Cosmic Masers - from OH to H_0
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EVLA imaging of the water masers in the massive protostellar cluster NGC6334I

Todd R. Hunter and Crystal L. Brogan

NRAO, 520 Edgemont Rd, Charlottesville, VA 22903, USA;
email: thunter@nrao.edu

Abstract. We have used the recently-upgraded Karl G. Jansky Very Large Array (VLA) in A-configuration to observe the water masers in the massive protostellar cluster NGC6334I with broad bandwidth and high spectral resolution. Four groups of maser spots are found. The two groups with the broadest velocity span (40 km/s) are towards the UCHII region and the hot core SMA1. The spatial kinematics of the SMA1 masers are consistent in sense and orientation with the large-scale CO outflow and appear to trace the base of the outflow from a protostar at the dust peak of SMA1. Additional masers at the southern end of SMA1 provide evidence for a second protostar. The highest intensity maser lies about $2''$ north of SMA1. Interestingly, no water masers are seen on the equally impressive hot core SMA2. Finally, we have detected maser emission toward the enigmatic source SMA4, which shows no millimeter molecular lines despite having strong, compact submillimeter continuum and may trace another protostar.

Keywords. masers, stars: formation, ISM: jets and outflows, ISM: molecules, radio lines: ISM, radio continuum: ISM, infrared: ISM, submillimeter

1. Introduction

The association of water masers with massive star formation has been clear for many decades. Surveys of molecular outflow sources show a strong correlation with the presence of water masers (e.g., Tofani *et al.* 1995). The detailed kinematics of these masers have been interpreted as arising either in protostellar accretion disks or outflows. Much of the uncertainty arises because massive protostars form in clusters with multiple outflows overlapping simultaneously (e.g., Zhang *et al.* 2007) which can make it difficult to disentangle the individual outflow axes. Thus it is important to identify well-collimated massive bipolar outflows and observe them at high angular resolution in both water maser and thermal molecular lines. A good example is found in the massive protocluster NGC6334I (Hunter *et al.* 2006; Beuther *et al.* 2005), whose bipolar outflow has been imaged by single-dish telescopes (Leurini *et al.* 2006; Qiu *et al.* 2011). Here we present the first interferometric CO(2-1) observations along with the 22 GHz water maser emission.

2. Observations

We performed 22.235 GHz observations of NGC6334I in September 2011 with the VLA in A-configuration to demonstrate the flexibility of the upgraded IF system and correlator and confirm the operation of high resolution modes. In both of the independently tunable 1 GHz basebands, we configured 8 adjacent subbands each with a bandwidth of 4 MHz (54 km/s) and channel width of 0.42 km/s. The IFs were shifted by 2 MHz in order to provide uniform sensitivity across the subband edges for a total bandwidth of 34 MHz. Similarly, we observed the central 2.1 MHz of emission using subbands of 250 kHz bandwidth (3.4 km/s) with 0.026 km/s channels. CO(2-1) was observed with the Submillimeter Array (SMA) in February 2004 in extended config and in August 2008

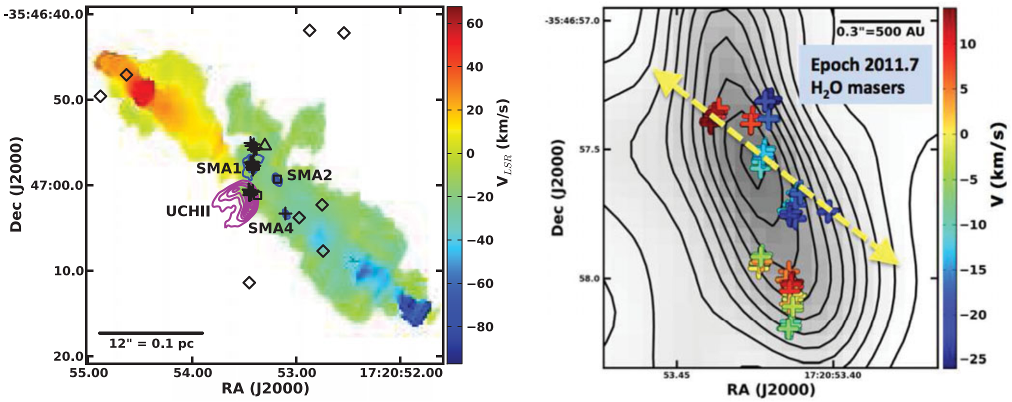

Figure 1. Left: Image of the CO (2-1) velocity field ($2.5'' \times 1.0''$ beam), with 870μm continuum overlaid in blue contours (Brogan *et al.* in prep.), VLA 8.4 GHz continuum in magenta contours (Hunter *et al.* 2006), 22 GHz H_2O masers (black crosses), 44.069 GHz CH_3OH 7_0-$6_1 A^+$ masers (crosses) (Gómez *et al.* 2010), 12.2 GHz CH_3OH $2_0 - 3_{-1} E$ masers (squares) (Breen *et al.* 2012), and the 23.121 GHz CH_3OH 9_2-$10_1 A^+$ maser (triangle) (Kurtz, Hofner & Álvarez 2004). **Right:** 870μm continuum contours ($0.5'' \times 0.3''$ beam) overlaid with the water maser positions.

in very-extended config. The 870μm continuum was observed in the very-extended config in August 2008.

3. Results

In Figure 1, the CO(2-1) velocity field reveals the outflow to be highly-collimated on 0.5 pc scales. Of the two hot cores (SMA1 & SMA2), SMA1 lies closest to the outflow axis and the interface between the redshifted and blueshifted CO. Similar to its neighboring source NGC6334I(N) (Brogan *et al.* 2009), multiple groups of maser spots are found. The masers with the broadest velocity span (40 km/s) are towards the UCHII region and the hot core SMA1. The spatial kinematics of the SMA1 masers match the large-scale CO outflow in sense and orientation and appear to trace the origin of a protostellar outflow at the dust peak of SMA1. Additional masers at the southern end of SMA1 provide evidence for either an outflow or a disk toward another protostar. The highest intensity masers lie $\sim 2''$ north of SMA1. Interestingly, no water masers are seen on the equally impressive hot core SMA2. Finally, we detect maser emission toward the enigmatic source SMA4, which shows no thermal molecular lines despite having strong, compact submillimeter continuum. The compact spatial velocity gradient here could trace another outflow or a disk with dynamical mass of $2M_\odot$, suggesting the presence of another protostar.

References

Breen, S., Ellingsen, S., Caswell, J., *et al.* 2012, arXiv:1201.1330
Beuther, H., Thorwirth, S., Zhang, Q., *et al.* 2005, *ApJ*, 627, 834
Brogan, C. L., Hunter, T. R., Cyganowski, C. J., Indebetouw, R., *et al.* 2009, *ApJ*, 707, 1
Hunter, T. R., Brogan, C. L., Megeath, S., Menten, K., *et al.* 2006, *ApJ*, 649, 888
Gómez, L., Luis, L., Hernández-Curiel, I., *et al.* 2010, *ApJS*, 191, 207
Kurtz, S., Hofner, P., & Álvarez, C. V. 2004, *ApJS*, 155, 149
Leurini, S., Schilke, P., Parise, B., *et al.* 2006, *A&A*, 454, L83
Qiu, K., Wyrowski, F., Menten, K. M., *et al.* 2011, *ApJ*, 743, L25
Tofani, G., Felli, M., Taylor, G. B., & Hunter, T. R., 1995, *A&AS*, 112, 299
Zhang, Q., Hunter, T. R., Beuther, H., *et al.* 2007, *ApJ*, 658, 1152

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