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A collimated molecular jet in W 43A traced by water maser emission

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Abstract. We present the spatial and velocity distributions of water masers in W 43A. Most of the maser features are spatially and kinematically collimated to a surprising extent. It is very likely that the jet in W 43A is predominantly composed of warm molecules traced by water maser emission. The position angle of the spatial collimation of the maser clusters is slightly different from the directions of both the cluster separation and the proper motions. We propose a model involving a precessing jet to explain the axis offsets. The discovery of a molecular jet with precession in W 43A provides important information on our understanding of the formation of collimated molecular jets and may provide clues on specific stages of stellar evolution.

1. Observations and Data Reduction

Water masers in W 43A have been observed using the NRAO's VLBA on three occasions: 1994 June 25, 1994 October 10, and 1995 March 17. The observations covered the Doppler velocities around V_{LSR} =120, 60, 0, and -60 km s^{-1}, with a velocity coverage of 27 km s^{-1}, each in dual circular polarization. The correlated data had 128 velocity channels in each base-band channel, corresponding to a Doppler velocity spacing of 0.21 km s^{-1}.

Data reduction was performed with the NRAO's AIPS package following a standard procedure. The difference in instrumental delays, delay rates, and phase offsets among the different base-band channels were corrected by using the data of the continuum calibrator NRAO 530. The synthesized beam was 1.0$\times$0.4 mas and elongated north-south. We found a few tens of maser features in each epoch. We measured proper motions of 21 water maser features that were detected in two or three epochs. Figure 1 shows the angular distribution of water maser features and their proper motions in W 43A. Figure 2 shows the details of the time variation of the angular distributions of water maser spots (individual velocity components).

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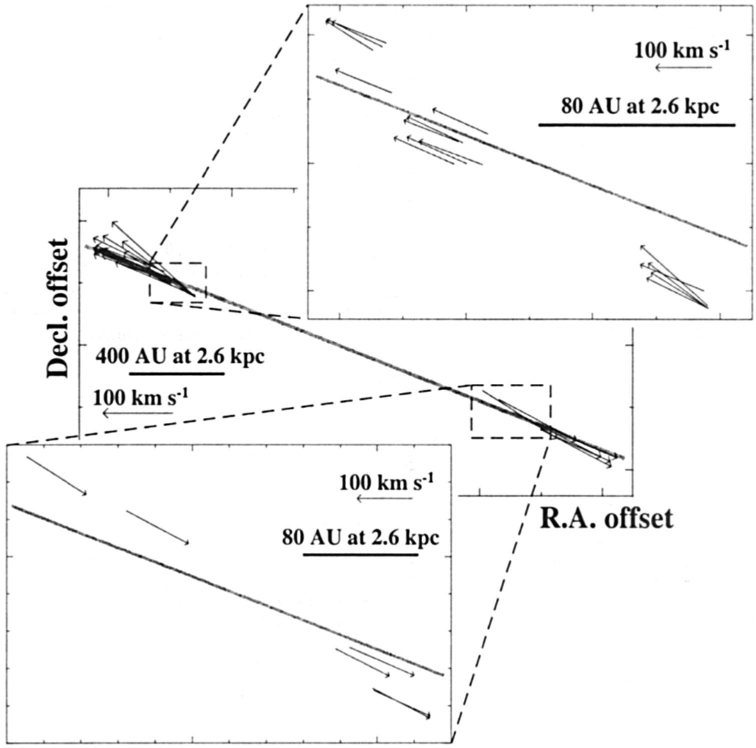

Figure 1. Angular distribution of water maser features and their proper motions in W 43A. The straight lines in the upper, middle, and lower panels show the same direction of the alignment between the blue-shifted and red-shifted maser clusters.

2. Results and Discussion

2.1. Surprising spatial and kinematical alignments of water masers

Figure 1 indicates that the water masers in W 43A are extremely collimated, both spatially and kinematically. Most of the features are concentrated in blue-shifted (south-west side) and red-shifted (north-east side) 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 proper motions of the water masers indicate a collimated, fast jet-like motion with a 3-D velocity of ± 150 km s^{-1}.

Water masers trace warm (T=400–1000 K) molecular materials and probably lie in extended "molecular outflows" dragged by a central thin jet composed of hot (or ionized and neutral atomic) materials. Therefore, the morphology and kinematics of water masers are expected to be complicated. Recently, systematic spatial alignments of water masers have been discovered, which show elongations perpendicular to the directions of the outflows, or a U-shaped pattern (e.g., Fu-

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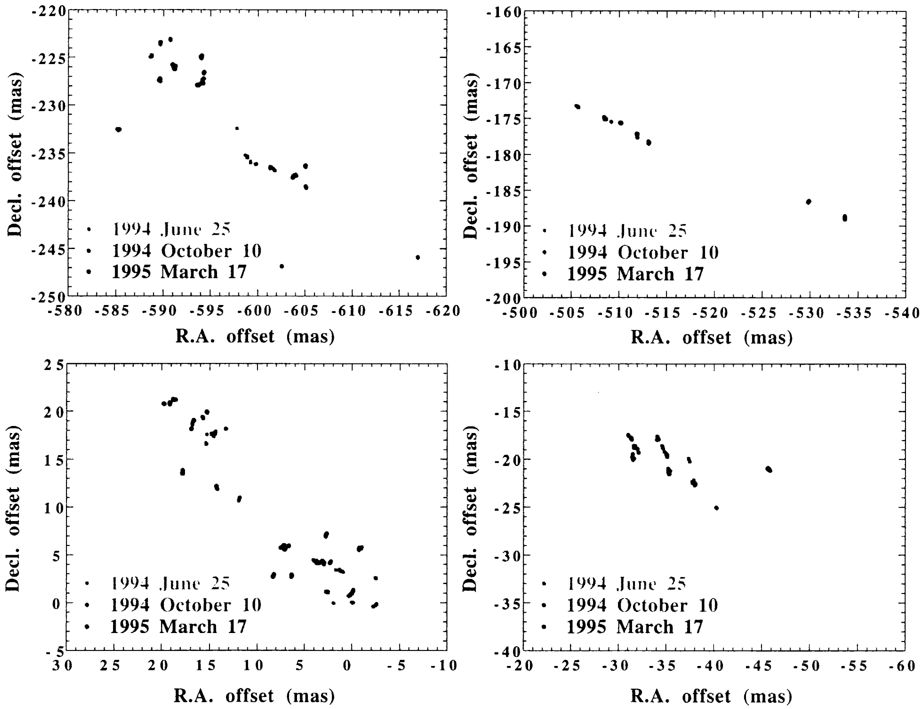

Figure 2. Time variation of angular distributions of water maser spots in W 43A.

ruya et al. 2000). These clearly indicate the presence of interfaces or bow shocks between the jets and the ambient clouds or materials in the molecular outflows.

The water masers in W 43A show, however, very different characteristics from those described above. The masers exist in warm molecular materials, which are aligned with a collimation factor larger than 50 in W 43A. Figure 2 demonstrates that our data do not show spatial alignments perpendicular to the directions of the proper motions of water masers, or the direction of the jet. Thus, there is a possibility that molecular materials are associated with the central jet itself. It is likely that the water masers are excited by oblique shocks in the jet, not in the ambient materials.

2.2. A precessing jet model

We also note in Figure 1 that the direction of the spatial alignments of the water masers in W 43A is shifted slightly by about 10° from both the direction of the cluster separation and the jet direction. It is likely that the jet is precessing. We propose such a model, in which we consider a jet with 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.

This model fits well the observed angular distribution of water masers, and will be unambiguously confirmed by future observational results. Monitoring observations of water masers in W 43A with VLBI, about 10 years after our first observations, should reveal the time variation of the spiral pattern of the precessing jet.

2.3. What is W 43A?

W 43A itself is a mysterious object. OH (1612 MHz) masers in W 43A exhibit a doubly-peaked profile, resulting in its classification as an evolved OH/IR stars (e.g., Masheder et al. 1974). Just recently, we found that OH masers in W 43A have clear arc-shaped structures that indicate a roughly spherically-expanding shell with a radius of 500 AU around the star. Molecular-line observations (Diamond et al. 1985) did not show the existence of any extended and dense molecular cloud around W 43A. The absence of indicators of star formation and the lack of clear signs tracing interactions between the jet and the ambient cloud also suggest that W 43A may be an evolved star.

On the other hand, the spectral energy distribution at infrared bands obtained by IRAS shows that W 43A (IRAS 18450−0148) has a large excess at the 60 and 100 μm bands, suggesting a cold (T $\simeq$ 25 K) cloud as seen in a star forming region. Single dish observations searching for the tracers of a molecular cloud core are required to unambiguously identify the evolutionary stage of W 43A.

Furthermore, it is clear that the OH and H_2O masers are associated with different structures, a roughly spherically-expanding flow and a collimated jet, respectively. It is interesting that both of the masers have almost the same systemic (center) velocity around $V_{LSR} = 34$ km s^{-1}, but the opposite velocity gradients against each other. There are two possibilities: W 43A is a single stellar system with both of the above two gas components or a binary system including an evolved star having the OH maser flow and a compact object having the H_2O maser jets. These hypotheses can be confirmed by astrometric observations of the OH and H_2O masers using differential VLBI to determine the dynamical centers of the two flows with respect to the common reference radio source.

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References

Diamond, P.J., & Nyman, L.-A. 1988, in IAU Symp. 129, VLBI and their impact on Astrophysics, ed. J.M. Moran & M.J. Reid (Dordrecht: Reidel), 249

Diamond, P.J., et al. 1985, MNRAS, 212, 1

Furuya, R.S., et al. 2000, ApJ, 542, L135

Masheder, M.R.W., Booth, R.S., & Davis, R.D. 1974, MNRAS, 166, 651