Cosmic Masers - from OH to H_0
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Distance and Maser Outflows of the Galactic Star-forming Region W51 Main/South

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Abstract. We report on high-resolution astrometry of 22 GHz H_2O maser emission in the Galactic massive star-forming region W51 Main/South using the Very Long Baseline Array. We measured the trigonometric parallax of W51 Main/South to be 0.185 ± 0.010 mas, corresponding to a distance of $5.41^{+0.31}_{-0.28}$ kpc. The H_2O maser emission in W51 Main/South traces four powerful bipolar outflows within a 0.4 pc size region, three of which are associated with dusty molecular hot cores and/or hyper- or ultra-compact HII regions. The maser outflows in W51 Main/South have a relatively small range of internal 3D speeds, suggesting that multiple speed maser outflows in other Galactic massive star-forming regions may come from separate young stellar objects closely spaced on the sky.

Keywords. astrometry, masers, stars: formation, ISM: jets and outflows

1. Observations and Results

W51 Main/South is a well-studied massive star-forming region that hosts one of the strongest H_2O maser sources in the Galaxy. We conducted phase-referencing observations of the 22 GHz H_2O maser line in W51 Main/South using the Very Long Baseline Array (VLBA) at four epochs on 2008 October 22, 2009 April 27 and 30, and 2009 October 20. Two background quasars J1922+1530 and J1924+1540 were observed as phase references to measure the absolute position of the maser source in W51 Main/South.

We measured the parallax of W51 Main/South to be $\pi = 0.183 \pm 0.006$ mas using J1922+1530 and $\pi = 0.187 \pm 0.009$ mas using J1924+1540. The uncertainty of each parallax fit was obtained from the formal fitting uncertainty. By combining the two fits and estimating the partially correlated errors for the two quasars, we obtained $\pi = 0.185 \pm 0.010$ mas as the best estimate, which corresponds to a source distance of $5.41^{+0.31}_{-0.28}$ kpc. Our parallax distance is in good agreement with previous distance measurements of W51 (e.g., $5.1^{+2.9}_{-1.4}$ kpc by Xu *et al.* 2009 from a 12 GHz methanol maser parallax), but has a much higher accuracy of ≈5% and thus gives a strong constraint on the distance to W51.

We searched for maser spots in W51 Main/South by mapping a field of $\approx 20'' \times 20''$ and, in the first epoch's data, detected 1362 spots making up 280 unique "features" (i.e., groups of spots at the same position but in adjacent velocity channels). We detected 37 H_2O maser features that we could identify at all four epochs. Figure 1 gives a map of positions and internal motions of the detected maser features, after subtracting the mean motion of all four regions. The positions of the hyper- and ultra-compact HII regions (e.g., W51e2-E, e2-NW) are also plotted by crosses with sizes marking the approximate beam sizes from previous observations. We classified all 37 features into four separate groups according to their likely exciting sources: W51e2-NW, W51e2-E and W51e8, and a region

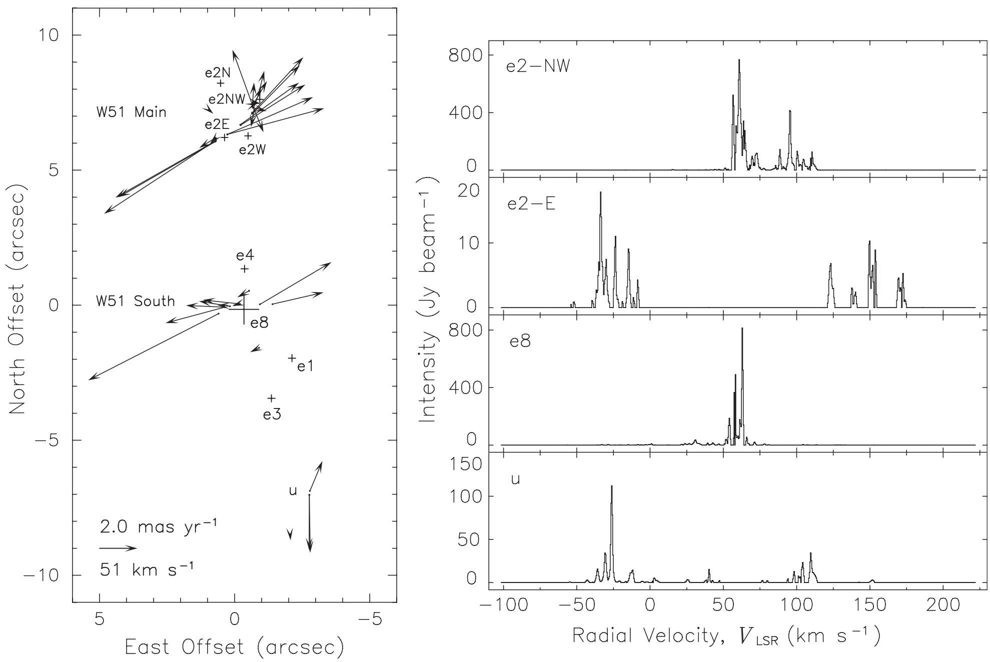

Figure 1. Left: map of the positions and internal motions of H_2O maser features in W51 Main/South, after subtracting the mean motion of all regions. Absolute coordinates of the map origin are R.A. (J2000)= $19^h23^m43\overset{s}{.}93427$ and Dec. (J2000)= $14°30'28\overset{''}{.}3498$. The hyper- and ultra-compact H II regions are marked by crosses with positions and beam sizes from previous observations (Gaume, Johnston & Wilson 1993; Zhang & Ho 1997; Shi, Zhao & Han 2010). Right: H_2O maser spectra of the four regions with intensities summed over all detected spots.

we call "u" without detected millimeter or centimeter continuum emission. For the W51e2 region, we identified two outflows: a high-velocity outflow and a low-velocity outflow that arise separately from the e2-E and e2-NW cores, respectively. Each H_2O maser outflow in W51 Main/South shows a relatively small range of internal 3D speeds. This is contrary to previous observations of other Galactic star-forming regions, e.g., Orion-KL (Genzel & Downes 1977) and W49N (Gwinn *et al.* 1992), which suggested that high and low velocity outflows might originate from the same young stellar object. In W49, a strong acceleration region at a radius of 0.1 pc is required if all masers are associated with a single young stellar object. However, these conclusions were based on observations with less precise maser motions and much lower resolution dust emission maps. Our results for W51 suggests that multiple speed outflows may come from separate young stellar objects that can be very closely spaced on the sky (see Sato *et al.* 2010 for details of the measurements and for further discussion).

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