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Proper Motions of Water Masers in Circumstellar Shells

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Abstract. We present measurements of proper motions for circumstellar water maser observations obtained with the VLBA. Results of the observations and modeling indicate that the water masers exist in a kinematically complex region of the circumstellar envelope. A change in position of the maser spots as a function of velocity is discussed.

1. Introduction and Observations

Proper motions of masers have been historically difficult to measure due to sparse sampling with *ad hoc* VLB arrays. The VLBA easily allows multi-epoch campaigns with a uniform set of antennas, simplifying the data processing and allowing reliable measurement of maser proper motions.

We obtained three epochs of observation with the VLBA to study the proper motions and spatial distributions of water masers in seven evolved stars. The stars (VX Sgr, U Her, RX Boo, S Per, VY CMa, NML Cyg, and IK Tau) were selected for their consistently strong water maser emission and for the fact that they sample a broad spectrum of evolved star characteristics. After reducing the data using AIPS, we were able to form proper motion plots for a number of stars and epochal pairs. Due to space constraints, the figures have been placed on a WWW page. Interested parties should access http://www.ovro.caltech.edu/kbm/IAU164.html. Further, copies of Marvel's recent dissertation and preprints of papers detailing results obtained for S Persei and VX Sagittarii will soon be available at the same URL. Individuals without web access may email the author at kbm@ovro.caltech.edu to obtain either electronic or paper copies of any of the work mentioned.

2. Results

Building on the work of Bowers (1991), we attempted to fit a geometric ellipsoidal shell of varying thickness to the spot distribution along with a variety of underlying kinematic models (simple radial outflow, radial outflow with rotation, and radial outflow with acceleration). For a given ellipsoidal distribution, the observed characteristics of the emission (radius vs. velocity, observed spectrum and position angle of maser spots vs. velocity) are strongly dependent on the kinematic model applied. We found that, in most cases, simple kinematic models assuming an ellipsoidal geometry were not able to explain the observed distribution of masers. Furthermore, the standard radius vs. velocity plots used frequently in the literature did not exhibit the so-called "standard model" shape of a simple parabola (Goldreich & Scoville 1976; Elitzur, Goldreich, & Scoville 1976). This has been noticed by other authors (Bowers & Johnston 1994). The fact that the water masers are not well fit by simple kinematic models should not be particularly surprising. The dust formation process, which initiates the wind, is likely to be both inhomogeneous and anisotropic, not to mention irregular in time, causing a very non-uniform velocity field in the water maser region (Habing 1996).

Because no simple kinematic model fits the maser distribution, we were forced to assume that the mean observed proper motion is proportional to the projected mean velocity to estimate the distance to each source. This assumption implies that the observed proper motions and velocities fully sample the circumstellar shell, which may or may not be the case. Our derived distances and their formal errors are shown in table 1.

As is being found in a number of recent maser observations with the VLBA (D. Boboltz, K. Desai, S. Ellingsen; private communications), a clear change of position with velocity for individual maser spots has been detected. In magnitude, it is similar to that expected by simple gas acceleration in the region (for these observations). Instrumental effects have been ruled out as a possible cause. Past network VLBI observations have been checked for this effect, and it is present within the errors imposed by the larger beam and poorer dynamic range (Marvel & Diamond, in preparation). Further theoretical work may be needed to help constrain this effect and its cause.

Table 1. Estimated distances of sources observed

Star	$D_{accepted}$ (kpc)	$D_{thiswork}$ (kpc)	σ_D (kpc)
S Persei	2.2	2.3	.5
VX Sagittarii	1.5	1.7	.3
VY Canis Majoris	1.5	1.4	.2
NML Cygni	2.0	3.5 (up limit)	-

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