A birth and growth of a collimated molecular jet from an AGB star

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Abstract. With the VLBA, we have observed water masers associated with the OH/IR star, W43A, which trace a birth and growth of a molecular jet. The water masers exhibit the collimated distribution (1700 AU: 20 AU) and fast motions (±150 km s\(^{-1}\)). The maser distribution was well fit by a precessing jet model. The jet length has extended by 800 AU within 8 years, indicating that the extension rate is roughly equivalent to the jet speed (150 km s\(^{-1}\)). Very likely the jet was born around the year 1960. An elongated planetary nebula will be formed by such a jet during an extremely short period (<< 1000 yrs) of the transition to form a proto-planetary nebula. Then fading of the water maser jet will be observed during our own life.

1. Introduction

Evolved stars of about a solar mass generally are spherically symmetric, yet the planetary nebulae (PNe) that immediately follow them on their evolutionary path often are not. Collimated stellar jets of material have been observed up to 0.3 pc from central objects of planetary nebulae, and precessing jets have been proposed as the origin of the asymmetries in the subsequent planetary nebulae (e.g., Sahai & Trauger 1998). Moreover, it has recently been shown theoretically that magnetic fields could launch and shape the jets (Blackman et al. 2001).

We consider here a member of a small, but exceptionally interesting class of stellar water maser sources that are characterized by extremely large spreads of maser velocities (up to 260 km s\(^{-1}\), Likkel, Morris, & Maddalena 1992). This class of "water fountains" includes only three bona fide objects: IRAS 16342–3814 (Morris, Sahai, & Claussen 2003), IRAS 19134+2131 (Imai et al. 2003) and W43A (Diamond & Lyman 1988; Imai et al. 2002). This class of sources appear to be closely related morphologically and kinematically to other post-AGB stars revealed by optical, infrared and mm-wave observations.
Here we report VLBA observations of the W43A water masers during 1994–2002, which present a birth and growth of a stellar jet with precession, occurring formed prior to forming a proto-planetary nebula.

2. VLBA observations

The VLBA observations have been made in the following epochs, 1994 June 25 and October 10, 1995 March 17, 2002 April 3, July 26, and November 24. We observed W43A and calibrators for 10 hrs in total in each of the epochs. Since the year 2002, the phase-referencing technique has been applied to precisely estimate the source coordinate with respect to the stable reference frame fixed with extragalactic quasars and the W43A 1612-MHz OH masers.

3. Growing and precessing stellar jet

The W43A jet traced by water maser emission is highly collimated, both spatially and kinematically (see figure 1). Most of the maser spots are concentrated in the receding (north–east side) and approaching (south–west side) clusters. Both clusters have lengths of 250–350 AU but widths of only \( \approx 20 \) AU. The two clusters are separated by \( \approx 1700 \) AU. The width of the aligned masers is
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The angular distribution of the H$_2$O masers detected on 1994 October 10 and 2003 April 3, fitted by the spiral patterns expected from a precessing jet model. The modelled jet has a constant velocity of 150 km s$^{-1}$ and a jet axis with an inclination of 39° with respect to the sky plane, a position angle of 65°, and an axis precession with an angular amplitude of 5° and a period of 55 years. We assumed that only the direction of the bipolar ejection of material is varying continuously with time. The dynamical center of the jet has a systemic radial velocity of 34 km s$^{-1}$ and a relative position of ($\Delta \alpha = -296$ mas, $\Delta \delta = -112$ mas) in Figure 1.

F urthermore, we found that the observed angular pattern of the water masers has grown during 1994–2002, the growth rate is roughly same as the speed of the maser feature motions. The angular pattern is well fit by a precess- ing jet model (figure 2). These results support that the jet was born around the year 1960 and precessing since its birth.

4. Water fountain before becoming a planetary nebula

Previous observations have inferred that stellar jets have already been formed $\sim$1000 yrs before an AGB star evolves into a post-AGB star and starts the photoionization of its circumstellar envelope (Miranda et al. 2001). On the
other hand, the dynamical age of the jet in W43A is only $\approx 40$ yrs. Combined with the presence of SiO masers in W43A (Nakashima & Deguchi 2003), which are detected in very few PPNe and with the OH masers such as those typically found in OH/IR stars (figure 1), this estimate strongly suggests that we are observing a star in transition. Another two ”water fountains” also have similar dynamical ages ($\sim$100 yrs for IRAS 16342−3814, Morris, Sahai, & Claussen 2003, 50 yrs for IRAS 19134+2131, Imai et al. 2003), but their morphologies seem already to be destroyed; it is difficult to find clear alignment and point symmetry in their maser distributions. Very likely, the water fountains last for a very short period ($\leq$100 yrs). The latter two sources have already exhibited (bipolar) nebulosity (Sahai et al. 1999; Sahai et al. 2003 in preparation), while W43A does not exhibit any nebulosity (Deguchi 2003 in private communication). Thus the water fountain appears just before or during the transition to a PPN. Comparing the above time scales with the duration of significant mass-loss rate from OH/IR stars (1000-4000 yrs, Lewis 2001), a water fountain should affect the development of PN morphology from the beginning of its formation (Sahai & Trauger 1998).

5. Future prospective

The driving object and the formation mechanism of the W43A jet are still unclear. W43A could be an AGB star able to create a collimated jet driven by the magnetic force due to the dynamo action at the interface between the rapidly rotating core and the more slowly rotating envelope of the star (Blackman et al. 2001). Alternatively, W43A could be a binary system where the ejected material from a mass-losing star falls onto an accretion disk surrounding a companion that creates the jet. These hypothesis are examined by astrometric technique for the water and hydroxyl masers in W43A, they are associated with the collimated jet and a spherically-expanding envelope, respectively. The locations of the dynamical centers of these jet and envelope should provide a strong constraint on binary system models. Therefore, we are performing phase-referencing VLBI observations to determine their coordinate with respect to the common extragalactic quasars. The location of the SiO masers also precisely indicate the position of the star that create the envelope and provides material to the jet.

Furthermore, because the devolution of the W43A jet is expected before our death, we will monitor the water maser morphology and kinematics for elucidating a growth of a planetary nebula developing its asymmetrical morphology.

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