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Monitoring the evolution of maser emission from water fountain stars.

Gómez, J.F.[1], Imai, H.[2,3], Uscanga, L.[4], Suárez, O.[5], Cala, R.[1], Miranda, L.F.[1], and Tafoya, D.[6], and Orosz, G.[7]

[1] Instituto de Astrofísica de Andalucía, CSIC, Glorieta de la Astronomía s/n, 18008 Granada, Spain
[2] Amanogawa Galaxy Astronomy Research Center, Graduate School of Science and Engineering, Kagoshima University, 1-21-35 Korimoto, Kagoshima, Kagoshima 890-0065, Japan
[3] Center for General Education, Institute for Comprehensive Education, Kagoshima University, 1-21-30 Korimoto, Kagoshima, Kagoshima 890-0065, Japan
[4] Departamento de Astronomía, Universidad de Guanajuato, A.P. 144, 36000 Guanajuato, Gto., Mexico
[5] Laboratore Lagrange, Observatoire de la Côte d'Azur, Université Côte d'Azur, CNRS, Bd de l'Observatoire, CEDEX 4, F-06304 Nice, France
[6] Department of Space, Earth and Environment, Chalmers University of Technology, Onsala Space Observatory, 439 92 Onsala, Sweden
[7] Joint Institute for VLBI ERIC, Oude Hoogeveensedijk 4, 7991 PD Dwingeloo, The Netherlands

Abstract

Water Fountains (WFs) are objects in a transitional phase from the asymptotic giant branch to early planetary nebulae (PNe) of stars $M < 8\,M_{\odot}$, which show high-velocity collimated jets traced by water masers. Here we present some results from an ongoing monitoring of maser emission 14 WFs, carried out with the Nobeyama and Effelsberg radio telescopes, as well as with the Australia Telescope Compact Array. The water masers trace very different kinematical and spatial distribution depending on the source, with accelerating, decelerating, or kinematically stable mass-loss. In the case of the nascent PN IRAS 15103-5754, the masers have quickly evolved in less than 10 years, from tracing a collimated jet to a circumstellar toroid. These different patterns might be related to the particular evolutionary stage of each source, or to the properties of central binary stars. We expect that the analysis of our full monitoring data will provide important clues to explain the diversity of patterns in WFs.

1 Introduction

During the final stages of evolution of low and intermediate-mass stars ($M < 8\,M_\odot$), there occur dramatic changes in morphology, so that the spherical symmetry that is present during most of the stellar lifetime turns into the plethora of shapes seen in planetary nebulae (PNe). It is now widely accepted that the non-spherical shapes of PNe are the result of interactions in a binary/multiple stellar system [3].

This contribution focus on a particular category of evolved objects, which host water maser emission with high velocities, tracing winds that reach velocities > 250 km s^{-1} [12], significantly larger than the expansion velocities of circumstellar envelopes in Asymptotic Giant Branch (AGB) stars, 10–30 km s^{-1} [4, 14]. Given these characteristics, these objects are collectively called "water fountains" (WF). Radio interferometric observations of masers in WFs reveal that they trace collimated jets with kinematic ages < 100 yr. This means that these events are short-lived. It is still to be determined whether WF events are episodic and could happen during relatively long periods of times (e.g., the whole post-AGB phase), or they are restricted to a particular limited phase of the evolution of these stars. Fortunately, given that the kinematic ages of WF jets are comparable to the human lifetimes, significant changes are expected to happen over just a few years. Therefore, some questions can be solved by carrying out a long-term monitoring of their water maser emission.

2 Monitoring projects of the maser emission from water fountains

We are currently monitoring the maser emission of 14 WFs, collecting data from different observational projects. In project FLASHING (Finest Legacy Acquisitions of SiO- and H_2O-maser Ignitions by Nobeyama Generation) we are using the Nobeyama 45 m antenna to simultaneously observe SiO and H_2O masers in WFs with declination $> -32^\circ$ [10]. We have also used the Effelsberg 100 m radio telescope to specifically monitor the water masers in IRAS 18113-2503 during three years. These single-dish data allow us to track velocity variations in the maser spectra, including acceleration/deceleration of the ejections, or the appearance of new mass-loss events.

These observations have been complemented with interferometer monitoring observations of maser emission with the Australia Telescope Compact Array (ATCA), to obtain information on possible variations of the spatial distribution of the maser emission. In the particular case of IRAS 15103-5754, we have collected interferometer data from 2011 to 2022.

3 Preliminary results

FLASHING has provided some interesting results that have already been published elsewhere, such as the detection of SiO masers in IRAS 16552-3050 [1] (the second WF known to have this type of emission after W43A [9]), or the detection of new high-velocity ejections in IRAS 18286-0959 [10]. We have also confirmed IRAS 18043-2116 as the WF with the largest velocity spread in its water masers to date [15]. The data analysis of the whole data set does not show a consistent behavior in the kinematic and morphological variations of masers in WFs, but a variety of patterns, whose origin is still to be determined.

An interesting case is that of W43A, the only WF that has been proposed to be still in the AGB phase [9]. The FLASHING spectra indicate that the water maser components are accelerating [8]. Since this water maser emission is found at the locations where the jet is shocking against the circumstellar envelope [13], this acceleration indicates that this shock is accelerating the gas entrained by the jet.

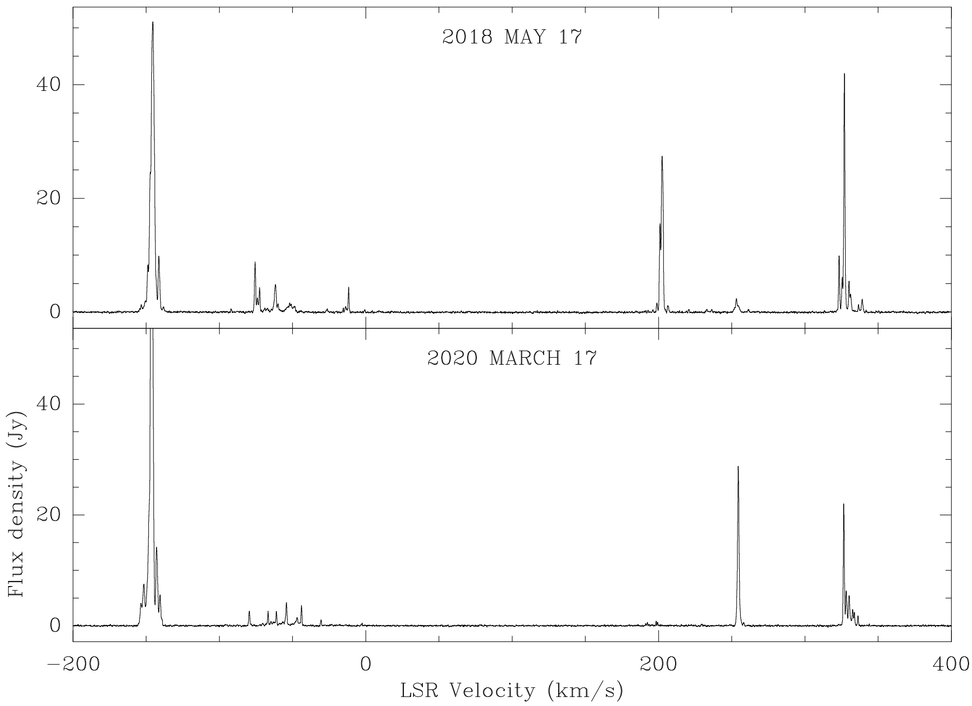

Figure 1: Water maser spectra of IRAS 18113-2503 taken on 2018 May 17 and 2020 March 17, with the Effelsberg 100m radio telescope.

The opposite kinematic trend (deceleration) was proposed for the post-AGB star IRAS 18113-2503 by [12] from high resolution water maser observations taken with the Very Long Baseline Array. These authors detected three nested bipolar ejections, with lower velocities for those farther away from the central source. This was interpreted as episodic ejections with similar initial velocities that were decelerated as they move along a dense circumstellar envelope. The estimated interval between these ejections (12 years) was linked to the period of a possible binary companion to the central star. The estimated deceleration of the water maser components under this model (2 km s^{-1} per month) should be easily seen in a single-dish monitoring. Moreover, a new ejection should already been produced, since the most recent one was already 12 years old by the time of the VLBA observations (epoch 2015). However, our monitoring with Effelsberg shows water maser spectra with relatively stable kinematics. In Fig. 1 we show two spectra taken almost two years apart. Apart from an obvious flux variability, the velocities of the spectral components do not show any significant drift. This velocity stability is more clearly seen in Fig. 2, where we show the temporal variation of the velocities in the most redshifted components. A deceleration should have been seen as a drift to the left from bottom to top. The stable velocities suggest that the ejections are moving freely against a low-density medium, and their injection velocities increase with time.

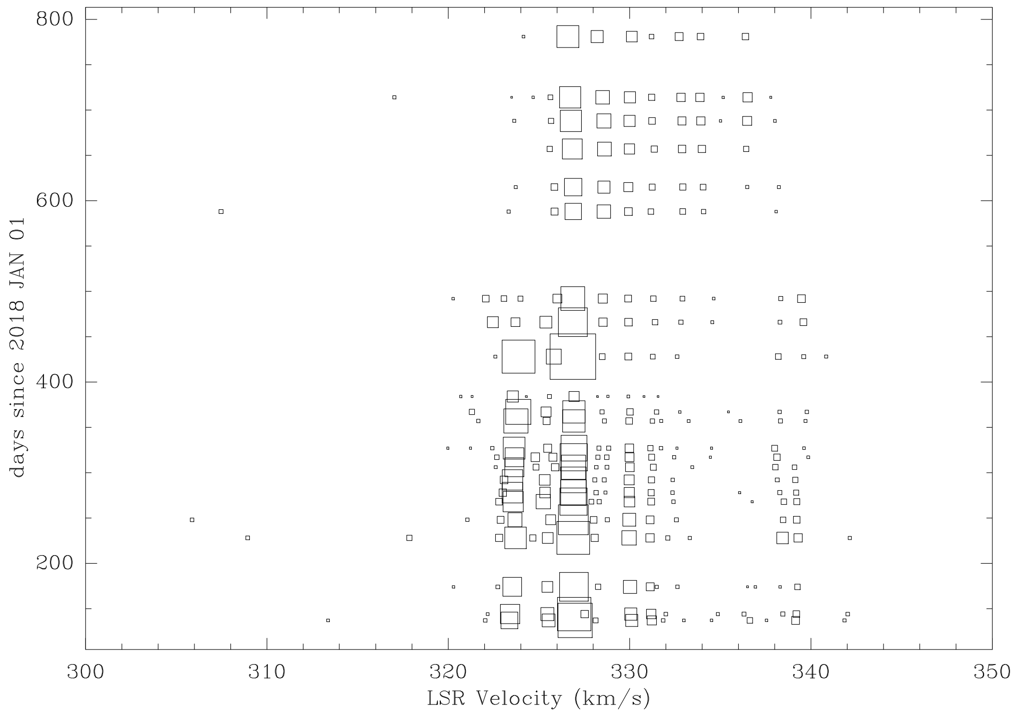

Figure 2: Temporal variation of the velocity of the most redshifted water maser components in IRAS 18113-2503. Each component is marked with a square, whose size is proportional to flux density

While maser deceleration has not been confirmed in IRAS 18113-2503, there is some hints that it could be occurring in IRAS 18286-0959 [10]. However, further data from FLASHING will be needed to confirm this.

The WF that seems to be more evolved is IRAS 15103-5754, which has been suggested to be a nascent PN [6, 7]. It is, in fact, the only known WF that has already started photoionization of its envelope. Our interferometric observations showed its water masers to be tracing a high velocity jet, also aligned with the infrared nebula, until 2014, but the position angle of the maser distribution significantly changed after that [7, 5], departing from the jet axis. More recent observations (March 2019, Fig. 3) shows that this source is no longer a WF, since all its water maser components are of low velocity (< 20 km s^{-1} from the systemic velocity), and their distribution is nearly perpendicular to the collimated jet, which was traced by the water masers in 2011 [7]. Actually, the maser distribution in 2019 in oriented in a similar direction as the toroid of molecular gas (traced by $C^{18}O$ and HCO^+) seen with ALMA [6]. All this seems to indicate that physical conditions for maser pumping are rapidly evolving in this source, and water masers are changing from tracing a high-velocity jet, as seen in other AGB and post-AGB WFs, to a low-velocity toroid, as in the water masers observed in young PNe [2, 11].

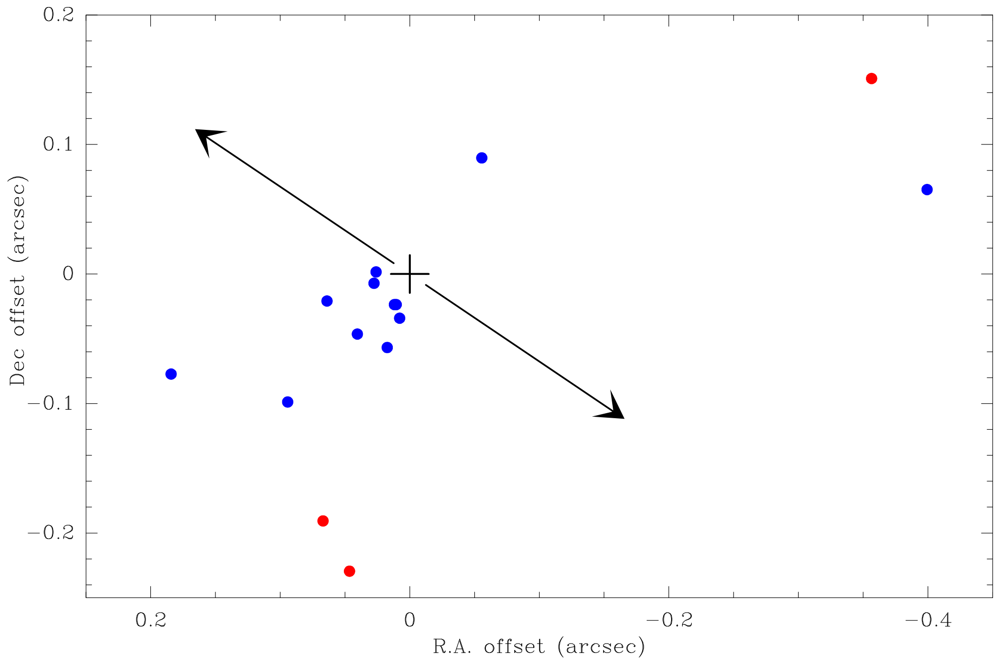

Figure 3: Distribution of water masers in IRAS 15103-5754, as observed with ATCA in March 2019. Blue and red filled circles mark the position of the spectral maser components that are blue- and redshifted with respect to the systemic velocity, respectively. The cross at offset [0,0] marks of the peak of radio continuum emission, coinciding with the location of the central star. The arrows show the direction of the jet, as traced by the water masers in 2011 [7].

4 Final remarks

Our monitoring shows very different patterns in the kinematics and spatial distribution of water masers in WFs. It is difficult at this point to explain the reason behind each particular pattern. It is tempting to think of the evolutionary stage of the source as the main explanation. In this framework, masers could be tracing accelerating gas in outflows during early stages (AGB), stable or decelerating outflowing gas in the post-AGB phase, and dramatically changing to trace toroids with low velocities as the star becomes a PN. Obviously the data presented here refer to only a few WF, and no solid evolutionary trend is possible at this point. Moreover, there are other possible parameters that could be key to explain the kinematical patters, such as the initial mass of the central star, or the mass and orbital period of a putative binary companion. The data from our ongoing monitoring of WFs could certainly provide further clues on the behavior of masers in these objects.

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References

[1] Amada, K., Imai, H., Hamae, Y., et al. 2022, AJ, 163, 85

[2] de Gregorio-Monsalvo, I., Gómez, Y., Anglada, G., et al. 2004, ApJ, 601, 921

[3] García-Segura, G., Villaver, E., Langer, N., et al. 2014, ApJ, 783, 74

[4] Goldman, S. R., van Loon, J. T., Zijlstra, A. A., et al. 2017, MNRAS, 465, 403

[5] Gómez, J. F., Miranda, L. F., Uscanga, L., et al. 2018, in IAU Symp 336, Astrophysical Masers: Unlocking the Mysteries of the Universe, 377

[6] Gómez, J. F., Niccolini, G., Suárez, O., et al. 2018, MNRAS, 480, 4991

[7] Gómez, J. F., Suárez, O., Bendjoya, P., et al. 2015, ApJ, 799, 186

[8] Imai, H., Amada, K., Gómez, J. F., et al. 2022, in IAU Symp 370, Winds of stars and exoplanets, in press

[9] Imai, H., Obara, K., Diamond, P. J., et al. 2002, Nature, 417, 829

[10] Imai, H., Uno, Y., Maeyama, D., et al. 2020, PASJ, 72, 58

[11] Miranda, L. F., Gómez, Y., Anglada, G., et al. 2001, Nature, 414, 284

[12] Orosz, G., Gómez, J. F., Imai, H., et al. 2019, MNRAS, 482, L40

[13] Tafoya, D., Imai, H., Gómez, J. F., et al. 2020, ApJ, 890, L14

[14] te Lintel Hekkert, P., Caswell, J. L., Habing, H. J., et al. 1991, A&SS, 90, 327

[15] Uscanga, L., Imai, H., Gómez, J. F., et al. 2023, ApJ, submitted