Study of the H42a (86 GHz) Recombination Line in W3(OH)

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STUDY OF THE H42α (86 GHz) RECOMBINATION LINE IN W3(OH)

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ABSTRACT

We have observed the H42α recombination line at 86 GHz in the compact H II region W3(OH). We find the central velocity of the line to be -45.6 ± 1.0 km s^{-1}, only 1.3 km s^{-1} from the measured mean velocity of the OH masers in front of the region. We argue that the OH masers are not in free-fall onto the central O star, as suggested in 1980 by Reid *et al*. We also find the width of the line to be 27.3 ± 1.5 km s^{-1}, too small to fit the model proposed in 1983 by Berulis and Erschov of a shell expanding at 18 km s^{-1}.

Subject headings: masers — nebulae: H II regions — stars: circumstellar shells

I. INTRODUCTION

We report observations of the H42α recombination line emission from the H II region W3(OH) which provide important information about its dynamical evolution. W3(OH), a limb-brightened, compact H II region (Scott 1981; Dreher and Welch 1981), is a well-studied example of recent O star formation. At a distance of 2.2 kpc (Humphreys 1978), its angular size of 1''.25 corresponds to a linear diameter of about 0.02 pc. Its continuum emission displays shell-like structure and exhibits a spectral turnover near 12 GHz, becoming optically thin at higher frequencies. A cluster of 18 cm wavelength OH masers in front of the H II region emit at an average radial velocity of -44.3 km s^{-1} (Reid *et al.* 1980; Norris and Booth 1981). Emission from the ionized gas at 23 GHz was observed at average radial velocities of -52 ± 2 km s^{-1} in the H66α recombination (Hughes and Viner 1976) and -50.1 ± 1.1 km s^{-1} in the H65α line (Jaffe, Wilson, and Thomasson 1978). Suggesting that the mean velocity of the 23 GHz emission might correspond with that of the enclosed O star, Reid *et al.* (1980) proposed that the velocity difference between that of the masers and that of the ionized gas was due to residual infall of the masers and the outer neutral gas layer onto the star.

Further recombination line observations have been published by Thum, Mezger, and Pankonin (1980): -48.9 ± 0.4 km s^{-1} for H66α (23 GHz) and -51.3 ± 1.0 km s^{-1} for H76α (15 GHz), Wink, Altenhof, and Mezger (1982): -53.6 ± 1.3 km s^{-1} for H90α (9 GHz) and -50.6 ± 0.3 km s^{-1} for H76α (15 GHz), and Garay, Reid, and Moran (1985): -51.2 ± 0.2 km s^{-1} for H76α (15 GHz) and -49.6 ± 0.2 km s^{-1} for H66α (23 GHz). As well, ammonia observations in the (1,1), (2,2), and (3,3) lines by Wilson, Bieging, and Downes (1978) showed absorption at -44.5 km s^{-1}, close to that of the OH masers, and emission at -47.2 km s^{-1}. VLA studies at high angular resolution in ammonia by Guilloteau, Stier, and Downes (1984) and Reid, Myers, and Bieging (1987) show absorption at an average velocity of -44.8 km s^{-1}. Forster and Boland (1982), on the other hand, observed the peak of the 5 GHz H_2CO absorption to be at -46.6 km s^{-1}.

The study by Garay, Reid, and Moran (1985) showed a small, but evidently significant, difference between the velocity centroids at the two frequencies, 15 GHz and 23 GHz, in the sense that at the higher frequency the velocity difference with respect to the OH masers was smaller. Observing the H56α line at 37 GHz, Berulis and Ershov (1983) found the shift in the velocity centroid to continue to -47.6 ± 0.8 km s^{-1}. They interpreted the trend as the result of optical depth effects associated with a radial expansion of the ionized shell at a velocity of 18 km s^{-1} centered on a mean velocity of -46 km s^{-1}. Because the plasma absorption coefficient is inversely proportional to the square of the frequency, the optical depth decreases rapidly at the higher frequencies, where one may more reliably observe the true mean velocity of the H II region. In order to measure more accurately the average velocity of the plasma and better understand the velocity trend, we have studied the H42α emission at 86 GHz and report the results here.

II. OBSERVATIONS

The observations were carried out with the three-element millimeter-wave interferometer of the Hat Creek Observatory. Since the small H II region was spatially unresolved, the three baselines gave three independent spectral measurements of the line. Two sets of observations, one in 1985 November and the other in 1986 December, gave essentially the same result.

The average over the three baseline measurements for the latter observation is shown as a solid line in Figure 1. Because the signal-to-noise ratio of the 1985 data is 2–3 times poorer than that of the 1986 data, we do not include it in this figure. The spectral resolution is 2.1 km s^{-1}. The dashed line is a Gaussian fit having a centroid of -45.6 ± 1.0 km s^{-1} and FWHM of 27.3 ± 1.5 km s^{-1}. The ratio of line to continuum is 0.70. Figure 2 displays plots of velocity centroid and line width as functions of frequency for all the studies sited above, including the present. Wherever a line has been measured by several observers, we have used an average weighted by the reciprocal of the reported uncertainty. There is also a dashed line corresponding to both the mean velocity of OH maser

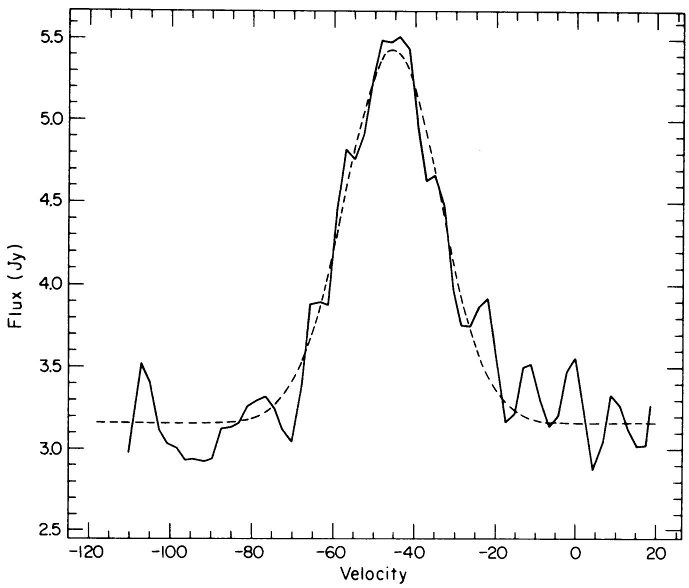

FIG. 1.—(*solid line*) Observation of the 86 GHz H42α recombination line. (*dashed line*) Gaussian fit. The continuum level is 3.2 Jy. Line center is -45.6 ± 1.0 km s^{-1}, and line width is 27.3 ± 1.5 km s^{-1}. Line/continuum is 0.70.

emission (Reid *et al.* 1980) and NH_3 absorption (Wilson, Bieging, and Downes 1978).

III. DISCUSSION

Figure 2 shows clearly that the trend in velocity shift of the recombination line toward higher velocities at higher frequencies continues to the H42α line at 86 GHz. Since the plasma absorption coefficient is proportional to the square of the electron density and inversely proportional to the square of the frequency, and the overall nebular spectral turnover is about 12 GHz, the optical depth at 86 GHz is probably very small everywhere in the nebula, even in the presence of density fluctuations. Because there is thus no shielding of the gas, the observed emission at 86 GHz should contain contributions from gas everywhere in the nebula, but will be most sensitive to the higher density regions. If the random motions of the gas are the same in every region and at all densities, our high-frequency line measurement should give a good measure of the average motion of the nebula. Then, if the average nebular motion is the same as that of the star, the line velocity centroid is a measure of the star's velocity. From this point of view, we have found the velocity of the central star to be -45.6 ± 1.0 km s^{-1}.

If the OH masers lie in a layer of neutral gas that is a remnant of the original accretion that formed the O star and is still in free fall, then its infalling velocity would be approximately $0.1[M(M_\odot)/R(\mathrm{pc})]^{0.5}$ km s^{-1}, where M is the mass of the O star and R is the distance of the layer from the star. From the high angular resolution VLA maps, we know that the radius of the H II region is about 0.01 pc. That is the minimum radius allowed the neutral gas layer which contains the OH masers (Dreher and Welch 1981). The nominal difference between the 86 GHz recombination line velocity and that of the OH masers is 1.3 ± 1.5 km s^{-1}. An infall of 1–2 km s^{-1} implies a mass of 1–4 $M_\odot$ for the star. On the other hand, the observed free-free radio flux of the H II region corresponds to that of an O7 ZAMS star whose mass is of the order of 25 $M_\odot$ (Dreher and Welch 1981). Even if the residual velocity difference is real, it is too small to represent remnant accretion in free fall onto the massive central star. We must emphasize here, however, that our conclusions rest on the assumption that the 86 GHz recombination line velocity represents the true velocity of the central star. It is possible, for example, that the recombination line emission might be dominated by a dense clump of gas that happens to be on the other side of the star and is redshifted because the nebula is expanding.

It is important in any case to understand the reason for the shift in the recombination velocity centroid with frequency, since it would be useful to be able to estimate the velocities of the central stars of compact H II regions from the nebular recombination lines. The possibility of detecting infall, as discussed above, is just one example of the potential value. Berulis and Ershov (1983) suggested that the effect might be due to the expansion of the dense outer shell of the H II

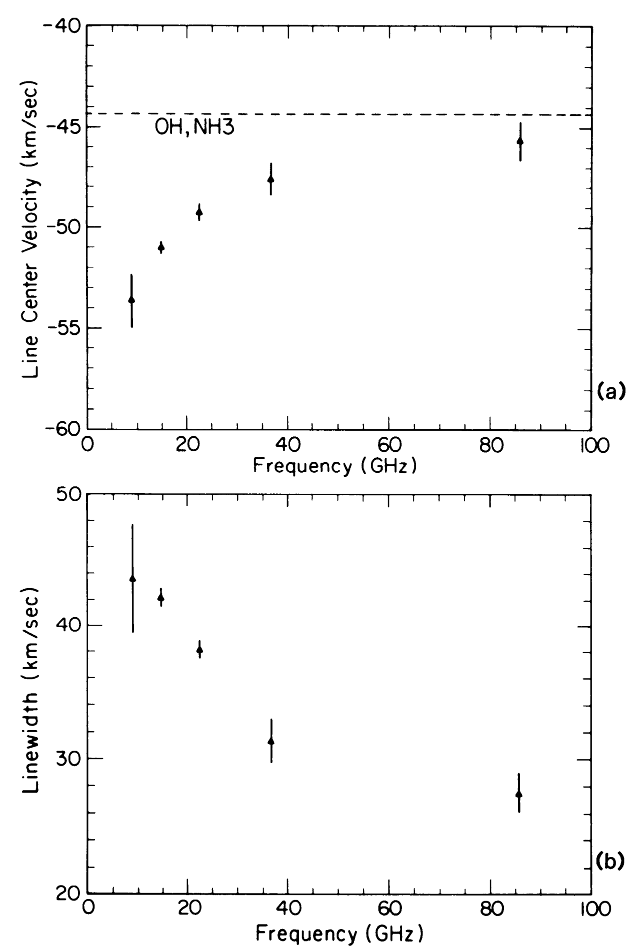

FIG. 2.—(*a*) Line center velocity as a function of transition frequency. Horizontal dashed line is the OH maser velocity and NH_3 absorption velocity. Data taken from the results cited in the text. (*b*) Line width as a function of transition frequency. Data taken from the references cited in the text.

region. At the lower frequencies where the nebula is partly optically thick, one observes the approaching edge, and the receding parts are somewhat hidden by the continuum opacity. Then at the higher frequencies, the entire shell is observed, and one detects the true average velocity. Their model for W3(OH) has a shell expanding at a radial velocity of 18 km s^{-1} with a central velocity of -46 km s^{-1}. This model predicts the line shape at 86 GHz to be a box-shaped spectrum of width 36 km s^{-1} convolved with a Gaussian of width at least as large as that corresponding to a thermal plasma of about 10,000 K. The full width at half-maximum of such a line is at least 41 km s^{-1}, much wider than the observed value of 27.3 ± 1.5 km s^{-1} which is shown in Figure 2*b*. Evidently, some other explanation is required.

The smooth trend in the line velocity of Figure 2a suggests a systematic effect. An attractive alternative to the expanding shell is the suggestion of Guilloteau, Stier, and Downes (1984) that W3(OH) is a blister H II region on the front edge of a flattened layer of gas with ionized gas flowing out of the observed foreground hole along an axis normal to the layer. They suggested this morphology in part to explain the fact that both the OH masers and the ammonia absorption are observed only on the western side of the nebula. The plasma flowing out of the hole will have a lower density than that in the shell or torus and will emit with more relative strength at lower frequencies. As it emerges toward us with relative velocities up to 30 km s^{-1}, it will shift the center of the lower frequency recombination lines to more negative velocities. The presence of this gas is apparent in the 5 GHz map of Forster and Boland (1982), and it may be the component W3OHB in Harten's original Westerbork map (1976). It has also been observed recently by Guilloteau, Baudry, and Walmsley (1985) in a deep 5 GHz VLA map. Verification of whether this ionized outflow is indeed the reason for the trend in the recombination line velocity with frequency will require careful well-calibrated mapping of a short centimeter wavelength recombination line with the VLA. The H110α line at 6 cm has been detected and found too weak (M. J. Reid, private communication). When the VLA has capability at 8 GHz, the experiment can be attempted.

IV. CONCLUSION

In using the 86 GHz H42α recombination line to determine the mean velocity of the H II region, we find no evidence that the OH masers are in free fall onto the central star. As well, the data argues against the expansion of the ionized shell at a velocity as large as 18 km s^{-1}. It is clear that one must be cautious in using recombination line velocities for kinematic interpretations. Complex gas motions, such as champagne flows, may be present.

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