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A collimated jet of molecular gas from the AGB star W43A

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Abstract. We present VLBA observations of the spatial and velocity distributions of 22-GHz H_2O and 1612-MHz OH masers in the OH/IR star W43A. These masers have the same systemic velocity ($V_{\rm LSR} \simeq$ 34 km s^{-1}) and are, therefore, likely to be associated with a common stellar object. However, their kinematical structures are quite different and independent. Most of the H_2O masers are extremely collimated spatially and kinematically. The W43A jet is very likely to be predominantly composed of hot molecules traced by H_2O maser emission and formed in the immediate vicinity of the stellar object. The observed angular pattern of the H_2O masers is well fit by a precessing jet model. In contrast, the OH masers exhibit clear arc-shaped structures indicating a spherically-expanding shell. Taking into account the detection of SiO masers and the periodic intensity variation of the OH masers in W43A, we infer that elongated planetary nebulae are formed by such a "molecular jet" during the short period (< 1000 years) of the transition through the proto-planetary nebula phase.

1. Introduction

W43A has been classified as an OH/IR star at an estimated distance of 2.6 kpc (Diamond et al. 1985). Not only OH and H_2O (e.g., Herman & Habing 1985; Diamond et al. 1985; Diamond & Nyman 1988) but also SiO masers (Nakashima 2002) have been observed towards W43A, all with a central velocity of $V_{\rm LSR}$= 34 km s^{-1}. The 1612-MHz OH masers exhibit a double-peaked spectral profile that varies in flux density with a period of ∼400 days (Herman & Habing 1985). SiO masers in W43A were discovered by Nakashima (2002) with the Nobeyama 45-m telescope; SiO masers have been detected in very few proto-planetary nebulae (PPNe) (Nyman et al. 1998). Although the true evolutionary status of W43A is still to be clarified, the characteristics of the OH masers are very similar to those in OH/IR stars; the existence of SiO masers and the lack of developed nebulosity (Deguchi & Nakashima, private communication) suggest that W43A is an OH/IR star on the asymptotic-giant-branch (AGB) in the HR diagram.

Previous observations of the H_2O and OH masers have yielded a somewhat puzzling picture of the object. Since H_2O and OH masers are excited in gases with temperatures and hydrogen densities of T $\sim$ 400 K, $n_{\rm H_2} \sim 10^9$ cm^{-3} and T$\sim$ 50 K, $n_{\rm H_2} \sim 10^4$ cm^{-3}, respectively, it was natural that almost all known H_2O masers associated with evolved stars have been found closer to the star and have exhibited lower expansion velocities than OH masers. In the case of W43A, however, while both the H_2O and OH masers show similar, double peaked spectra centered around the same line-of-sight velocity, the H_2O maser peaks have a much larger velocity separation (≈180 km s^{-1}) than those of the OH maser (only ≈16 km s^{-1})(e.g., Diamond & Nyman 1988). MERLIN and VLA images of both species of maser (Diamond et al. 1985; Diamond & Nyman 1988) are clustered in two complexes: the approaching OH and receding H_2O lie to the north–east of the receding OH and approaching H_2O. The angular separation between the two H_2O complexes (≈ $0''.5$ or 1300 AU) is twice as large as that of the OH and much larger than those typically observed in the circumstellar envelopes of many evolved stars (10–100 AU).

2. Observations

H_2O, and OH masers at 1612, 1665, 1667, and 1720 MHz in W43A have been observed using the NRAO's VLBA on three occasions: 1994 June 25, 1994 October 10, and 1995 March 17. The obtained angular and velocity resolutions were 0.5 mas (R.A.), 1.0 mas (decl.) and 0.21 km s^{-1} in the 22.2 GHz band and 9 mas (R.A.), 21 mas (decl.) and 0.36 km s^{-1} in the 1.6 GHz band, respectively. We measured proper motions of 21 H_2O maser features which were detected in two or three epochs. We could map only the brightest lines of the 1612-MHz OH masers. Figure 1 shows the kinematics of the H_2O and OH masers.

3. Results and discussion

Most of the H_2O masers in W43A are concentrated in blue-shifted and red-shifted clusters, both of which are surprisingly spatially collimated with a width of only 20 AU. The two clusters have lengths of 250–350 AU and are separated by ≈1700 AU. The 3-D motions of the masers indicate a collimated, fast jet-like motion with a 3-D velocity of ≈150 km s^{-1}. In addition, the direction of the spatial alignments of the water masers in W43A is shifted slightly by about 10° from both the direction of the cluster separation and the jet direction, implying that the jet

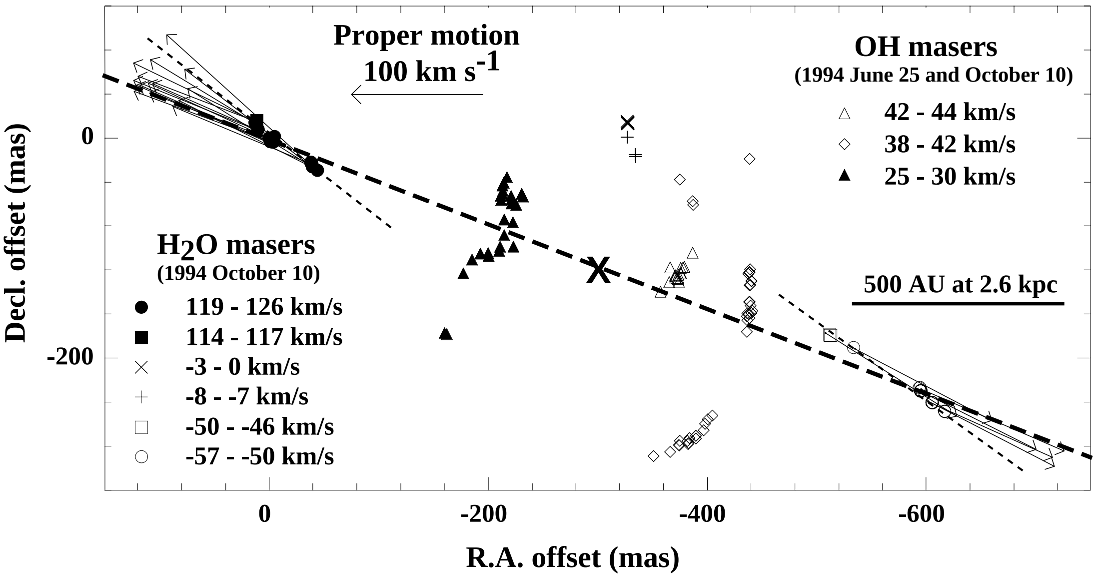

Fig. 1. Kinematics of H_2O and 1612 MHz OH masers in W43A. Arrows show velocity vectors of 21 H_2O masers. A dashed line shows the direction of the jet at a position angle of 69°. Two thin dotted lines show the alignments of maser spots in the individual clusters. A cross shows the estimated location of the central object at ($\Delta\alpha = -296$ mas, $\Delta\delta = -112$ mas) with a systemic radial velocity of $V_{\rm LSR} = 34$ km s^{-1}. The position offsets of the OH masers relative to the H_2O masers were estimated by assuming a common central object at the middle point of the red-shifted and blue-shifted OH masers with uncertainties of 30 mas in R.A. and 50 mas in declination.

is precessing. The observed spatial pattern is well fit by a precessing jet model which has a constant velocity of 150 km s^{-1}, an inclination of 36° with respect to the sky plane, a position angle of 63°, and an axis precession with an angular amplitude of 5° and a period of 55 years.

In contrast to the H_2O masers, OH masers in W43A have clear arc-shaped structures that can fit a model of a spherically-expanding shell around the star with a radius of ∼500 AU and an expansion velocity of 9 km s^{-1} (e.g. Diamond & Nyman 1988). Usually the morphology and kinematics of H_2O masers are complicated, or elongated perpendicular to the directions of the outflows, because H_2O masers are excited around shocks between an outflow and the ambient gas cloud. In addition, H_2O masers around an evolved star are located closer to the star than OH masers. From the present results, we propose a model of the H_2O and OH masers in W43A as follows. The circumstellar envelope of W43A is destroyed close to the star in the final phase of the OH/IR star stage. The H_2O masers are excited only at the ends of a highly-collimated jet with compact clumps simultaneously ejected from the star in the opposite directions.

Miranda et al. (2001) observed the proto-planetary nebula (PPN) K3–35 and inferred that its stellar jet had already been formed ∼1000 years before the star started the photoionization of its circumstellar envelope. On the other hand, the dynamical age of the W43A jet is only ≈28 years as estimated from the distances to the ends of the jet from the dynamical center (≈900 AU) and the, presumably constant, jet velocity (∼150 km s^{-1}). Combined with the characteristics of W43A (similar to an OH/IR star as mentioned before) this estimate strongly suggests that W43A is a star in transition from the AGB to the post-AGB phase. It is likely that the "molecular jet" traced by H_2O masers was created in the OH/IR star phase, before the transition to a PPN. Comparing the above time scales with the duration of significant mass-loss rate (1000–4000 years, Lewis 2001) from an OH/IR star, a molecular jet should affect the development of planetary-nebula morphology from the beginning of its formation.

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