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Associations of H_2O and CH_3OH masers at milli-arcsec angular resolution in two high-mass YSOs

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Introduction

Single-dish surveys of 6.7 GHz methanol and 22.2 GHz water masers in high-mass star forming regions (SFRs) have shown that both maser species trace the earliest evolutionary stages of the high-mass star forming process (outflows, hot molecular cores, and UC HII regions).

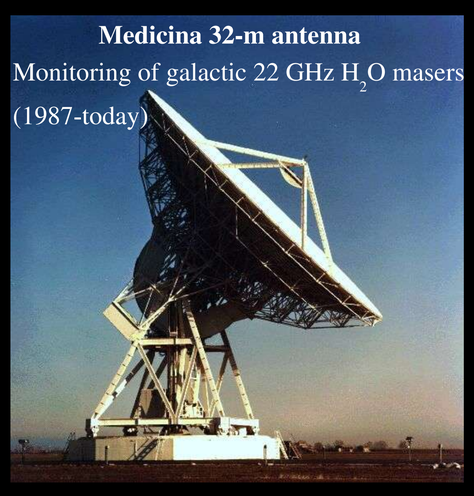
Very Long Baseline Interferometry (VLBI) multi-epoch observations have clarified that water masers originate from shocks associated with winds/jets ejected from the massive young stellar objects (YSOs). Instead, the birthplace of 6.7 GHz methanol masers is still debated and different environments have been proposed in several sources (Keplerian disks, jets, hot molecular cores, and HII regions).

Comparing the spatio-kinematic distribution of both maser species in the same YSO at high-angular resolution constrains better the interpretation of the kinematic structures and the evolutionary stages traced by the masers. So far only a few studies have been performed in both maser types with sufficient angular resolution (<0.1") to investigate the nature of the CH_3OH maser birthplace and the possible association between H_2O and CH_3OH masers in the same YSO.

Since a few years we have been conducting a multi-epoch VLBI campaign of a sample of high-mass YSOs where both the 6.7 GHz methanol and 22.2 GHz water masers are observed.

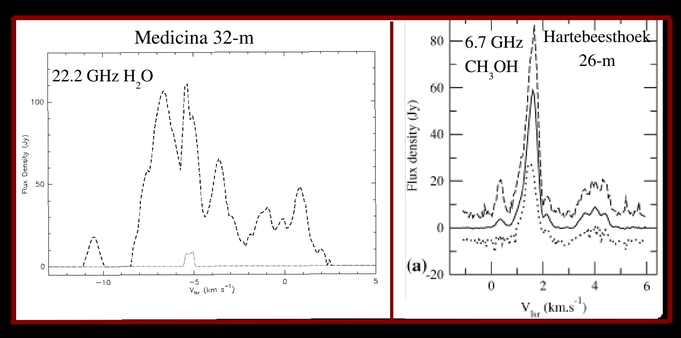
In this poster, we present the results obtained toward two high-mass YSOs: Sh 2-255 IR and AFGL 5142.

Observations



Observational results on the two sources

AFGL 5142 (L ~ 4×10^3 $L_\odot$, D ~ 1.8 kpc)



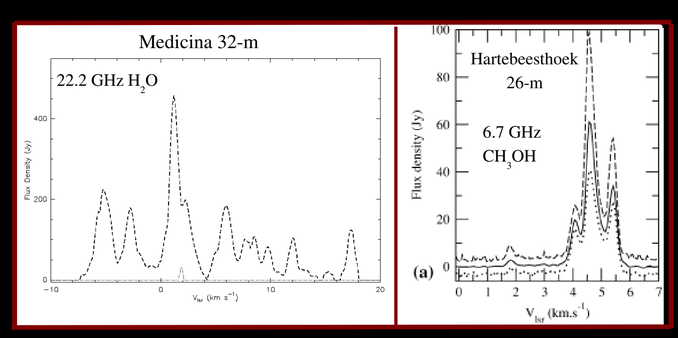
H_2O and CH_3OH maser variability from single-dish monitoring

The figures on the sides show the range of variation in the spectrum of H_2O masers from Medicina monitoring and CH_3OH masers from Hartebeesthoek monitoring [5], in AFGL 5142 and Sh 2-255 IR respectively. The dashed and dotted lines are the upper envelope and the lower envelope of the maser emission, respectively, calculated by finding the maximum and minimum at each velocity channel in the time interval 1999-2003.

In both sources, water masers have spectra changing completely over the years, whereas the main methanol features emit always at the same velocities. Water and methanol emissions emerge also at clearly different ranges of LOS velocities.

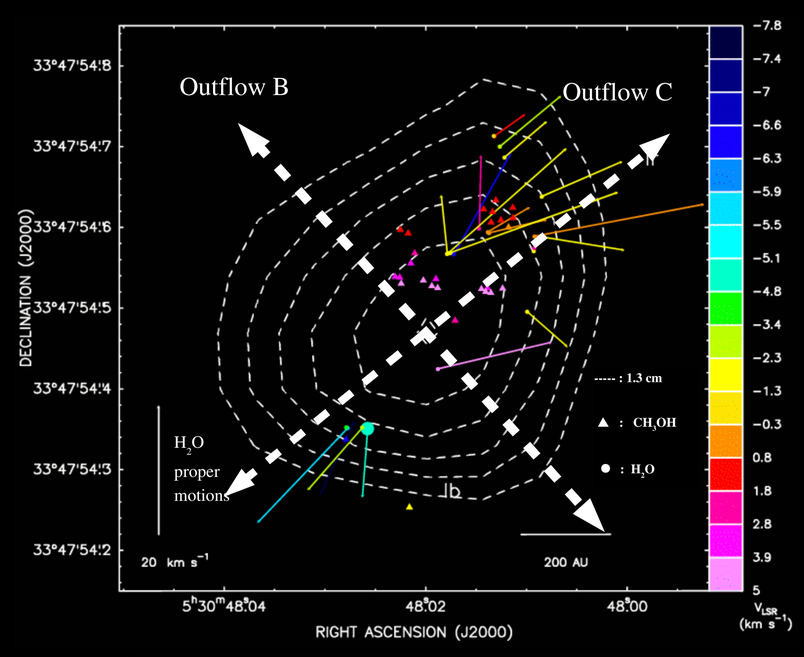
The different degree of time variability between water and methanol masers and, mainly, the rather clear separation in LOS emission velocities, for both sources, suggest that they trace different kinematic structures in the same YSO.

Sh 2-255 IR (L ~ 9×10^3 $L_\odot$, D ~ 2.5 kpc)



Association and kinematics of methanol and water masers at VLBI scales

AFGL 5142



The water masers show a bipolar spatial and LOS velocity distribution. Based on their 3D velocities, H_2O masers clearly trace expansion from the YSO, pinpointed by the 22 GHz continuum emission peak.

Two interpretations are possible:
1. They trace the innermost portion of the *collimated* CO outflow "C" [2] .
2. They trace the *wide-angle* disk-wind at the base of the CO outflow "B" [2].

High-angular resolution observations in continuum might help to identify the driving YSOs of outflow "B" and "C", and, hence, discriminate between the two options.

6.7 GHz methanol masers :

- are closer to the flow center and show higher LOS velocities than water masers:
  - ➔ in disagreement with an Hubble flow
- are seen in projection against the HC HII region, which is optically thick at 6.7 GHz:
  - ➔ must be located in the *foreground* of the HII region
- have strongly *red-shifted* LOS velocities:

➔ *Methanol masers might trace gas infalling toward the YSO!*

Fitting positions and LOS velocities of CH_3OH spots with a model of spherical infall:

$\mathbf{V}(\mathbf{r}) = -(2\,G\,M/r^3)\,\mathbf{r}$, the following parameters were derived:

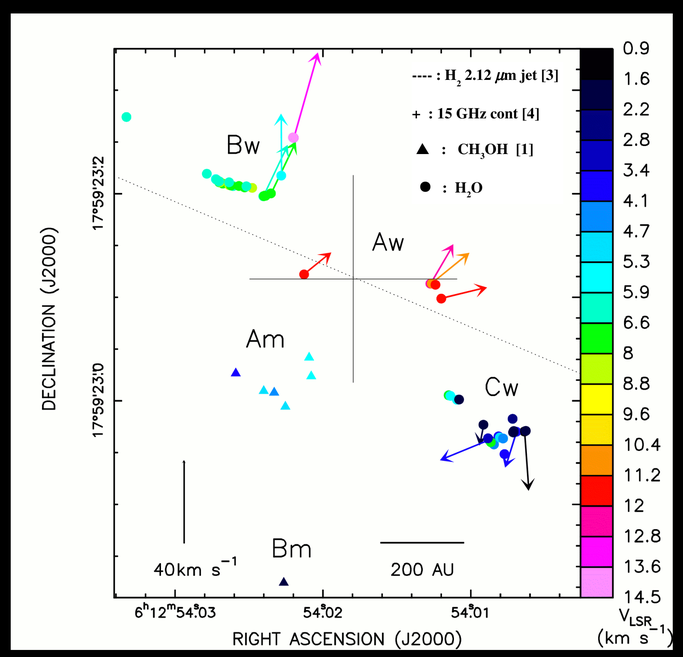
$r_s = 540 \pm 36$ AU, $M_s = 24 \pm 4$ $M_\odot$, $v_{inf} = 9$ km/s, $dM_{inf}/dt = 2 \times 10^{-5}\, n_6\, M_\odot$ yr^{-1}.

Water maser emission in Sh 2-255 IR consists of three main clusters of features (Aw, Bw, and Cw) distributed nearly along the axis of a H_2 ionized jet [3]: water masers are possibly associated with the inner part of the jet. However, all the measured proper motions are not aligned along the jet axis but form large angles with it.

Two scenarios can be considered:
1. precession of the jet axis
2. rotation around the jet (e.g. disk-wind)

The data in hands do not allow us to discriminate unambiguously between the two scenarios.

Sh 2-255 IR



The **6.7 GHz methanol maser** emission appears to arise from two distinct areas, Groups Am and Bm [1]. The present data are too scarce even to attempt a qualitative interpretation of their birthplace.

New multi-epoch EVN observations of the 6.7 GHz methanol masers are scheduled in order to determine their *absolute* positions and proper motions: they will help clarify the kinematic structures traced by both maser species toward this YSO.

Summary

Phase-reference VLBA multi-epoch observations of the 22.2 GHz water masers and EVN single-epoch observations of the 6.7 GHz methanol masers were conducted toward two high-mass YSOs in AFGL 5142 and Sh 2-255 IR.

With absolute positions as accurate as a few mas, our data reveal a *true* association of both CH_3OH 6.7 GHz and H_2O 22.2 GHz masers with the same massive YSO in AFGL 5142: the two maser types can then trace a common stage in the evolution of a forming high-mass star.

Albeit associated with the same YSO, in AFGL 5142 water and methanol masers appear to trace different kinematic structures, in particular *expansion* at the base of a molecular outflow and *infall* in a molecular envelope, respectively.

References

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