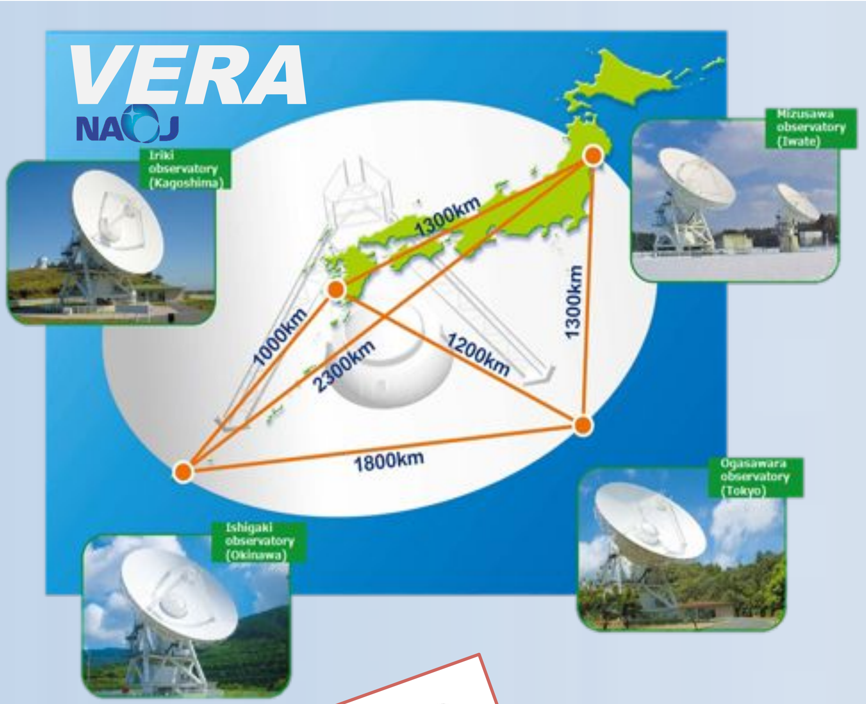

Jets in Massive young stellar objects: The `Water spout' and the `Micro-jet'

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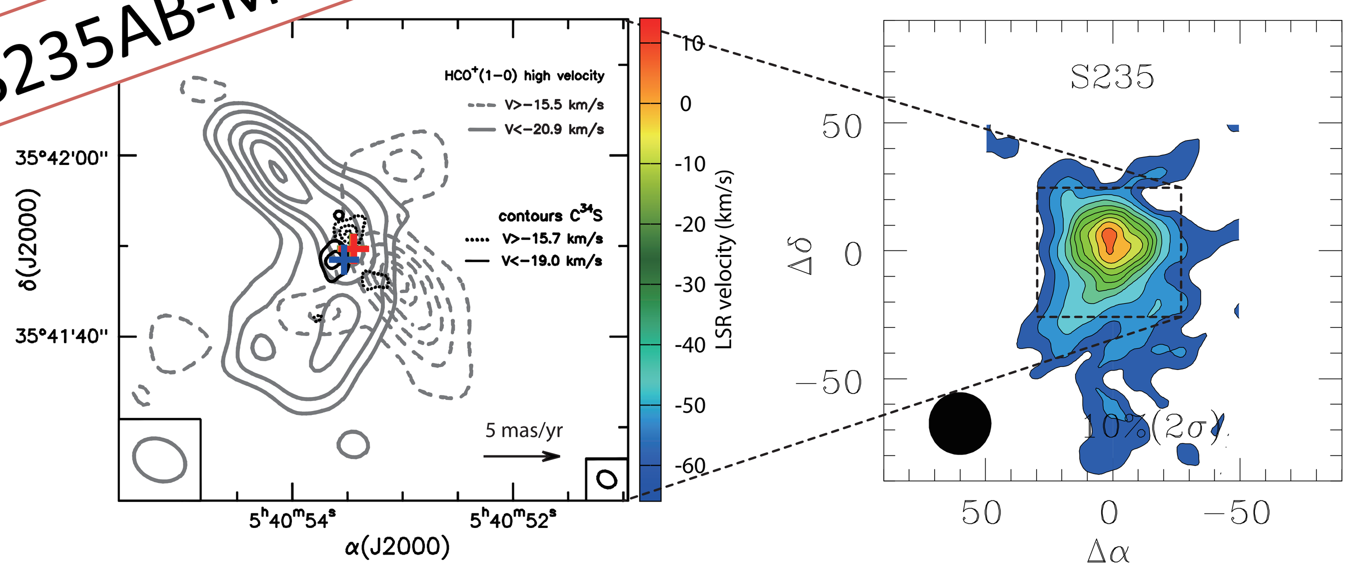
Abstract: In our recent water maser VLBI observations with VERA we found examples of two interesting and rare types of jets associated with massive young stellar objects (MYSOs), these are the `water spout' and the `micro-jet'. In this poster we introduce recent observational results and briefly discuss their implications for theories of massive star formation.

Water Spout

S235AB-MIR



S235AB-MIR is a 11Mo, very young MYSO with two sets of bipolar outflows and no centimeter emission. The water masers align with the NNE-SSW outflow which is traced by HCO+ and $C^{34}S$.

Fig 1. Illustrative description of the S235AB-MIR MYSO outflow system showing (left) HCO+ (1-0) and C34S (5-4) from [1], and, (right) CS (7-6) from [2]

Observations

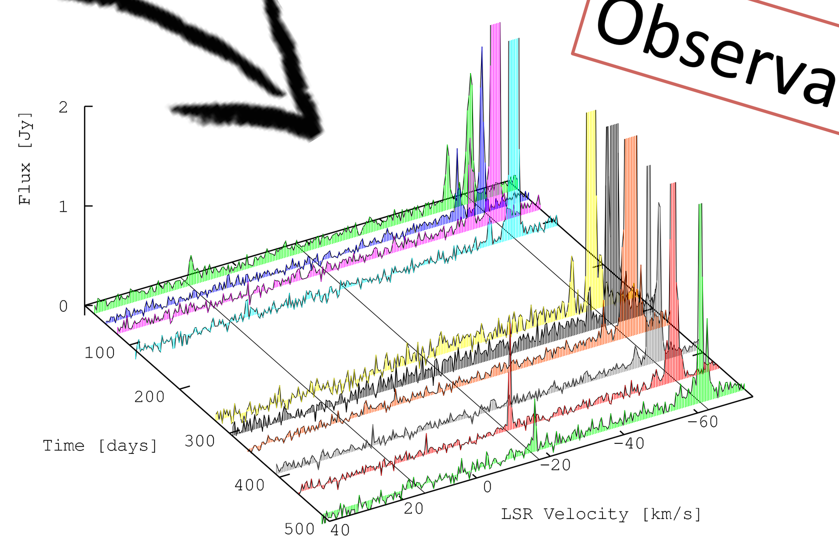


Fig 2. The maser spectrum of S235AB-MIR as a function of time.

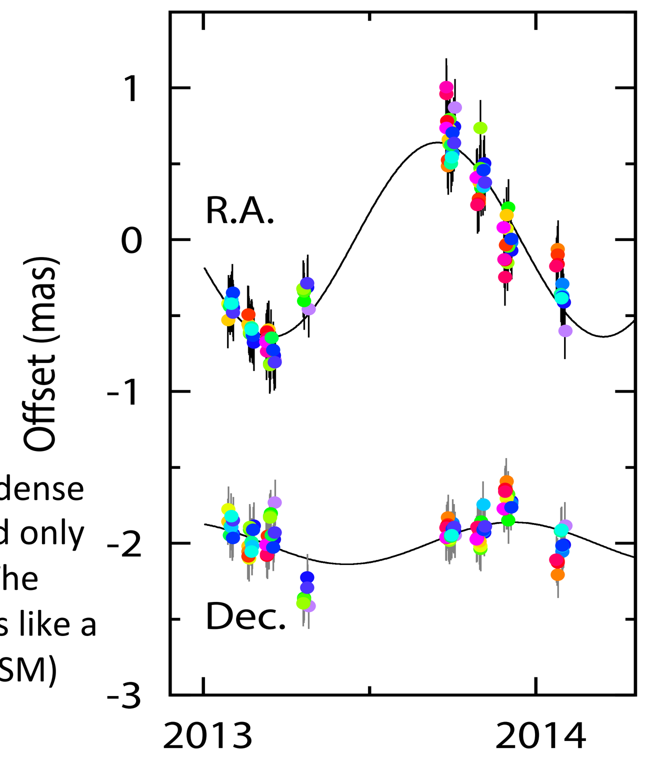


Fig 3. Parallactic motion in R.A. (above) and Dec. (below) for masers associated with the two most persistent features, after subtracting linear proper motions.

We observed 12 epochs using dense scheduling with VERA, but used only 10 epochs for parallax fitting. The spectrum of S235AB-MIR looks like a dominant blue-shift maser (DBSM) (Fig 2).
VLBI data were reduced using inverse phase referencing in AIPS.
The parallax was D = 1.56 ± 0.09 kpc (Fig 3).

Angular momentum

In disk accretion theories of massive star formation there must be a mechanism of removing angular momentum from the inner disk region in order to allow accretion onto the star. Proposed ways of removing angular momentum include: Alven waves, magnetic breaking and physical removal by a rotating jet launched by magnetic fields [3]. In S235AB-MIR, presented here, we found evidence of jet rotation in the 3D motions of water masers, observed with VERA. We named this type of jet a `water spout' [4]. The existence of jet rotation may provide the `missing link' in the unexplained momentum budget of accreting MYSOs. We are proposing follow up observations to image the molecular gas in the jet using millimeter interferometers.

The 3D motions of the water masers modeled as a rotating cylindrical jet of 7 AU radius. The best-fit model (Fig. 5) had 80% agreement with the data. The model parameters are v_{out} = 45 ±2 km/s, v_{rot} = 22 ±3 km/s, i = 12±2° An artist's impression of what the `water spout' might look like is shown in Fig 6.

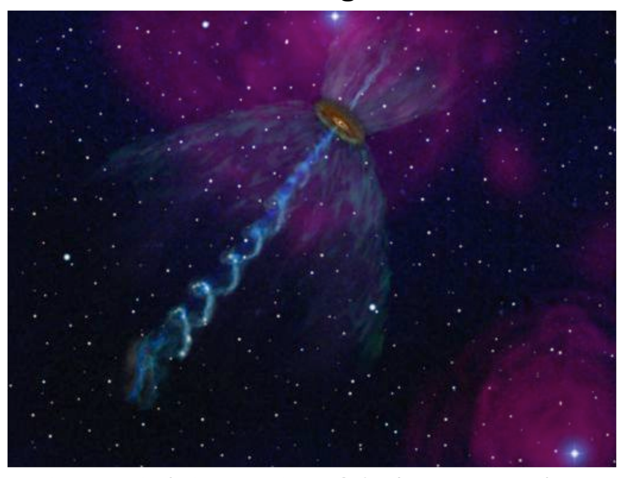


Fig 6. Artist's impression of the `water spout'

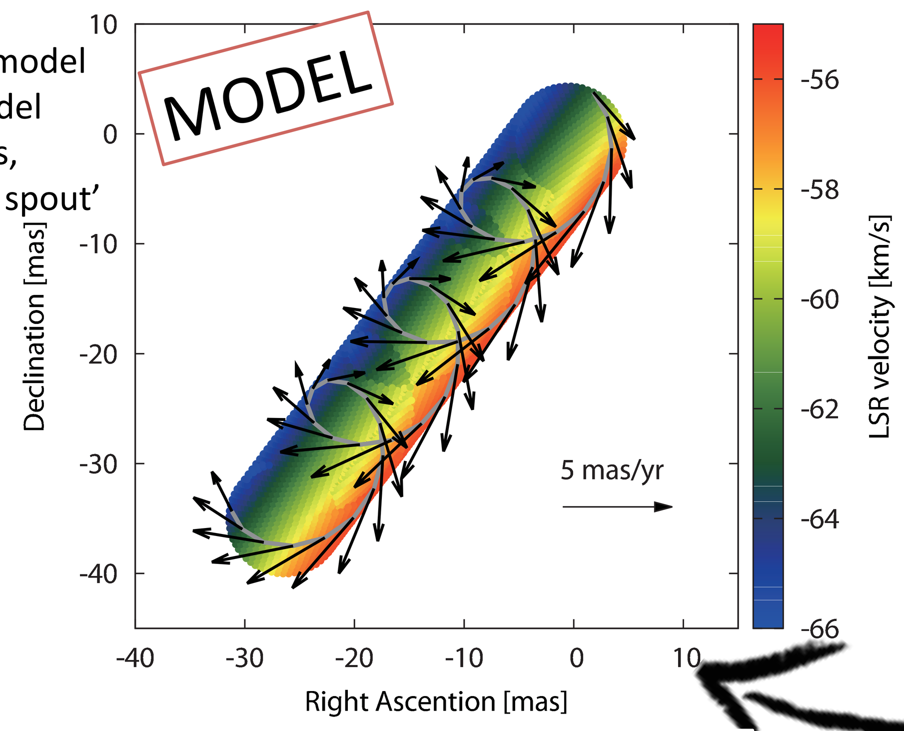


Fig 5. The best-fit model to the 3D maser data

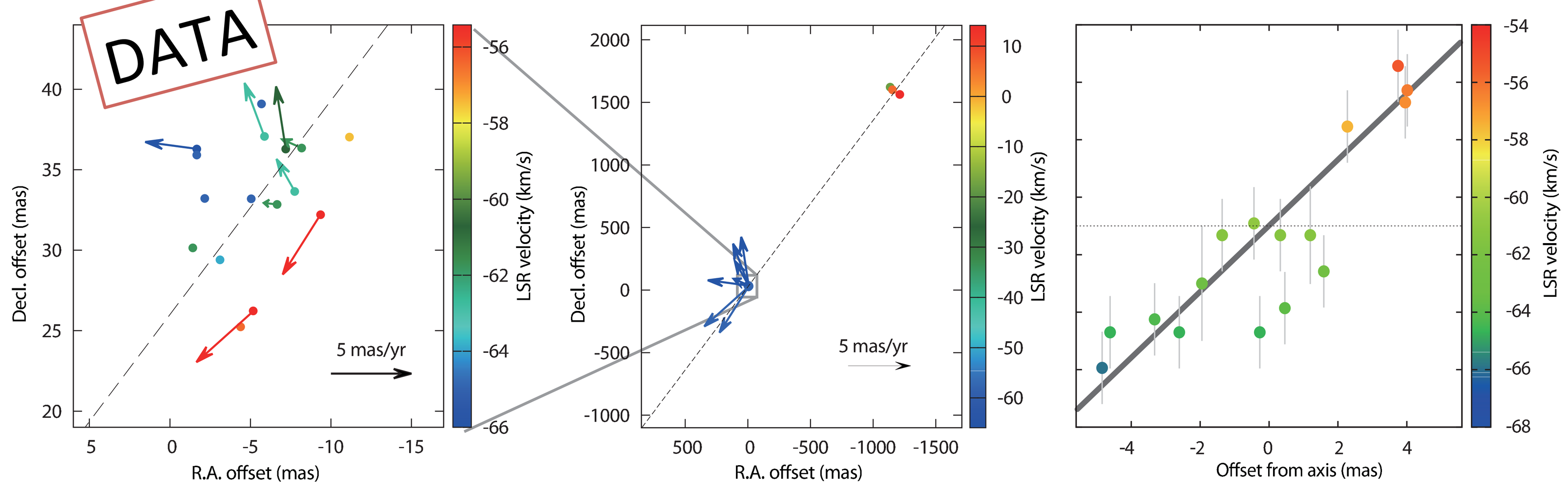


Fig 4. (middle) the distributions and 3D motions of water masers in S235AB-MIR at full scale. The dotted line illustrates the jet axis. (left) Zoom of the blueshifted maser group, showing the velocity gradient. (right) A position-velocity (p-v) diagram perpendicular to the jet direction. The straight slope in the p-v diagram is suggestive of solid-body rotation.

Micro-jet

S255IR

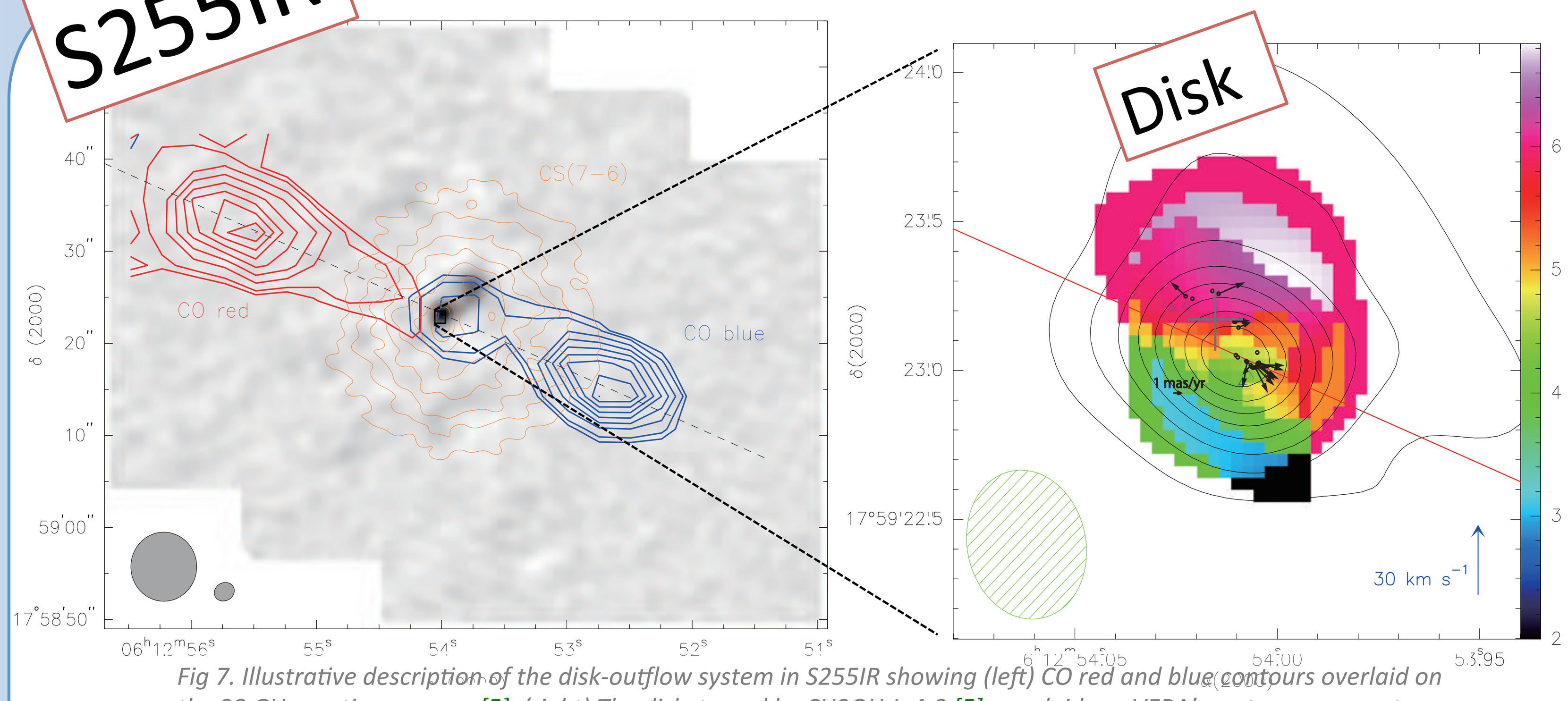


Fig 7. Illustrative description of the disk-outflow system in S255IR showing (left) CO red and blue contours overlaid on the 38 GHz continuum map [5]. (right) The disk, traced by CH3OH J=4-3 [5], overlaid are VERA's water maser vectors

S255IR is a 20 Mo, and slightly more evolved MYSO, as inferred by centemeter emission in the dense core. The MYSO has a clear disk-outflow system (Fig 7).
S255IR has water masers that align to the outflow and has 6.7 GHz methanol masers near the center of the system [8]

Observations

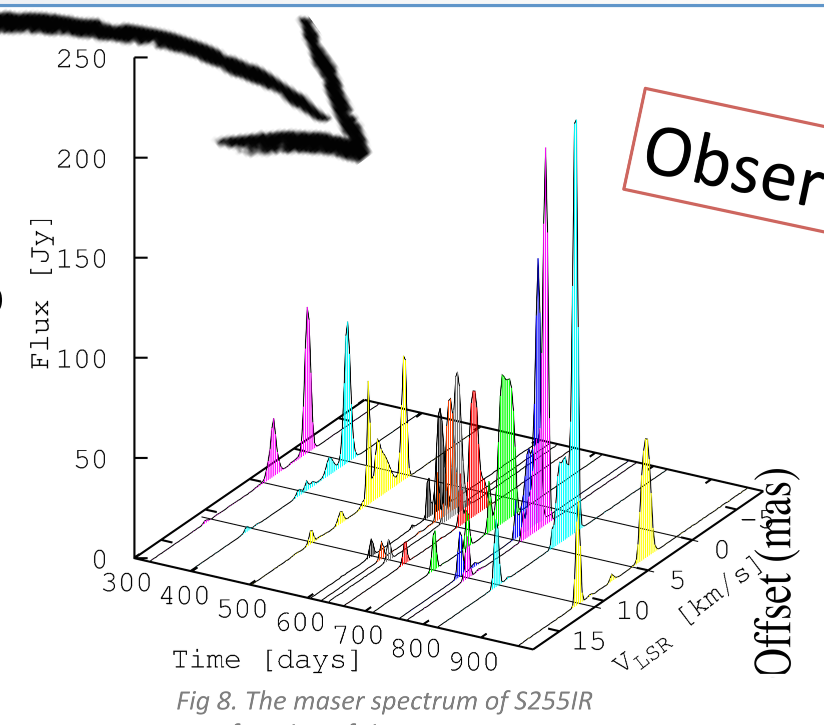


Fig 8. The maser spectrum of S255IR as a function of time.

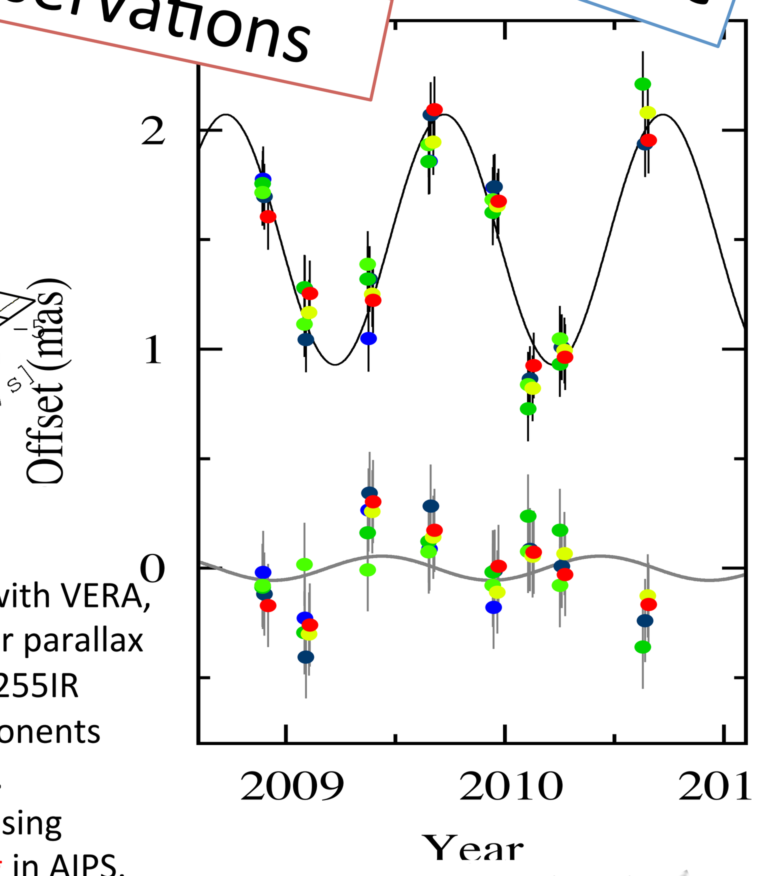


Fig 9. Parallactic motion in R.A. (above) and Dec. (below) for 6 features after subtraction of linear proper motions.

We observed 12 epochs with VERA, but used only 8 epochs for parallax fitting. The spectrum of S255IR shows many maser components evolving over time (Fig 8).
VLBI data were reduced using inverse phase referencing in AIPS.
The parallax was D = 1.79 ± 0.09 kpc (Fig 9) which is consistent with the VLBA parallax (1.59 ± 0.07 kpc) measured using 6.7 GHz methanol masers [8].

Episodic ejection/accretion

Another proposed feature of disk-theory massive star formation is that accretion occurs in multiple intense bursts. In our recent observations of S255IR (IC2162), presented here, we see a `micro-jet' – which is the very youngest jet structure. This is significant because S255IR already has a large-scale (older) outflow (Fig 7, [5]) in the same direction as the `micro-jet' (Fig 10) – therefore the ejections from S255IR happen periodically. The tight correlation between ejection activity and accretion activity [6] suggests that S255IR is also accreting periodically too – in agreement with theory [7].

Comments and questions?

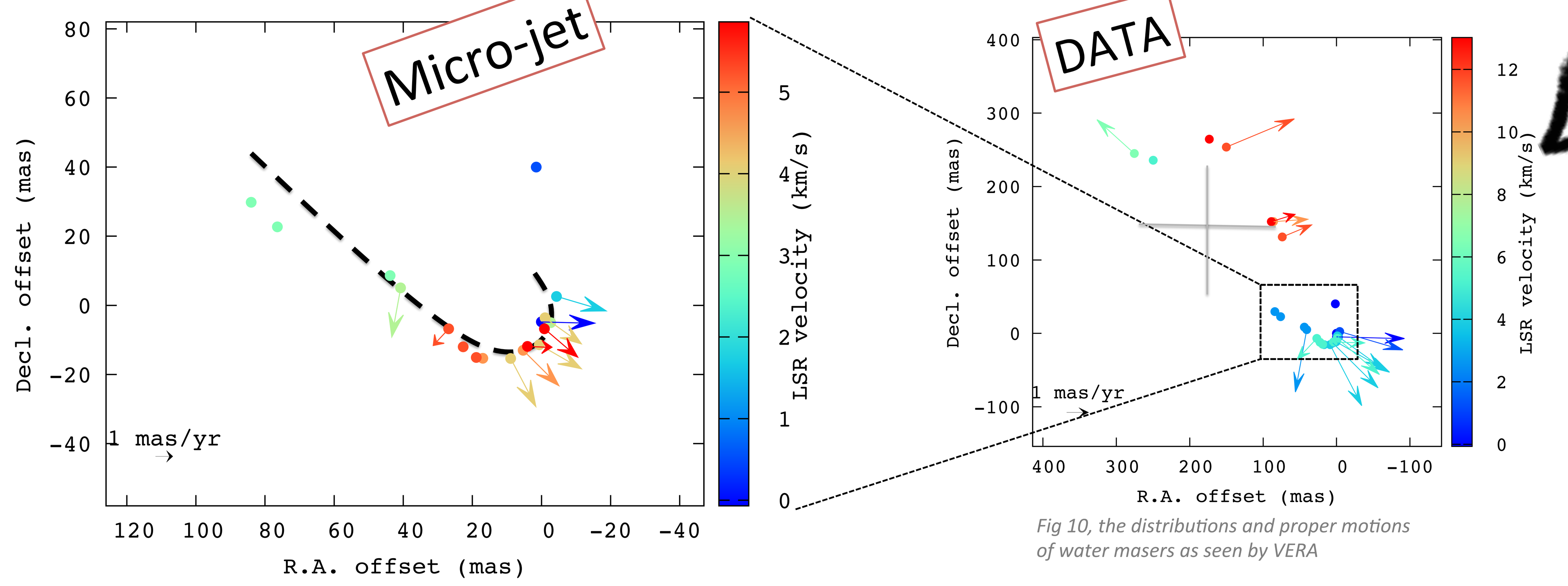


Fig 10, the distributions and proper motions of water masers as seen by VERA

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