# EVN OBSERVATIONS OF $H_2O$ MASERS TOWARDS THE HIGH-MASS YOUNG STELLAR OBJECT IN AFGL 5142

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**Abstract.** We have conducted multi-epoch EVN observations of the 22.2 GHz water masers towards the high-mass young stellar object in AFGL 5142. With four observing epochs, spanning a time of ∼1 year, 12 distinct maser features have been detected and accurate values of the proper motions are derived for those persistent over three or four epochs. On the basis of their spatial distribution, the observed maser features can be divided into two groups. A model fit to the positions and velocities of the maser features of Group I, detected in the same region (within ∼500 mas) where the massive YSO should be located, demonstrates that these might arise on the surface of a nearly edge-on Keplerian disk, rotating around a massive young stellar object. The maser features of Group II, found at large distances from the YSO ($\geq 1''$), have positions and line-of-sight velocities in agreement with the blue-shifted lobe of a large-scale molecular outflow, and might result from the interaction between the gas flowing away from the young stellar object and the ambient gas of the progenitor molecular core.

**Keywords:** masers-stars, formation-ISM, individual objects (AFGL5142)-ISM, kinematics and dynamics-radio lines, ISM

## 1. Introduction

We present multi-epoch VLBI observations of the 22 GHz $H_2O$ masers towards the massive star forming region AFGL 5142 (IRAS05274 + 3345). Previous observations strongly suggest the presence of a YSO (at RA = $05^h27^m30^s$; DEC = $+33^\circ45'40''$), coincident with two compact thermal continuum sources (observed with the VLA at 8.4 GHz and with OVRO at 88 GHz), located at the origin of a $H_2$ and SiO jet and at the center of a CO and $HCO^+$ outflow (Hunter et al., 1995, 1999).

The flux density of the radio emission (interpreted as free–free emission from an ionized wind) and the bolometric luminosity (estimated using the IRAS fluxes) can be explained if the exciting source is a massive object, with spectral type B2 or earlier (Hunter et al., 1999). VLA $NH_3$-observations (Zhang et al., 2002) show a compact structure (diameter ∼1800 AU), coincident in position with the 8.4 and 88 GHz continuum sources, interpreted as an unresolved rotating disk.

The 22.2 GHz water masers in AFGL 5142 have been observed with the VLA at three epochs (1991, Torrelles et al., 1992; 1992, Hunter et al., 1995, 1998, 1999), and found to be distributed within a few arcseconds from the 8.4 and 88 GHz continuum sources. However, the VLA angular resolution ($\sim$0.″1) is inadequate to determine the detailed spatial distribution of the maser spots, to measure their proper motions and, consequently, to investigate the kinematics traced by the $H_2O$ masers in this source.

## 2. Observations and Results

AFGL 5142 was observed in the ($6_{16}$-$5_{23}$) $H_2O$ maser line (rest frequency 22235.080 MHz) using the European VLBI Network (EVN) at four epochs (October 1996, and June, September, November 1997). The data were processed with the MKIII correlator at the Max–Planck-Institut für Radioastronomie (Bonn, Germany), obtaining 112 spectral channels with a separation of 0.12 km $s^{-1}$. Data reduction was performed using the NRAO AIPS package, following the standard procedure for VLBI line data.

We have produced channel maps extended over a sky area of ($\Delta\alpha \cos\delta \times \Delta\delta$)$4'' \times 4''$ and covering a radial velocity range of 8 km $s^{-1}$. The CLEAN beam was an elliptical gaussian with a typical FWHM size of $\sim$1 mas. Each channel map was searched for emission above a conservative detection threshold (in the range 5–10 $\sigma$, where $\sigma$ = 0.03–0.3 Jy/beam), and the detected maser spots were fitted with two-dimensional elliptical Gaussians, determining position, flux density, and FWHM size of the emission. Hereafter, we use the term of maser “feature” to indicate a group of maser spots detected in at least three contiguous channels, with a position shift of the intensity peak from channel to channel smaller than the FWHM size.

Counting all four epochs, 26 $H_2O$ maser features were detected. Several of these show a good agreement in relative positions (within few mas) and line-of-sight velocities (within 1 km $s^{-1}$) for two or more epochs, and therefore we assume that in these cases we identified features which persist over time.

Figure 1 compares our VLBI results with previous interferometric observations. Top panels show the $HCO^+$ and SiO outflows observed with OVRO (Hunter et al., 1999). The area where the 22.2 GHz water maser emission has been detected with our VLBI observations is individuated by a small rectangle at the center of the field of view. This area is expanded in the lower panel of Figure 1, which shows the spatial distribution of the VLBI maser features superimposed on top of the distribution of the VLA emission centers found by Hunter et al. (1995, 1999) at two different epochs.

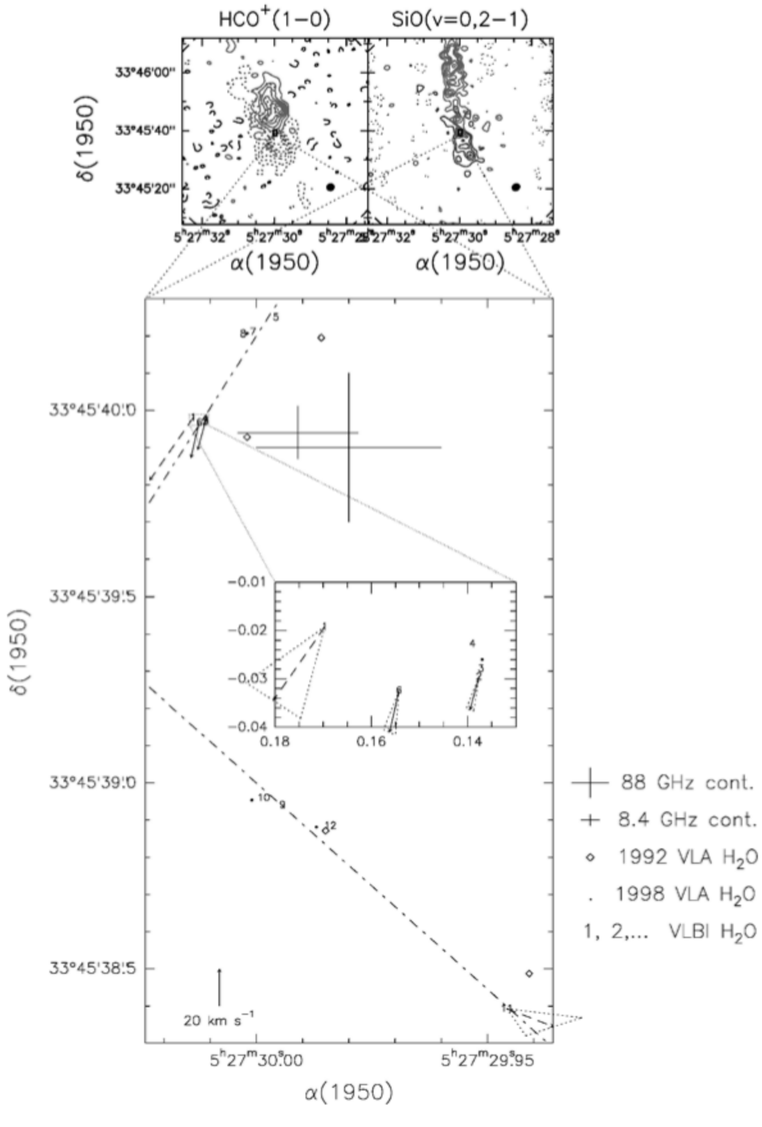


*Figure 1*. The upper panels show the contour maps of the OVRO high-velocity molecular line emission for $HCO^+$ ($1 \rightarrow 0$) (*left*) and SiO ($v = 0, 2 \rightarrow 1$) (*right*). The area at the center of the OVRO field of view, where the 22.2 GHz water emission has been detected by our VLBI observations, is expanded in the lower panel. This shows the spatial distribution of the VLBI features superimposed on top of the distribution of the VLA emission centers. The arrows indicate the measured proper motions, with dashed lines used in case of more uncertain values. The dotted triangles drawn around the proper motion vectors represent the amplitude and orientation uncertainty. The region in the northeast corner enclosed by the dotted lines is shown in greater detail in the box at the center of the lower panel, whose coordinates are arcsec offsets relative to the position: RA = $05^h27^m30^s$; DEC = $+33°45'40''$. The amplitude scale for the proper motions is given at the bottom left corner of the panel. For each of the two Groups of VLBI maser features, the dot-dashed line indicates the axis whose average distance from the feature positions is minimum.

The proper motions (indicated by the arrows in the Figure 1) have been calculated performing a linear least-squares fit of the positional offsets with time. Among the features observed at three or more epochs, the proper motions are derived only for those moving in a straight line at constant velocity. Tentative values of the proper motions (indicated by dashed arrows) are calculated also for the features observed at only two epochs.

The absolute position of the VLBI map has been determined by shifting it on top of the VLA map and minimizing the root mean square difference between the positions of the VLBI and VLA maser emission centers. Founding a good overlap between them, we are confident that the absolute position derived for the VLBI map is accurate within the VLA positional uncertainty.

On the basis of their spatial distribution, the VLBI maser features can be divided into two groups. Group I is found in the northeast corner of the area plotted in the lower panel of Figure 1, in the same region (within $\sim$500 mas) where the 8.4 GHz and 88 GHz continuum emissions are detected. Group II is more detached ($\geq 1''$) southward from the continuum emissions.

## 3. Discussion

The two groups of maser features have well distinct spatial and velocity distributions.

The maser features of Group I have a sky-projected distance $\leq$500–1000 AU from the 8.4 GHz and 88 GHz continuum sources, and should emerge near to the expected location of the massive YSO. At such a close distance to the YSO, the current theory of star formation predicts that an accretion disk and/or the base of the associated jet should be found. Both these environments might offer suitable physical conditions (high densities, $n_{\mathrm{H}_2} \sim 10^7\ \mathrm{cm}^{-3}$, and relatively high temperatures, $T \geq 400$ K) for the excitation of the 22.2 GHz water masers. Looking at Figure 1, one notes that the maser features of Group I have an elongated spatial distribution (the dot-dashed line indicates the elongation axis) and that the measured proper motions have an orientation close to that of the elongation axis. This geometrical condition is what one would in principle expect if these maser features traced a rotating disk seen edge-on or a collimated outflow motion along the disk axis. To establish more quantitatively which of these kinematical structures is compatible with our measurements, we fitted the position and the velocities of the maser features of Group I with two simple models: (1) a Keplerian disk; (2) a conical outflow.

As only the Keplerian disk model produces a solution for which the measured transversal velocities of the maser features are consistent with the corresponding line-of-sight velocities, we prefer it to the alternative conical flow model. The best fit solution is found with the disk seen almost edge-on and oriented on the sky parallel to the elongation axis of the Group I features (at P.A. $= 153^{\circ}$). The fitted value of the

YSO mass, $M_{\rm YSO} = 38\,M_{\odot} \pm 20\,M_{\odot}$, although determined with high uncertainty, strongly indicates that the central object is a massive YSO ($M > 10\,M_{\odot}$), consistent with the picture of an exciting object of spectral type B2 or earlier (Hunter et al., 1999). This result is also in agreement with previous mass estimates: the mass of the dusty core associated with the 88 GHz emission (Hunter et al., 1999) and the "disk" mass estimated from the $NH_3$ measurements (Zhang et al., 2002). Adopting a distance of 1.8 kpc to AFGL 5142, the range of disk radii traced in our model by the maser emission extends from $\sim$30 AU to $\sim$800 AU, which is consistent with the size of several hundreds of AU expected for an accreting disk around a massive YSO.

Owing to the large distance (2000–3000 AU) from the YSO, the Group II of maser features might also be associated with a distinct (as yet undetected) YSO. However, we found that the spatial and velocity distribution of these features is qualitatively in agreement with the blue-shifted lobe of the molecular outflow traced, on much larger scales, by the $HCO^+$ and SiO emission, suggesting that they might be tracing the flow motion in the innermost portion of the molecular outflow.

In conclusion, our 22 GHz water maser VLBI observations reinforces the idea that AFGL 5142 is a good candidate of high-mass YSO. The interpretation of the VLBI data is based on a scenario where the maser emission emerges both from a keplerian disk and from a jet/outflow system.

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