could arise if the W33 B cloud were at the far kinematic distance of 13.7 kpc and the foreground cloud were at the near kinematic distance of 5.4 kpc. This hypothesis could be tested by observing the region in an optically thin species such as $C^{18}O$, to see if it shows a maximum at the maser position.

vi) *GL 2139*

Spectra for the maser associated with GL 2139 are shown in Figure 8. The maser was found by Blitz, Cohen,

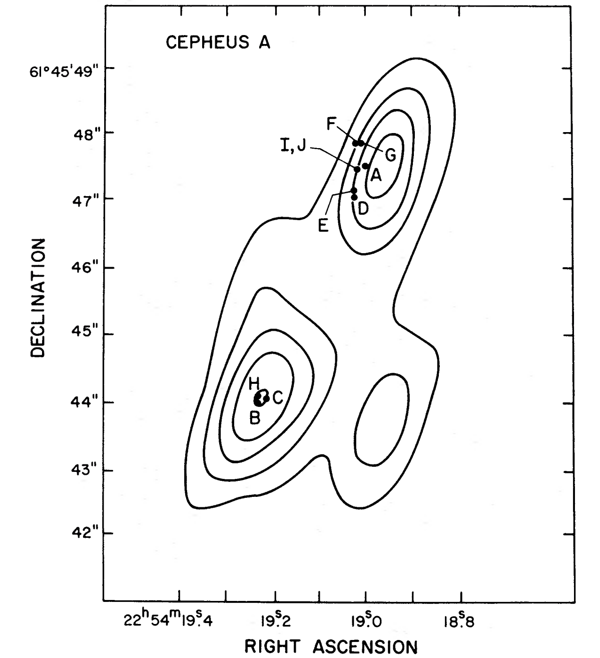

FIG. 3.—Map of the relative positions of the Cep A H_2O maser spots superposed on the 6 cm VLA continuum map of this region obtained by Rodriguez *et al.* (1980). Contours are in units of 0.76 mJy per beam area. The resolution was about 1″

and Lada (1981) in the molecular ring near a large molecular complex (CO 17.25−0.20) which they mapped. The complex is 6.0 kpc from the galactic center and is either 6.0 or 16.1 kpc from the Sun. The most intense component of the maser emission occurs at a velocity of 43.5 km s^{-1}, approximately equal to the velocity of the molecular complex. The maser occurs at the position of the infrared source but is displaced 19′ from the peak of the CO emission. Additional CO observations are needed to determine whether the maser and infrared source are part of the CO 17.25−0.20

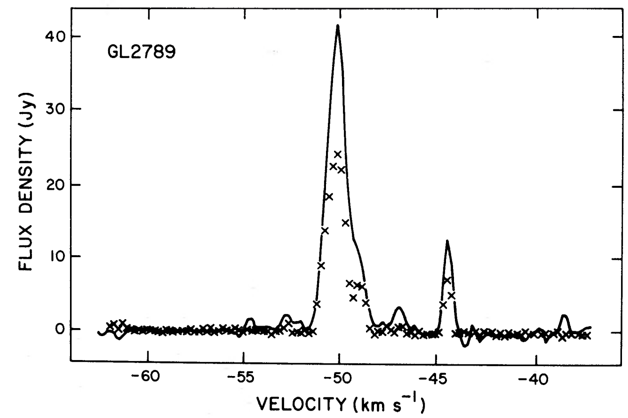

FIG. 5.—Spectra of the maser source in GL 2789. Otherwise same as Fig. 1.

complex or are independent objects with nearly identical velocities.

vii) *U Ori*

U Ori is a well known, long period variable (LPV) star. These stars can be strong H_2O, OH, and SiO maser sources, and many VLBI observations have been made of this type of source (see, e.g., Reid *et al.* 1977; Spencer *et al.* 1979; Moran *et al.* 1979). The maser emission from LPV stars probably comes from expanding circumstellar envelopes of gas and dust. U Ori was included in the present experiment when total-power spectra, taken just prior to the experiment (Bowers and Reid 1980, private communication) revealed that the H_2O emission had recently flared up. Such a flare-up has been seen in the 1612 MHz OH emission from U Ori in 1973 (Pataki and Kolena 1974). The OH maser emission was mapped in 1975 (Reid *et al.* 1977) and found to be concentrated in three clumps separated by only 0″.2.

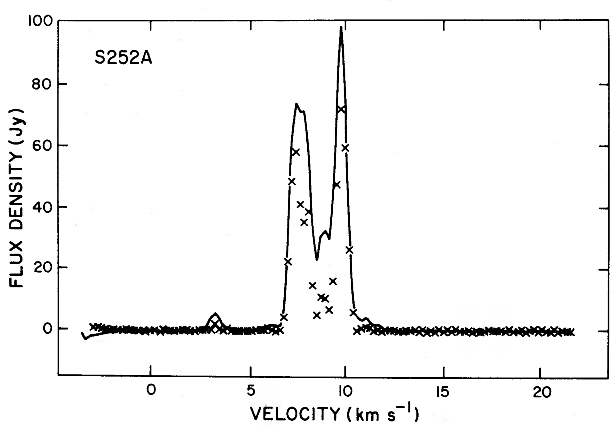

FIG. 4

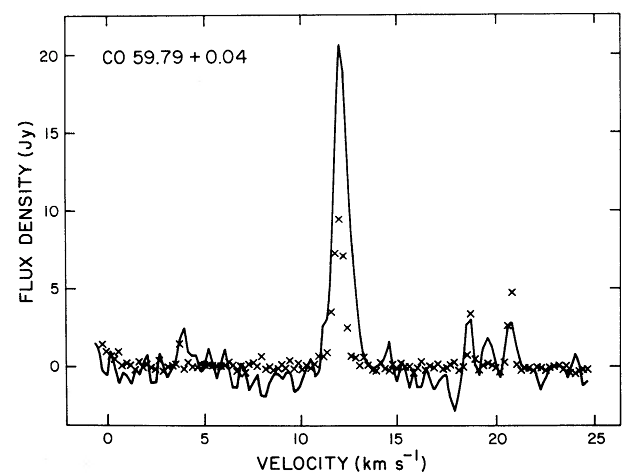

FIG. 6

FIG. 4.—Spectra of the S252A maser source. Otherwise same as Fig. 1.
FIG. 6.—Spectra of the maser source associated with CO 59.79+0.04. Otherwise same as Fig. 1.

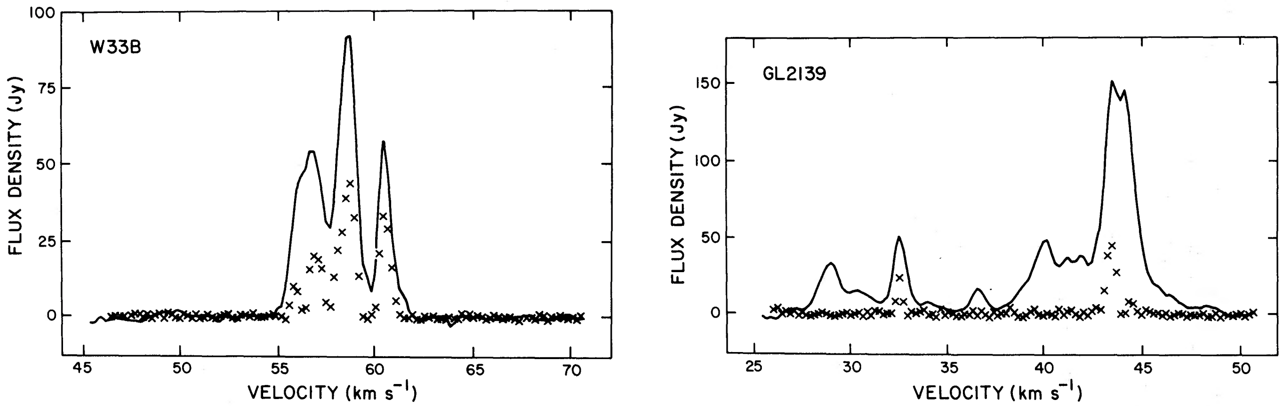

FIG. 7 FIG. 8

FIG. 7.—Spectra of the W33B water maser. Otherwise same as Fig. 1.
FIG. 8.—Spectra of the H_2O maser associated with GL 2139. Otherwise same as Fig. 1.

The H_2O total-power spectrum of U Ori from our experiment is shown in Figure 9, and the relative positions of the four identified components are given in Table 2. As is common in the LPV stars, the H_2O emission arises from a region less than 10 AU across. This is almost a factor of 10 smaller than the extent of the OH flare emission and is comparable to the diameter of the star. Thus, the H_2O emission probably originates within a few stellar radii of the star.

The H_2O spectrum is dominated by three nearly equal peaks whose LSR radial velocities are -35.8, -38.8, and -41.3 km s^{-1}. A very symmetrical triple-peaked spectrum might be expected if the H_2O emission originated in a rotating disk of circumstellar material (see Van Blerkom 1978). However, the -38.8 km s^{-1} feature, which is at the mid-point of the spectrum, does not appear to lie between the -35.8 and -41.3 km s^{-1} feature on the sky, which argues against a simple rotation model.

IV. DISCUSSION

a) *Cep A*

The H_2O maser associated with Cep A is one of the more intense water masers known. The spectrum consists of ~ 10 velocity components, and variations in the intensities of many of these components have been observed on time scales of less than two weeks (Rodriguez *et al.* 1980). A very luminous ($5 \times 10^4 L_\odot$), cool (88 K) infrared source and a pair of ultracompact H II regions have been found in the vicinity of this maser (Koppenaal *et al.* 1979; Beichman, Becklin, and Wynn-Williams 1979; Rodriguez *et al.* 1980). The CO emission has high-velocity wings indicating mass outflow from a compact object at a velocity of 40 km s^{-1} (Rodriguez, Ho, and Moran 1980). This complex of young objects appears to be within a dense fragment of a large molecular cloud (Sargent 1977) and may represent the youngest component of a sequen-

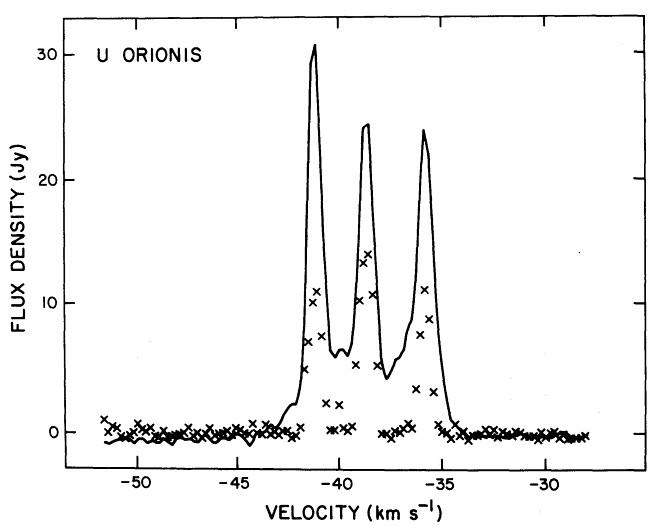

FIG. 9.—Spectra of the U Orionis maser. Otherwise same as Fig. 1.

tial formation pattern of OB subgroups in the Cepheus OB3 association (Blaauw 1964; Blitz and Lada 1979).

VLBI studies of many other maser sources associated with regions of star formation have revealed that maser spots cluster in centers of activity $\sim 10^{16}$ cm in extent (see, e.g., Johnston *et al.* 1977; Genzel *et al.* 1978). These studies suggest that each such center of activity may be identified with the envelope of a young massive star. However, lack of spatial coincidence between the maser spots and detectable compact H II regions or infrared sources has made it difficult to critically examine this suggestion.

Searches for embedded H II regions in Cep A by Beichman, Becklin, and Wynn-Williams (1979) and Rodriguez *et al.* (1980) using the VLA at a wavelength of 6 cm revealed two compact H II regions (~ 10 mJy) in the vicinity of the Cep A maser position. In Figure 3 we plot the positions of the maser components on the 6 cm continuum map of Rodriguez *et al.* The absolute positional accuracy of our VLBI observations for Cep A is about 0".2, and the absolute positional uncertainty in the VLA map is 0".5. Within the uncertainties, the two maser centers of activity are coincident with the centers of two ultracompact H II regions. *This close positional coincidence supports the contention that each maser center of activity is an individual structure associated with a young massive star.*

Rodriguez *et al.* (1980) estimate that the spectral types of the exciting stars for the two H II regions are B2 and B1.5 or possibly earlier if dust absorption of Lyman continuum photons within the compact sources is important or if the stars have not reached the main sequence. The total luminosity of the Cep A complex has been estimated from long-wavelength (20 μm–100 μm) infrared observations to be $\sim 2.5 \times 10^4\ L_\odot$ (Koppenaal *et al.* 1979). This is equivalent to a single B0 star or two B0.5 stars (ZAMS).

We found that the line widths of the H_2O maser features in Cep A appear to be correlated with their flux densities. This result has not been noted for any other masers. In Figure 10 the relation between line width and flux density for the H_2O maser components in Cep A is plotted on a log-log scale. The data are well fitted by a straight line whose slope indicates that

$$\Delta V \propto S^{-1/3}, \qquad (1)$$

where ΔV is the line width and S is the flux density. Qualitatively, this can be understood as a result of line narrowing during maser amplification. A preliminary analysis indicates that equation (1) can be explained if the maser is partially saturated, and somewhat beamed, and if the line narrowing continues after saturation, although more slowly than $\Delta V \propto \tau^{-1/2}$, where τ is the opacity in the maser line, for unsaturated amplification (see Goldreich and Kwan 1974). Alternatively, it is possible to explain the line width versus flux density behavior displayed in Figure 10 as due to turbulence within the masing region. In this case, the stronger, narrower features would emanate from regions of low turbulence, and the weaker broader features would emanate from regions

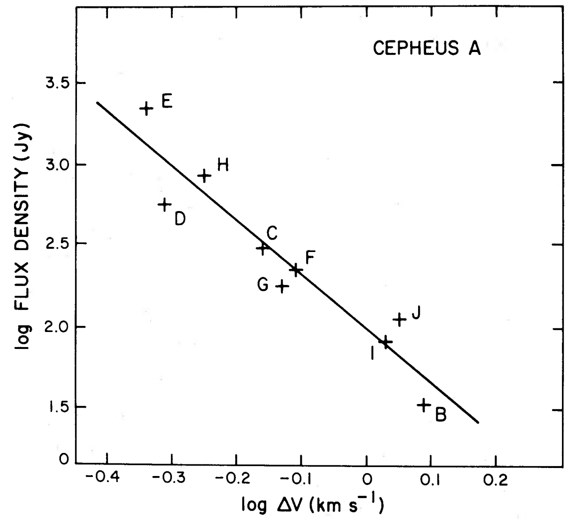

FIG. 10.—Plot of the relationship between flux density and line width for the individual components in the Cep A maser source. The data are well represented by the relation $\Delta V \propto S^{-1/3}$ which is described by the straight line in the diagram. Component A was not plotted since a reliable line width could not be obtained due to relatively low intensity.

of high turbulence. Our data are not adequate to distinguish between these possibilities. A full aperture synthesis of the maser source is required to determine whether or not the broader features are composed of multiple components.

b) GL 2789/V645 Cyg

GL 2789 is an unusual infrared source (Joyce *et al.* 1977), apparently associated with the optically variable star V645 Cyg. It has been extensively studied in the infrared, optical, and radio regions of the spectrum (Cohen 1977; Humphreys, Merrill, and Black 1980). The CO observations obtained by Harvey and Lada (1980) suggest that GL 2789 is embedded in a molecular cloud of relatively low column density whose LSR velocity (-45 km s^{-1}) implies a kinematic distance of 6 ± 1 kpc based on the CO rotation curve of Blitz, Fich, and Stark (1980). Observations by Blitz (1980, private communication) suggest that this molecular cloud is part of a large complex which includes the H II region S124. The infrared energy distribution of GL 2789 from 5 to 200 μm is much broader than that of a blackbody, suggesting emission from dust over a range of temperatures (Humphreys, Merrill, and Black 1980; Harvey, Thronson, and Gatley 1980), and also suggesting that GL 2789 is embedded within the molecular cloud (Harvey and Lada 1980).

The total integrated flux over the observed spectrum of GL 2789 suggests a luminosity of $9 \times 10^4\ L_\odot$ for a distance of 6 kpc. This is the luminosity of an O7.5 ZAMS star (Panagia 1973). From observations of the Brα recombination line at 2 μm, Harvey and Lada (1980) estimate that $N_e{}^2 V = 3.2 \times 10^{60}$ cm^{-3}, where N_e is the electron density and V is the emitting volume for GL 2789, which is equal to the total ionization of an O9 ZAMS star.

Surprisingly, Rodriguez and Moran (1980, private communication) mapped the region around GL 2789 with the VLA and found no continuum source within 30″ at a level of 2 mJy at 6 cm, implying that the radio continuum emission must be optically thick.

Optical observations of V645 Cyg are puzzling and have lead to conflicting interpretations of the nature of this object. Figure 11 shows a sketch of the optical appearance of this source based on a photograph and drawing published by Cohen (1977). The object appears to consist of a stellar-like image denoted as N0 in the notation of Cohen which is about 7″ from an extended nebulosity which consists of two main subcomponents, denoted N1 and N2. Cohen argues that the optical spectra of N0, N1, and N2 suggest an underlying star of spectral type O6–O9, whereas Humphreys, Merrill, and Black (1980) argued that the optical spectrum of N1 is in better agreement with a spectral type of A5e. Humphreys *et al.* suggest that the distance to V645 Cyg is only ~ 1 kpc and that the rough ($\sim 1'$) coincidence in the positions between the CO peak and V645 Cyg is fortuitous.

The VLBI observations enable us to place tighter constraints on interpretations of the nature of V645 Cyg. In particular the accurate positions we have obtained allow us to determine whether the H_2O maser spots are associated with any of the optical features. From the positions listed in Table 1 for the H_2O maser from our VLBI experiment, the 4.6 μm infrared emission measured by Joyce *et al.* (1977), and N0 obtained by Cohen (1980) it is clear that, within the observational errors, all three objects are coincident. In Figure 11 we plotted the positions of the H_2O maser spots on a sketch of the optical components of V645 Cyg. The angular coincidence at the arc second level of the maser and N0 indicates that the two sources are physically related. The velocity centroid of the maser is near -50 km s^{-1}, which greatly strengthens the contention that V645 Cyg and GL 2789 are at the distance of ~ 6 kpc and associated with the molecular cloud. This also implies that the spectral type is O, as Cohen (1977) originally suggested, and argues against the possibility that the underlying object is an Ae emission star.

An important question which remains unanswered is whether N0 is the image of the underlying star. Observations of the Brackett recombination lines and continuum at 2 μm indicate that the extinction toward the underlying star is relatively low ($A_V \sim 4$ mag), suggesting that the star should have an apparent magnitude of ~ 14, comparable to that of N0 (Harvey and Lada 1980). This suggests that the underlying star is located at the position of N0 and that a substantial amount of the light from N0 is stellar. Nevertheless, this is difficult to reconcile with the results of Cohen (1977) which showed that the light fron N0, N1, and N2 is partially polarized with similar position angles for each component, implying that some of the light fron N0 is reflected or scattered in a circumstellar shell. Since the infrared source is also coincident with N0, the underlying star and source of maser excitation must be at the position of N0, whether or not the actual optical light fron N0 comes directly from the star.

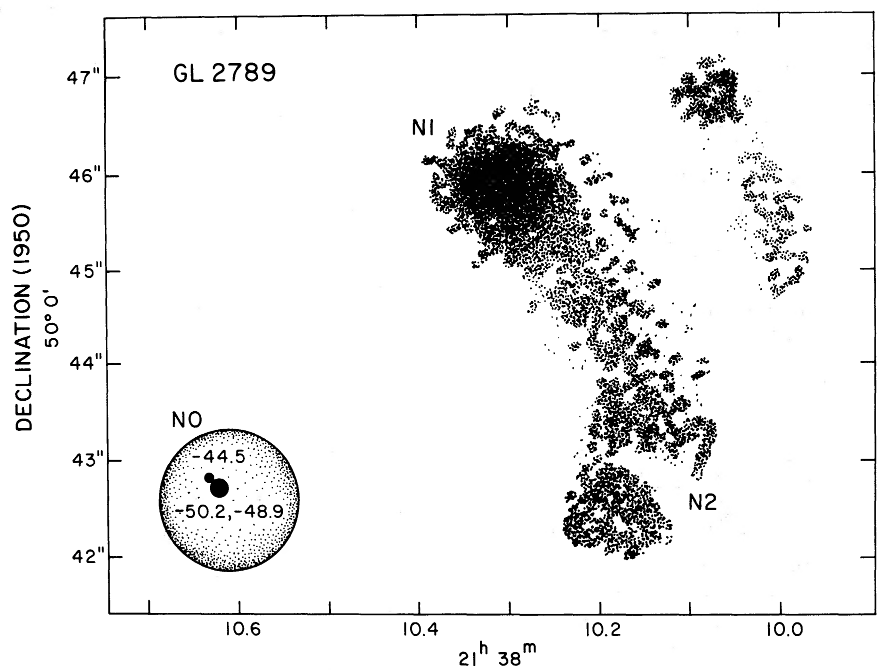

FIG. 11.—Sketch of the optical components of GL 2789/V645 Cyg adapted from Cohen (1977). The positions of the maser spots determined in our VLBI experiment are also plotted with the size of the maser spots in the drawing being proportional to their relative flux density. Note the remarkably close positional coincidence between the maser spots and N0, a stellar-like optical knot.

c) S252A

The H_2O maser in S252A is nearly coincident with a hot CO peak surrounding an optical emission knot which appeared to be associated with a compact H II region mapped by Felli, Habing, and Israel (1977) with the Westerbork array. The maser, CO peak, optical knot, and compact H II region appear to be embedded in a swept-up, high-density layer of the S252 molecular cloud, and this complex of young objects may represent the most recent burst of star formation in a sequential chain (Lada and Wooden 1979). Comparison of the VLBI position of the H_2O maser with the aperture synthesis map of Felli, Habing, and Israel (see their Fig. 5) shows that there is no continuum emission in the vicinity of the maser spots. The nearest significant continuum source is more than 10″ away. This is similar to the situation toward W30H (also at 2 kpc) where the H_2O masers are ~7″ away from the nearest continuum source. A clear understanding of the excitation source for this maser is not presently possible, but the data are consistent with the possibility that the S252A maser is excited by an embedded, as yet undetected, protostellar object.

V. CONCLUDING REMARKS

We made VLBI observations of H_2O maser sources in Cep A, GL 2789, S252A, GL 2139, CO 59.79+0.04, W33 B, and U Ori. We obtained precise absolute positions (accurate to 0″.3) for these sources, as well as relative positions of individual maser components in each source. We found that the positions of the H_2O masers in Cep A and GL 2789 locate the sources of maser excitation. It is noteworthy that in two of three sources in this study for which accurate positions of potential maser excitation sources are known the masers and underlying young stellar objects are coincident in angular position. This suggests that H_2O maser sources locate centers of activity surrounding individual young stellar objects as suggested by Genzel *et al.* (1978). For the Cep A maser we found an interesting correlation between the flux density and line width. Aperture synthesis observations of the Cep A maser are necessary to determine whether this correlation is caused by dynamical effects or by radiative processes in the maser itself.

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