Feeding Compact Objects: Accretion on All Scales
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Water fountains: bipolar fast stellar jets traced by water vapor maser emission

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Abstract. Highly collimated, bipolar fast jets are found in asymptotic giant branch (AGB) and post-AGB stars as well as in active galactic nuclei and young stellar objects. It is still unclear how to launch such jets from dying stars that were originally spherically symmetric. Exploration of the stellar jet evolution is also expected to probe its role in shaping a planetary nebula. Interestingly, some of stellar H_2O maser sources — water fountains — exhibit stellar jets with spatially and kinematically high collimation in the earliest phase (<1000 years) of the jet evolution. Such water fountains have been identified in 14 sources to date. We have recently conducted interferometric (VLBA, EVN, VERA, VLA) maser and the single-dish (ASTE) CO $J = 3 \rightarrow 2$ line observations of the water fountains. They have revealed a typical dynamical age (<100 yr) and the detailed kinematical structures of the water fountains, possibility of the coexistence of "equatorial flows", and their locations and kinematics in the Milky Way. Based on these results, the masses and evolutionary statuses of the host stars are also estimated.

Keywords. Masers, stars:mass loss

Stellar jets traced by H_2O maser emission in the water fountains are highly collimated in their morphology and kinematics with velocities up to 500 km s^{-1}(see example in Fig. 1). Precession of these jets might be of general characteristics of the water fountains. Point symmetric patterns of H_2O maser distributions suggest recurrent jet's launch; the derived dynamical ages (jet length/velocity <100 yr) may just provide their lower limits.

Some of the water fountains harbor "equatorial flows". They are similar to (spherical) AGB flows, but some of them have higher expansion velocities (>30 km s^{-1}). Their origins may be different from relic circumstellar envelopes of the host AGB stars and physically linked to the jets, suggesting binary interactions (Huggins 2007, see Fig. 2).

The annual parallax distances to the water fountains (e.g. Imai *et al. 2013*) strongly suggest that the source luminosities to be $L_* \lesssim 8\,000\ L_\odot$. The extremely strong ^{13}CO line emission (Fig. 3) also suggests the central stars to be intermediate-mass O-rich stars experiecing the "Hot-bottom-Burning" (Imai *et al. 2012*). However, larger deviation of the systemic source motion from the Galactic rotation (by up to 100 km s^{-1}) suggests longer-lived lower mass stars or binary systems (Imai *et al. 2013*).

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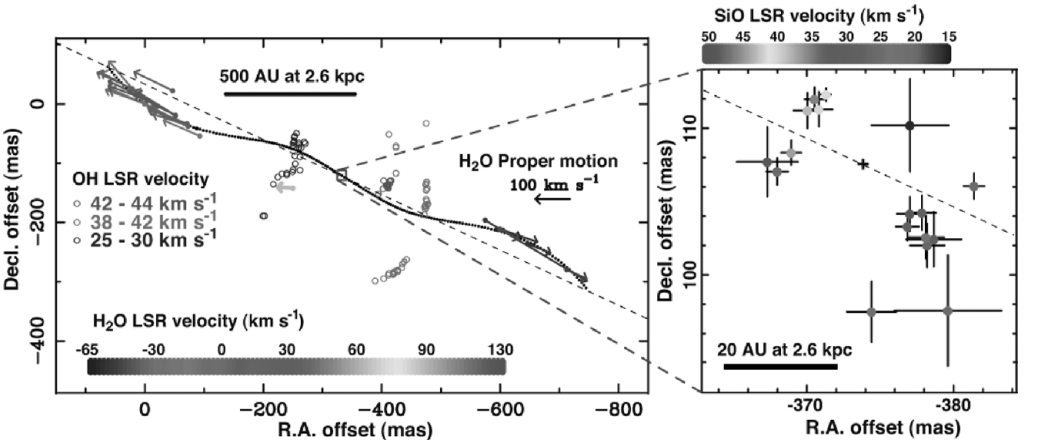

Figure 1. *Left*: H_2O and 1612-MHz OH maser features in W43A. Relative proper motions of the H_2O maser features are indicated by arrows. *Right*: SiO $v = 1$ $J = 1 \rightarrow 0$ maser features in W43A. The dashed line indicates the major axis of the jet precession. The dotted line indicates the spiral pattern of the precessing jet to fit to the distribution of the H_2O maser features. See Imai (2007) and references therein.

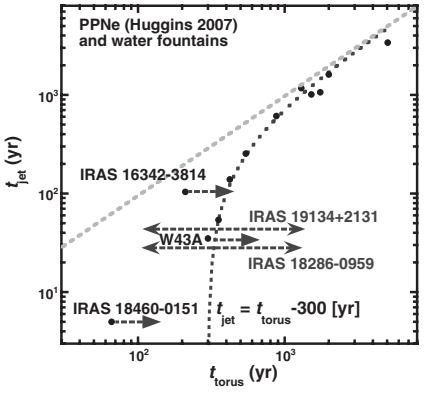

Figure 2. Comparison of the dynamical ages of jets and equatorial tori/flows in pre-planetary nebulae (Huggins 2007) and the water fountains. A dashed line shows the case in which the jet was launched 300 yr after the beginning of rapid growth of the jet in the same object and they expand in constant velocities.

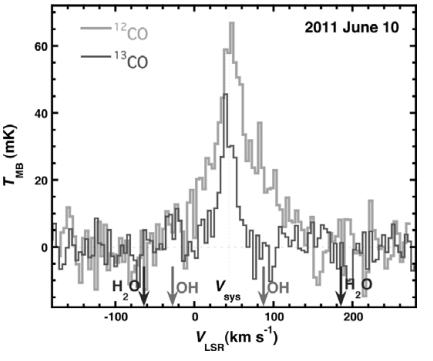

Figure 3. ^{12}CO (grey) and ^{13}CO (black) $J = 3 \rightarrow 2$ line spectra (Imai *et al. 2012*). The ^{12}CO spectra almost covers the velocity range of the H_2O masers (Claussen *et al. 2009*). The intrinsic $^{12}C/^{13}C$ isotopic ratio is suggested to be $\sim$1.3 even if the ^{12}CO and ^{13}CO lines are optically thick and thin, respectively.

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