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AU-scale collimation of protostellar outflows from H_2O masers

J.-F. Desmurs
Observatorio Astronómico Nacional, Spain
E-mail: desmurs@oan.es

C. Codella
IRA, INAF, Italy
E-mail: codella@arcetri.astro.it

J. Santiago-García
Observatorio Astronómico Nacional, Spain
E-mail: j.santiago@oan.es

M. Tafalla
Observatorio Astronómico Nacional, Spain
E-mail: tafalla@oan.es

R. Bachiller
Observatorio Astronómico Nacional, Spain
E-mail: r.bachiller@oan.es

We conducted a study of water masers at 22.2 GHz around the Class 0 protostars called A and B in the NGC1333-IRAS 4 star forming region. Using the VLBA, we observed water emission at milliarcsecond scale and in phase referencing over four epochs spaced by one month to measure proper motions. The observations confirmed the high variability of H_2O maser emission, shorter than one month. The high angular resolution allowed us to show that A2, the weakest source of the IRAS 4A binary system, is associated with water masers. On the other hand, the spots associated with IRAS 4B show a high degree of collimation down to 25 AU and they are probably tracing the protostellar jet producing a bipolar molecular outflow.

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1. Introduction

NGC1333 is a well-known star forming region located at a distance of 350 pc and containing a large number of Young Stellar Objects (YSOs). In particular, IRAS 4 is a well-studied protobinary system composed of two strong dust continuum sources (A and B) [5]. Recently, high angular resolutions mm-observations [5] have revealed that IRAS 4A is itself a binary system composed of A1 and A2 and is driving a highly collimated outflow in the northeast-southwest direction [2]. IRAS 4B is also associated with a bipolar outflow located along the North-South direction [1]. Water masers at 22 GHz are intimately connected with outflows and represent a unique tool to investigate the earliest phases of star formation. VLBI is the unique technique that can provide the resolution required to study the maser emission regions in detail. Past EVN observations [4] revealed a highly collimated chain in the northern direction well in agreement with the redshifted northern lobe of the IRAS 4A outflow. Unfortunately, the lack of information on the absolute positions of the spots did not allow us to clarify which, among A1 or A2, is the source associated with the water spots. VLBA observations presented in this paper have solved this problem.

2. Observations and Results

Using the VLBA network, we observed water maser emission at 22.2 GHz in phase referencing over four epochs spaced by about four weeks during 2003 (Apr 1st, May 14th, June 11th, July 07th) with a restoring beam of 1.2 x 1.2 mas. As three young stellar objects fell in the primary beam of the antennas, we made 3 separate passes at the correlator, using the coordinates of each 3 sources (IRAS 4 A,B,C). None of the sources have been detected at each of the four epochs but only at two (IRAS 4A and IRAS 4B), whereas IRAS 4C has never been detected. At the first epoch (Apr 1st) no emission was detected. This confirms the high variability of the water maser spots associated with low-mass YSOs [6, 3], with an active phase shorter than four weeks.

In IRAS 4A, water spots were detected at the second and third epochs. Unfortunately, only two spots were observed, and thus we could not measure the collimation of the jet. However, the images show that water masers are spatially associated with A2, observable at millimeter wavelengths. This confirms that A2 is the YSO that drives the outflows observable at SiO line frequency on larger scale (see Fig. 1) as suggested by [2]. The comparison between the maps of May 14th and June 11th suggests that the brightest spot (labeled ‘a’) represents the same source of emission. If this is the case, the projected velocity of around 45 km/s towards NE can be inferred. However, if we consider the individual velocities of the spots, it seems that the proper motions should be derived by comparing the position of the spot ‘a’ of May 14th with that of the spot ‘b’ of June 11th. In this case, we derived a fast proper motion to the North with a velocity of 144 km/s. In both cases, the present maps indicate slightly blueshifted H_2O emission moving to North-West, in disagreement with the SiO outflow. This could either be due to geometrical effects (low inclination to the jet/outflow system to the sky plane) or could simply mean that because of the high H_2O maser variability, the spots of May 14th and those of June 11th are not the same entities.

In IRAS 4B water emission has also been detected in only two epochs. However, in this case, up to five H_2O spots have been revealed. The feature composed of the spots named ‘a’, ‘b’, and ‘c’ (see Fig. 1) together with the southern spot ‘d’ show a high degree of collimation along the

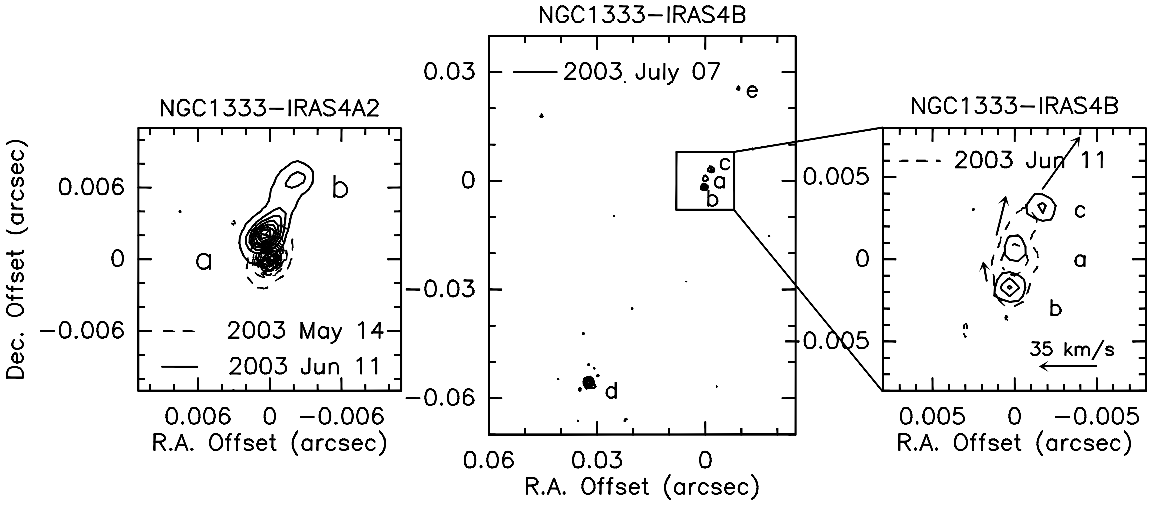

Figure 1: Water maser maps and apparent proper motion measure for IRAS 4A (left) and IRAS 4B (right).

25° NW direction. Only the northern spot ‘e’ is slightly displaced from such direction. The size of the water spots chain is around 80 mas (28 AU at 350 pc), while the direction is well in agreement with the molecular outflow observed at larger scale and driven by IRAS 4B. We were able to derive the apparent proper motion of the feature composed of the spots ‘a’, ‘b’, and ‘c’. In this case, water masers (i) are moving towards the North with projected velocities in the range 10–50 km/s, and (ii) are highly redshifted. These considerations, together with the spatial association with the mm-source IRAS 4B (offset: −104, +135 mas), are well in agreement with the outflow. In other words, thanks to the H_2O spots we are tracing the fast jet sweeping up the surrounding gas and creating the large-scale SiO outflow.

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