The Kinematics, Physical Condition, and Magnetic Field of the W3 IRS5 Region Traced by Water Masers

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We have investigated water masers associated with the star-forming region W3 IRS5 using the VLBA. The maser 3D motions exhibited outflows, which will be originated from two of hyper-compact HII regions. The distance to W3 IRS5 was also estimated to be about 1.8 kpc. The directions of maser linear-polarization are well aligned in the whole maser region and perpendicular to the estimated magnetic field, which is well consistent with an hourglass model of the field in W3 IRS5. The microstructures found in the individual maser features ($\sim$1 AU) exhibit the "fractal fashion" and express turbulence on such a tiny scale. Thus water maser study is applicable to comprehensively understanding the site of massive-star cluster formation at the early stage.

Motivation

- Estimation of the outflow driving sources in the cluster of newly-formed massive-stars from the 3D maser kinematics.
- Discussion on evolutionary status of the individual massive stars.
- Direct estimation of the distance (statistical parallax, model fitting).
- Understandig the relation between linear polarization of water maser emission and a magnetic field.
- Estimation of the magnetic field in the compact region in a star-forming region.
- Investigation of the physical condition (shocks, turbulence) on basis of statistics of the masers.

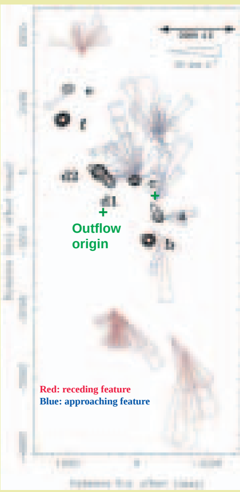

Figure 1: Spatial distribution and 3D motions of water maser features (cones) and the compact radio continuum sources (contours) (Claussen et al. 1994) in W3 IRS5.

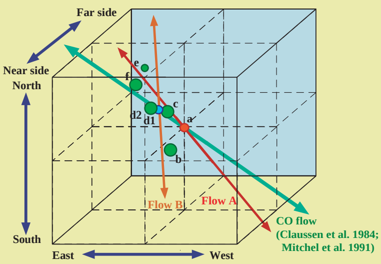

Figure 2: Schematic diagram of multiple outflows in W3 IRS5, which are expected from the CO outflow, the maser proper motions, and the continuum sources.

VLBA observations

- Epochs: 1997 March 26, October 8, 1998 January 5, and November 21 (polarimetry).
- Signal recording:
  LCP, 4MHz$\times$2ch (first 3 epochs),
  Full pol. data, 4MHz$\times$1ch (4th epoch).
- Velocity resolution of the correlated data: 0.1 km/s (3 epochs), 0.4 km/s (4th epoch).
- Synthesized beam (in unit of mas):
  0.3$\times$0.4(3 epochs), 0.5$\times$0.7(4th epoch).
- $\sim$100 maser proper motions measured.

Distance to W3 IRS5

- Model fitting: D =1.83$\pm$0.14 kpc.
- Statistical parallax: D =1.8$\pm$0.2 kpc
  (for the Flow A kinematics).
- Kinematic distance: $\sim$1.8 kpc
  (adopting $R_\odot$ =8 kpc).

Multiple outflows in W3 IRS5

- Clearly seen in the position–3D velocity diagrams (Imai *et al.* 2000).
- Outflow driving sources: may be the continuum sources a and either $d1$ or $d2$ (see figure 1).
- Outflows are roughly parallel to each other (see figure 2).
- Internal stellar motions in the cluster: $\lesssim$10 km s^{-1}.
- Time scale of the formation of the massive-star cluster: $\lesssim 10^5$ years.

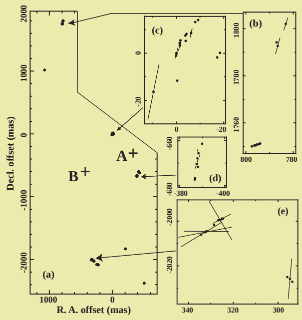

Figure 3: Map of linearly-polarized maser features in W3 IRS5. A bar indicates a logarithmic scale and a direction of the electric vector.

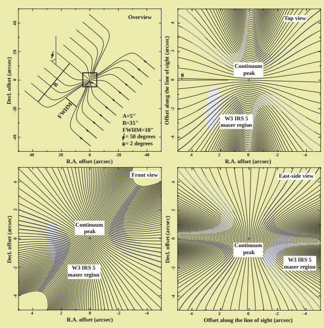

Figure 4: Model of the magnetic field around W3 IRS5.

Magnetic field in W3 IRS5

- Linear polarization directions are perpendicular to the magnetic field projected on the sky, because the magnetic field is aligned on the sky plane (see figure 3).
- The magnetic field estimated from the maser polarimetry is consistent with a "hourglass" model (Roberts *et al.* 1993).
- The hourglass model (see figure 4) is supported by the magnetic field strength in this region (Sarma *et al.* 2002).

Microstructures in water masers

- Velocity gradients in individual maser features are commonly found in most of water maser sources, but feature morphologies are different according as locations in the maser source (see figure 5).
- "Fractal fashion" on the maser feature scale ($\sim$1 AU) may be common among all maser sources (see figure 6).
- Higher velocity outflows (e.g. W49N, Gwinn 1994) create larger turbulence on larger scale (3–300 AU).
- Higher velocity outflows make the two-point correlation function of masers *flatter*.

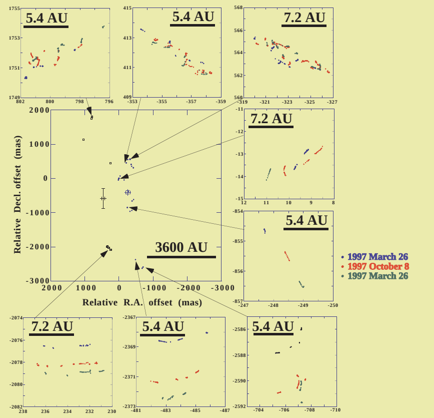

Figure 5: Microstructures found in individual maser features, clusters of velocity components.

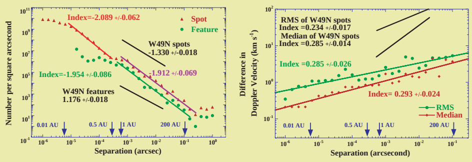

Figure 6: Two-point (left) and velocity (right) correlation functions for the W3 IRS5 and W49N water masers.

Future prospective

- Statistical analyses for water maser proper motions (3D motions) among star-forming regions to trace the evolution of outflows, ambient dense clouds, and massive protostars.

References

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