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# OH maser envelopes of the "water fountain" sources

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We present results of the EVN and global VLBI observations of 1612 MHz OH masers associated with circumstellar envelopes of three "water fountain" sources, W43A, IRAS 18286−0959 and IRAS 18460−0151, which exhibit highly collimated fast stellar jets from AGB or post AGB stars. The absolute coordinates measured in accuracy of $\sim$10 mas, radii and velocity fields of the masers (available from W43A and IRAS 18460−0151) suggest that the host stars of the fast jets and envelopes are commonly located within a small area ($<$100 AU) and that the physical parameters of the envelopes are typical as seen those in Mira and OH/IR stars, except the expansion velocity in the $H_2O$ maser region (10–30 km $s^{-1}$) slightly higher than those in Mira and OH/IR stars. We demonstrate that ignition of the stellar jet occurred within a period during which either the parental AGB envelope still keeps its intrinsic spatio-kinematical structure or it has just been transformed to an "fast equatorial flow", a sub-product of the stellar jet. Thus the OH maser properties have provided observational constraints on the evolutionary status (AGB phase is also possible) and mass of host stars (intermediate) of the water fountains.

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## 1. Introduction

A stellar jet appearing at the final stage of stellar evolution is a manifestation of the important, but still poorly understood phenomenon leading to the formation of asymmetric planetary nebulae (PNe). Bipolar and multipolar optical morphologies and the common presence of point symmetry are frequently found in a sample of young PNe. It is expected that collimated jets have been operational in a large fraction of PNe, and are one of the major factors shaping these objects. Similar morphologies have been found in a survey of pre-planetary nebulae (PPNe, [7]), leading to the current paradigm that such a collimated jet is launched near to, or at, an earlier phase of stellar evolution – the asymptotic giant branch (AGB) phase - and is frequently observable in molecular line emission.

There are a small number of candidate sources that show us the earliest stage of stellar jet emergence. "Water fountain sources" are the most promising candidates; they are stellar objects that have extremely high-velocity flows traced by $H_2O$ maser emission. The outflow velocity sometimes exceeds 100 km $s^{-1}$, much greater than the typical expansion velocity of circumstellar envelopes (CSEs) of Mira variable and OH/IR stars traced by 1612 MHz OH maser emission (10–25 km $s^{-1}$). About 10 water fountains have been identified in previous single-dish observations (see review by Imai [4]). VLBI observations of some of these $H_2O$ maser sources have revealed that the jets are highly collimated and have extremely short dynamical ages ($\lesssim$100 yr).

The spatio-kinematics of 1612 MHz OH masers is an important probe for diagnosing the true evolutionary status and the character of such water fountain sources. They are supposed to have a thick dust torus (as in the unified model of the Type I and II AGN). A hypothesis is that the optically observable object, such as IRAS 16342−3814, is seen from the polar-axis direction of the dust torus while the optically unseen objects, such as IRAS 18286−0959, W43A and IRAS 18460−0151, from equatorial directions. The central stars of OH/IR objects have been considered to be at the AGB or post-AGB phase of stellar evolution and their CSEs traced by OH masers may keep spherically symmetric spatio-kinematical structures. An alternative hypothesis is that some OH/IR sources such as water fountains are formed by stellar mergers (see an example; [2]). In such a case, the formed star after the merger event moves down on the track along the red-giant/red-supergiant branch (the Hayashi track in pre-main sequence stars), and settles down to a main sequence star after $\sim$100 yr. The high-velocity flow is attributed to the fast (100-200 km $s^{-1}$), hot mass flow occurring immediately after a merger event. The rich $H_2O$ maser emission in IRAS 18286−0959 may suggest that the outer envelope is not yet settled and is still considerably turbulent after the merging event. In such a case, the spatio-kinematical structures of OH masers also may exhibit unusual properties.

## 2. Observations and results

We have made the VLBI observations of 1612 MHz OH masers in IRAS 18286−0959 and IRAS 18460−0151 with the EVN in June 2007 and in W43A at five epochs during 1994–2007 with the VLBA and the global VLBI (VLBA+EVN). IRAS 18286−0959 and IRAS 18460−0151 are new water fountain sources discovered in the Spitzer/GLIMPSE images [1]. We have applied the phase-referencing technique in a source-switching cycle period of 5 min, except with the Lovell



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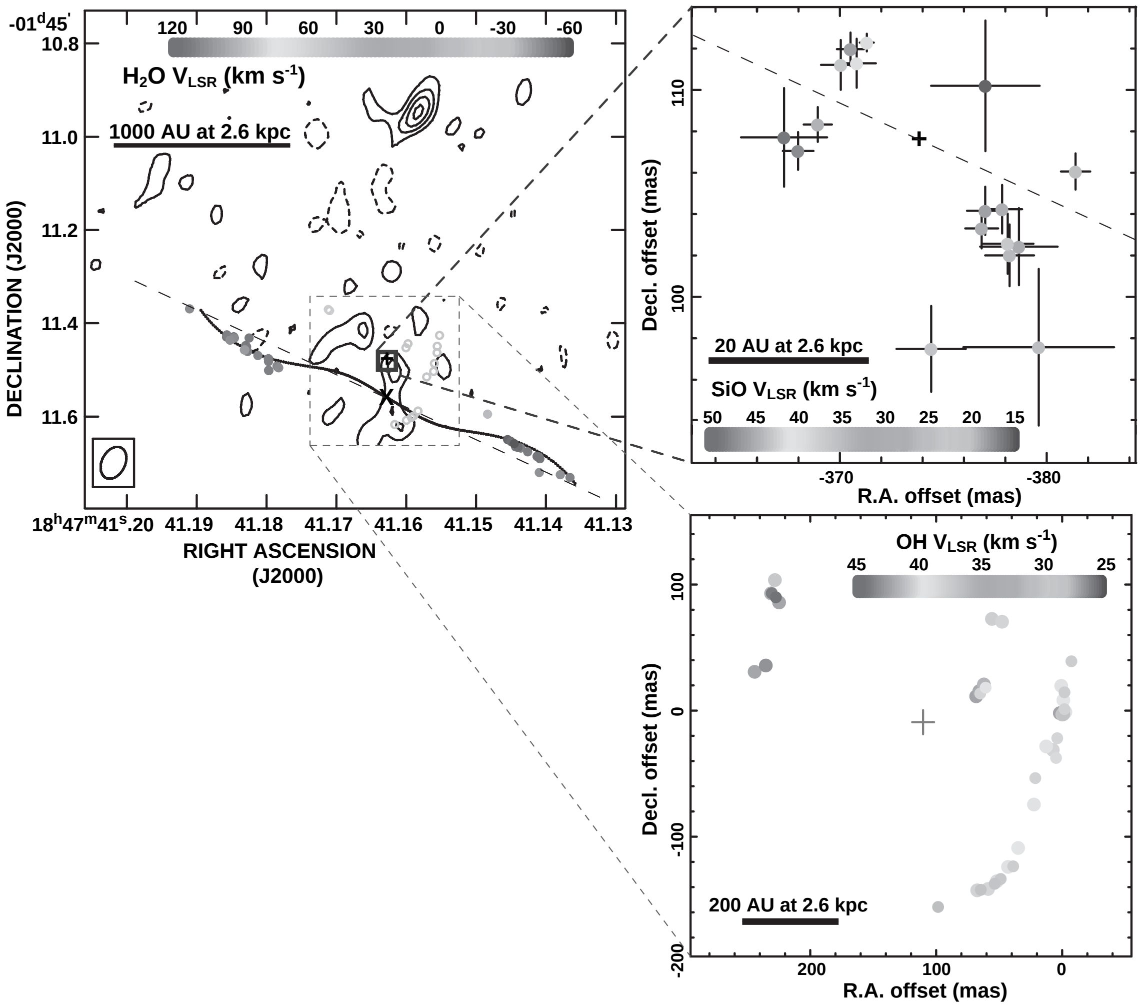


**Figure 1:** SiO, $H_2O$ and 1612 MHz masers in W43A. (a) $H_2O$ masers (grey-scaled filled circles) observed with the VLBA and 7 mm continuum emission (contour) observed with the VLA [5]. (b) SiO $v = 1, J = 1-0$ observed with the VLA [5]. (c) 1612 MHz OH masers observed with the EVN. A plus symbol in each sub-panel indicates the location of the dynamical center of the SiO masers. A dashed line in the NEE–SWW direction indicates the major axis of the collimated jet traced by $H_2O$ maser emission. The SiO and OH maser distributions have a velocity gradient with blue-shifted and red-shifted components on the NEE and SWW sides, respectively. On the other hand, the $H_2O$ maser distribution has the opposite velocity gradient.

Telescope, to accurately measure the absolute coordinates of the maser emission, whose maps are superposed on the $H_2O$ maser maps with a typical accuracy of 10 mas. The absolute coordinates of the $H_2O$ masers in IRAS 18460−0151 are now being measured.

## 2.1 W43A

Figure 1 shows the SiO/$H_2O$/OH masers in W43A. The OH maser emission exhibits clear circular arcs especially on the SW side. The spatio-kinematical structure is well explained by a spherically expanding shell model with an expansion velocity of $\sim$9 km s$^{-1}$and a radius of $\sim$190 mas (500 AU at 2.6 kpc). A transverse motion corresponding to the expansion velocity was also tenta-

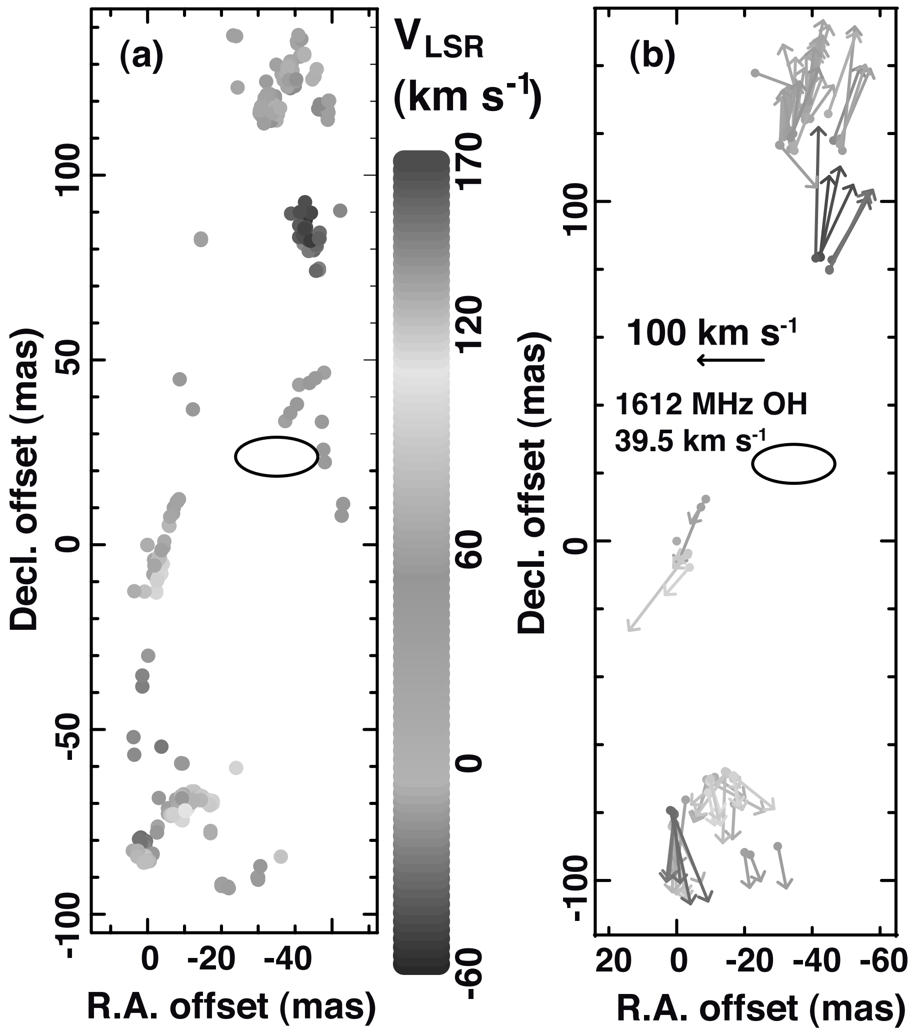


**Figure 2:** $H_2O$ and 1612 MHz OH masers in IRAS 18286−0959. (a) Distributions of $H_2O$ maser features observed with the VLBA at three epochs in 2007 [4]. (b) Relative proper motions of the $H_2O$ masers indicated by arrows [4]. The position and size of a solid ellipse in each sub-panel indicates, respectively, the location and its uncertainty of 1612 MHz OH maser at $V_{LSR}$=39.5 km s$^{-1}$.

tively detected. The dynamical center of the OH maser shell, which is expected to be at the mid point between the most blue-shifted and most red-shifted components, has an offset of 40 mas (100 AU) from that of the SiO maser flow. Note that a velocity gradient seen in the OH masers is consistent with that in SiO masers, but the total velocity width is smaller in OH than in SiO.

### 2.2 IRAS 18286−0959

Figure 2 shows $H_2O$ and OH masers in IRAS 18286−0959. There are approximately 140 $H_2O$ maser features detected. They exhibit a few groups of arc-shaped morphologies with bipolar expansion from at least three spatio-kinematical centers, whose existences are confirmed in the position-velocity (radial velocity and proper motion) diagrams. The location of the OH maser emission with a single-peaked spectrum is coincident with one of the kinematical center within

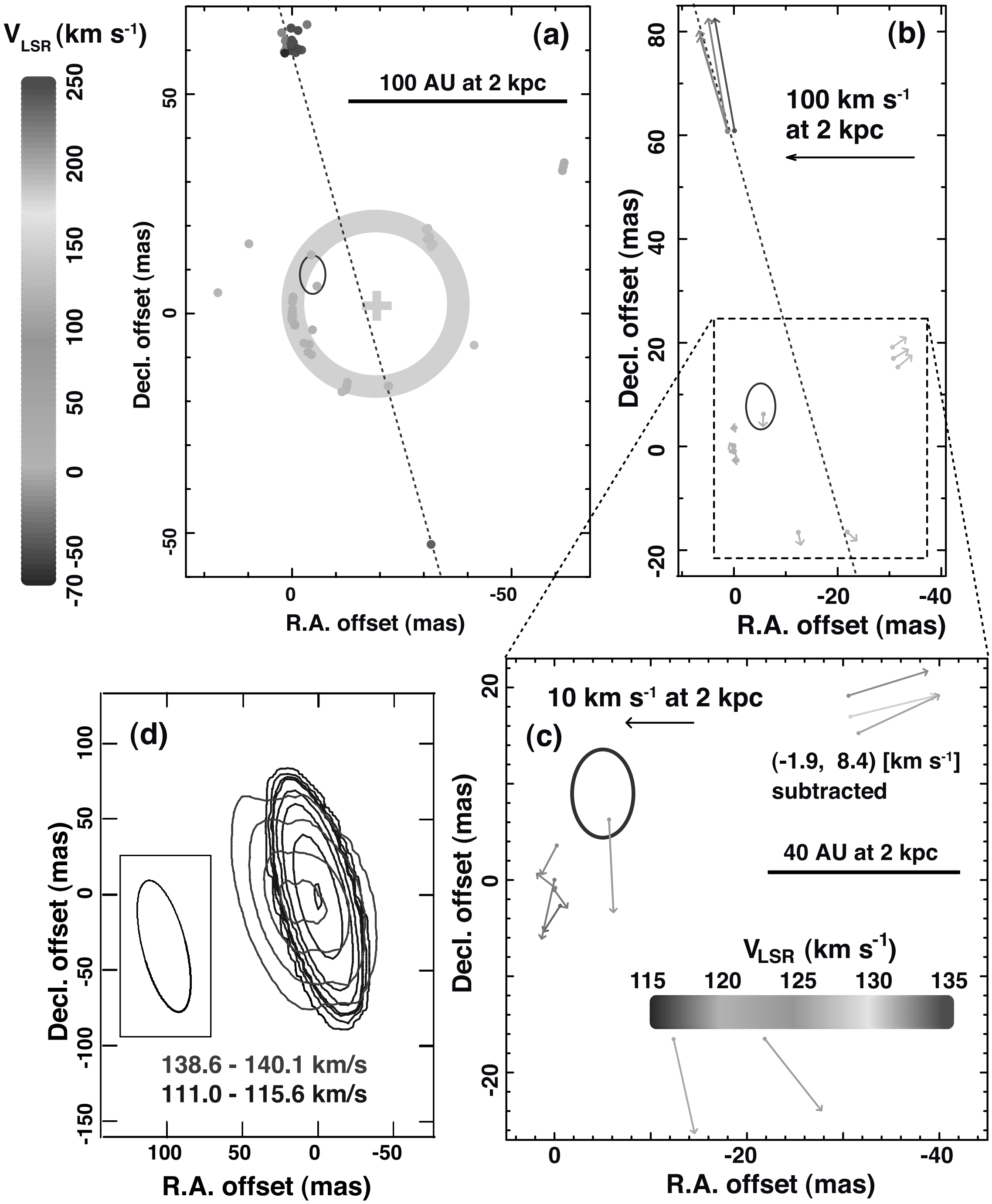


**Figure 3:** $H_2O$ and 1612 MHz OH masers in IRAS 18460−0151. (a) Distribution of the $H_2O$ maser features observed with the VLBA at three epochs in 2007 [4]. A grey thick circle indicates a possible circular shell of $H_2O$ masers, whose center is located within 20 AU from the dynamical center of the collimated jet. (b) Relative proper motions of the $H_2O$ masers indicated by arrows [4]. A mean proper motion is subtracted from the observed proper motion vectors. (c) Zoom-up view of (b). The maser motions indicate the existence of a spherically expanding flow with a small velocity gradient with the blue-shifted and red-shifted components at the east and west sides, respectively. The position and size of a solid ellipse in each sub-panel indicates, respectively, the location and its uncertainty of 1612 MHz OH masers. (d) Contour map of the 1612 MHz OH masers observed with the EVN. The OH masers have a velocity gradient with the blue-shifted and red-shifted components at the *west* and *east* sides, respectively.

10 mas (30 AU at 3.1 kpc).

### 2.3 IRAS 18460−0151

Although the OH and $H_2O$ maser maps have not yet been superposed onto each other, the spatial distributions and the total velocity widths are almost equal between the OH masers and the $H_2O$ masers in the "equatorial flow". Their expansion velocity is estimated to be $\sim$10 km s$^{-1}$, equal to, or slightly larger than, those of CSEs in Mira variable and OH/IR stars. Note that these masers are opposite velocity gradients perpendicular to the jet major axis, implying that the equatorial flow exhibits spherical expansion with small velocity deviations in the opposite senses between the $H_2O$ and OH maser regions; the latter is located at a slightly larger distance from the star.

## 3. Discussion

The spatio-kinematical characteristics of $H_2O$ and 1612 MHz OH masers in the water fountain sources suggest that the stellar jet ignition is an episodic event during a short period ($\lesssim$100 yr). Especially, arc-shaped pattern found in the IRAS 18286−0959 $H_2O$ maser jet clearly implies such events. The OH masers similar to those in Mira variable and OH/IR stars implies that the jet has been ignited and developed in a short period when the spatio-kinematical structures of the CSEs traced by OH masers still keep their intrinsic characteristics. Such a hypothesis is supported by comparison of the dynamical ages of the jets and tori observed in optical emission, in which the birth epochs of the two components have short time lags (200-300 yr) [3]. Note that the dynamical centers of the $H_2O$ jets and the OH envelopes coincide within $\sim$100 AU, suggesting that either a single AGB/post-AGB star forms the both components or different types of stars in a binary system within such a scale play different roles for jet/envelope development. However, especially the latter hypothesis should be examined more carefully because the system is expected to easily destroy the maser systems.

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