Water Maser Bipolar Outflow Associated SMA1 Massive Young Stellar Object of NGC 6334I(N)

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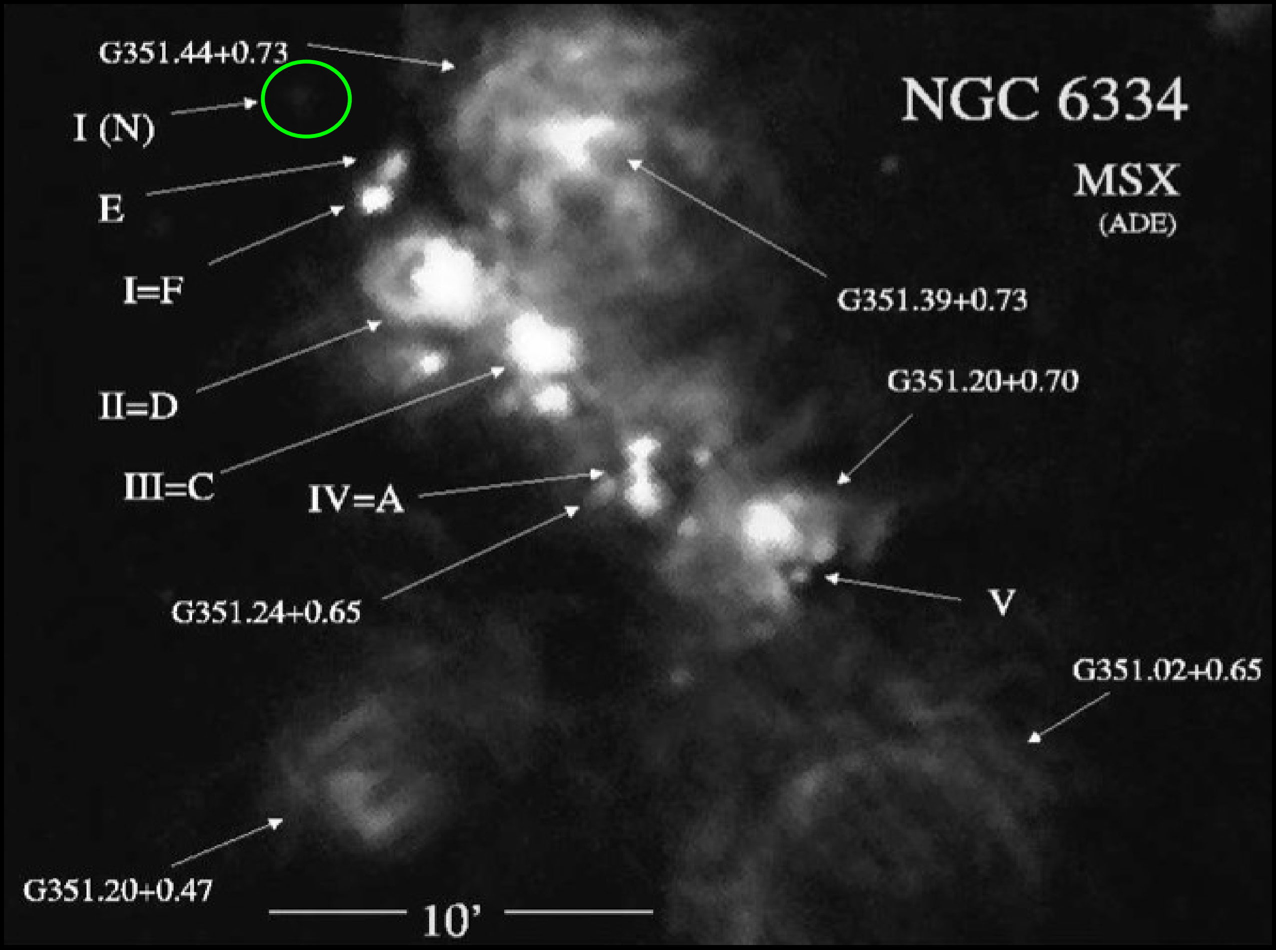
NGC 6334I(N) - Introduction

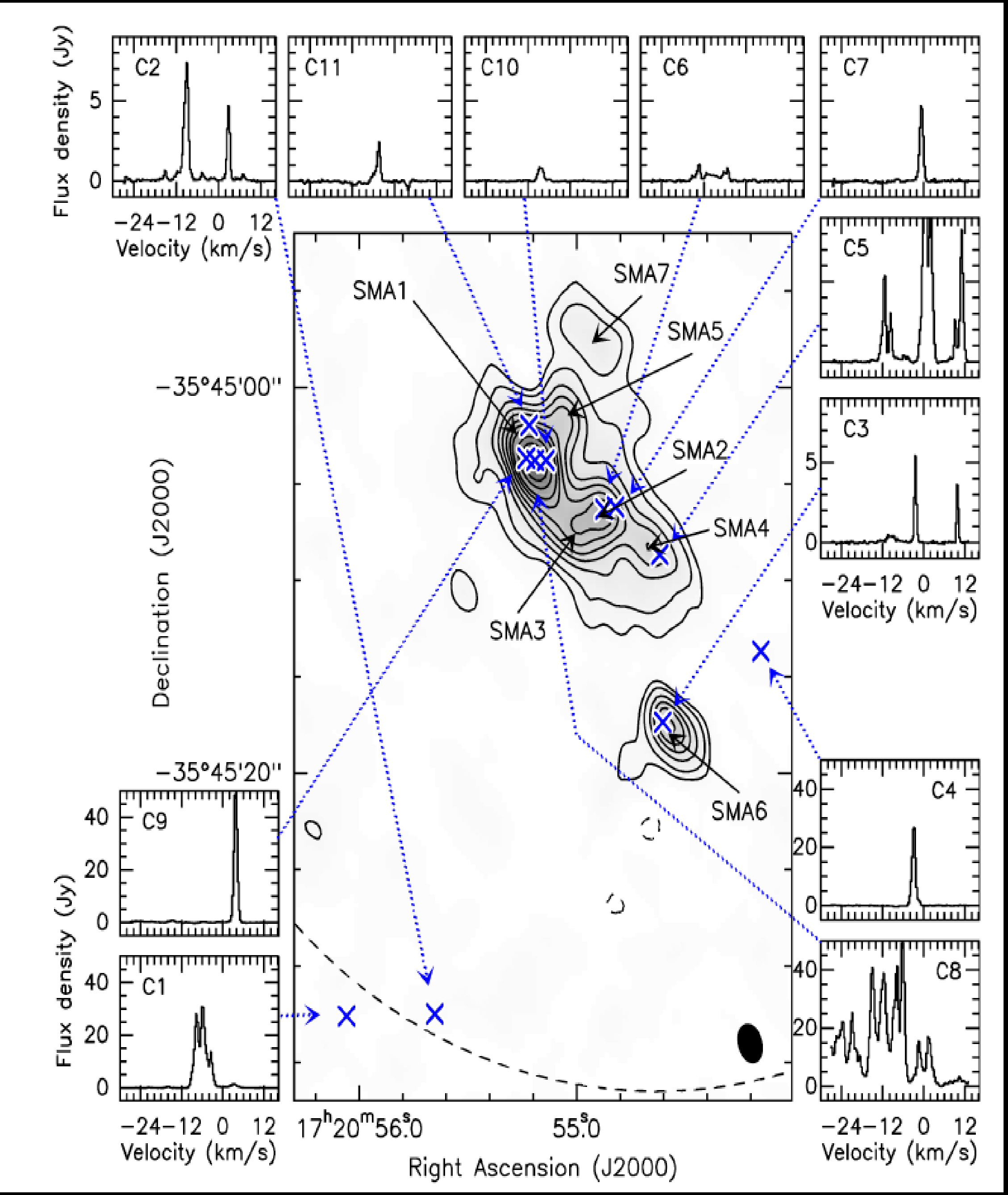
* The youngest region of the Cat Paw nebula. (earliest phase of MSF)
* At a distance of ~1.7 kpc (~1.2 kpc based on our trigonometric parallax results)
* Associated with CH_3OH and H_2O masers (Buether et al. 2005)
* Associated with shocked gas (Persi et al. 2005)
* Estimated total mass of ~ 2200 $M_\odot$ (Hunter et al. 2006)



Composite image of NGC 6334 in the mid-infrared. MSX bands A (8.3 μm), D (14.7 μm) and E (21.3 μm). The radio HII regions and mid- and far-infrared sources are labeled according to the adopted identification.

Motivation: Based on Brogan et al. (2009)

SMA 1.3 mm continuum objects, SMA 1-7, some associated with H_2O masers detected with VLA (blue crossses and arrows pointing to their spectra)



Brogan et al. (2009)

Observations

Japanese VLBI Network (JVN) Observations

K-band, ~ 22GHz

Target source: NGC 6334I(N)

Phase reference source: J1713-3418

Bandpass calibrator: NRO530

Number of epochs: 10

From February, 2010 ~ April, 2012

Angular resolution: 1.2 mas at 22 GHz

Velocity resolution: 0.21 km/s

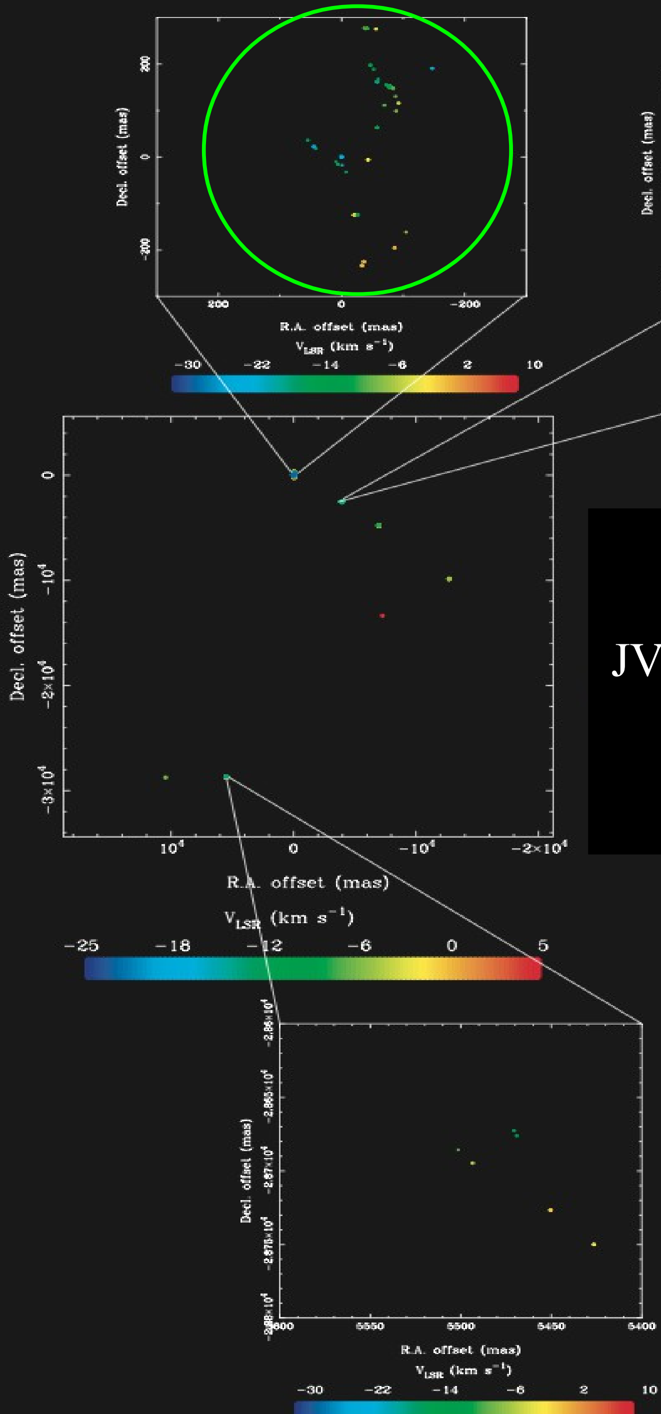
Data Reduction/Analysis

* Standard AIPS data reduction procedure, Self-calibration (relative position of maser features wrt the bright maser spot)

* Normal phase referencing (to obtain the absolute position of the reference maser spot, in order to compare with VLA continuum map).

* Maser maps, and proper motion identification (identified in 3 or more epochs and some in 2 epochs for cases of velocity or position isolation)

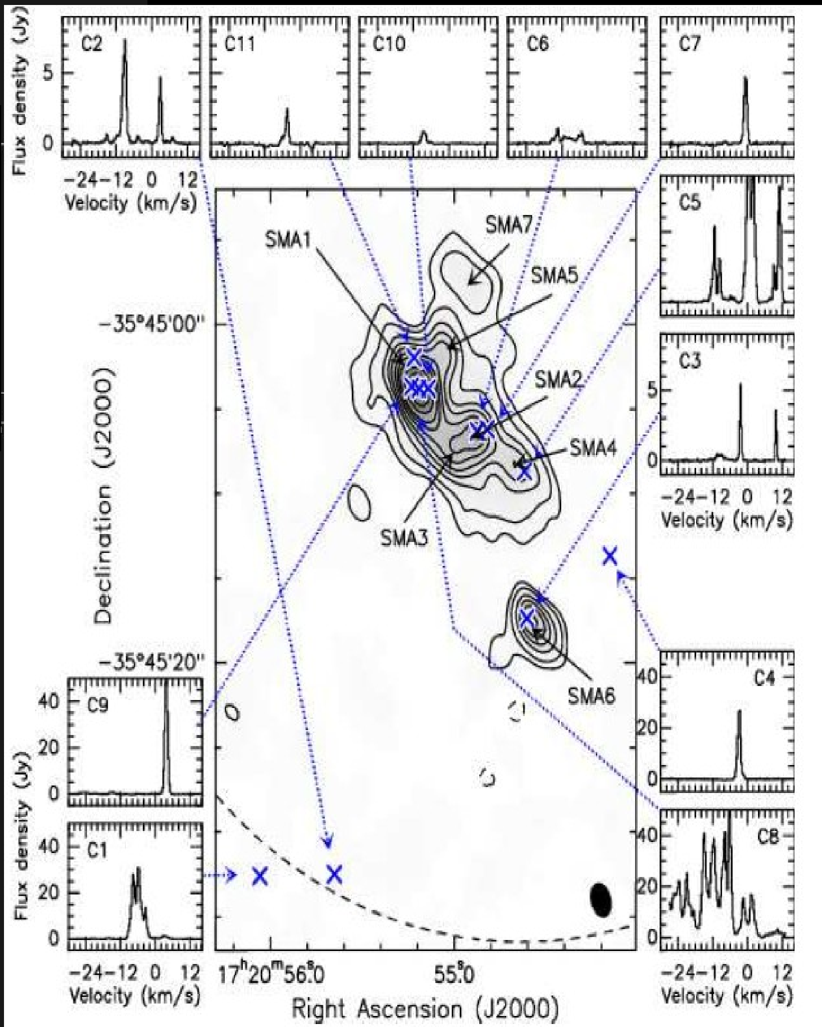
Results



JVN H_2O masers map

1.3mm SMA map, VLA H_2O masers

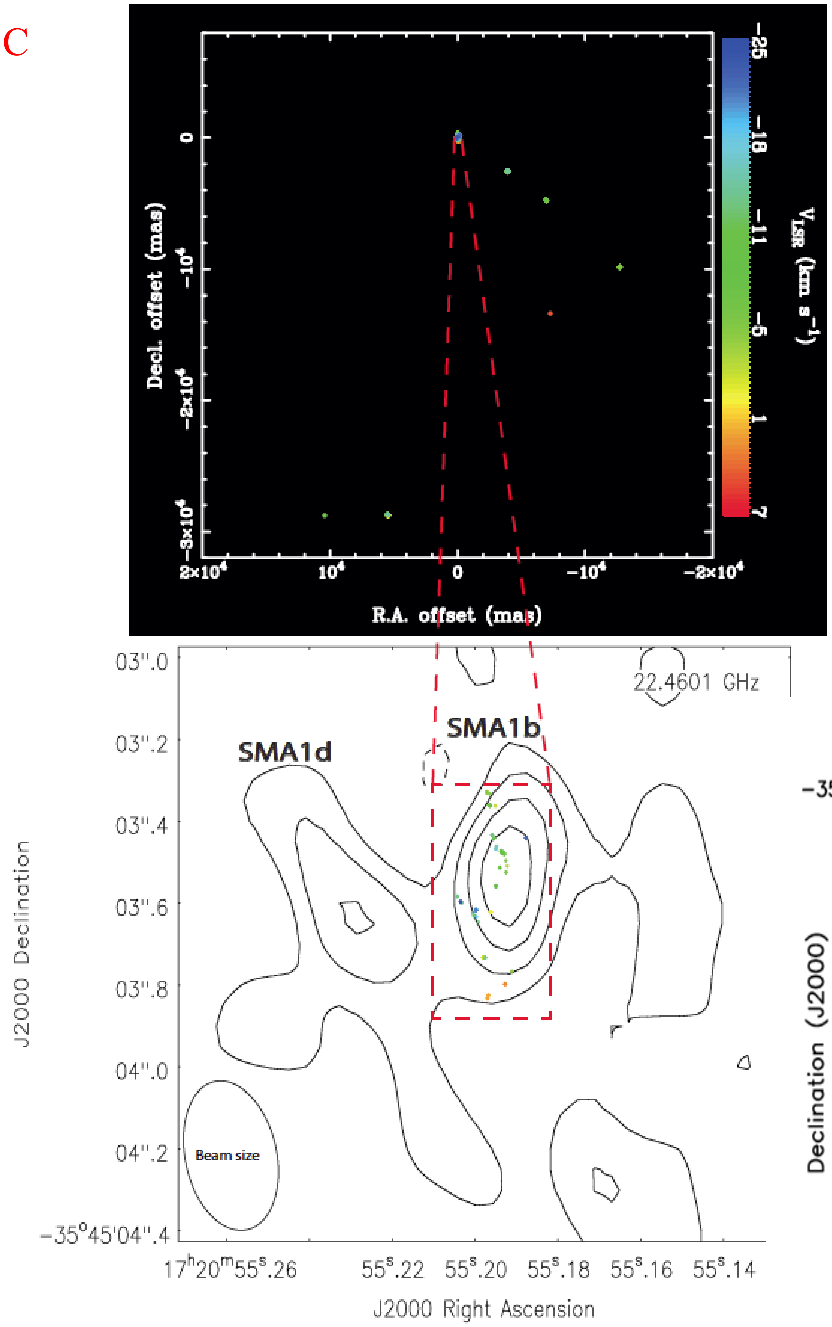
Brogan et al. (2009)

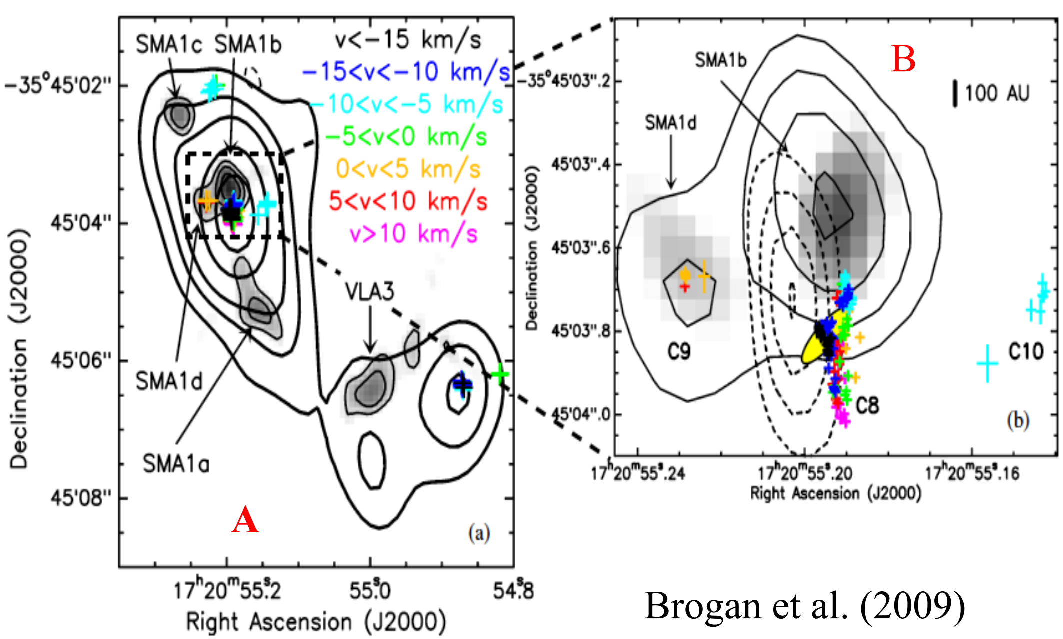


A: SMA 1.3 mm continuum (solid lines), VLA 7 mm continuum of SMA 1a-d and VLA3 (grey scale and solid lines)

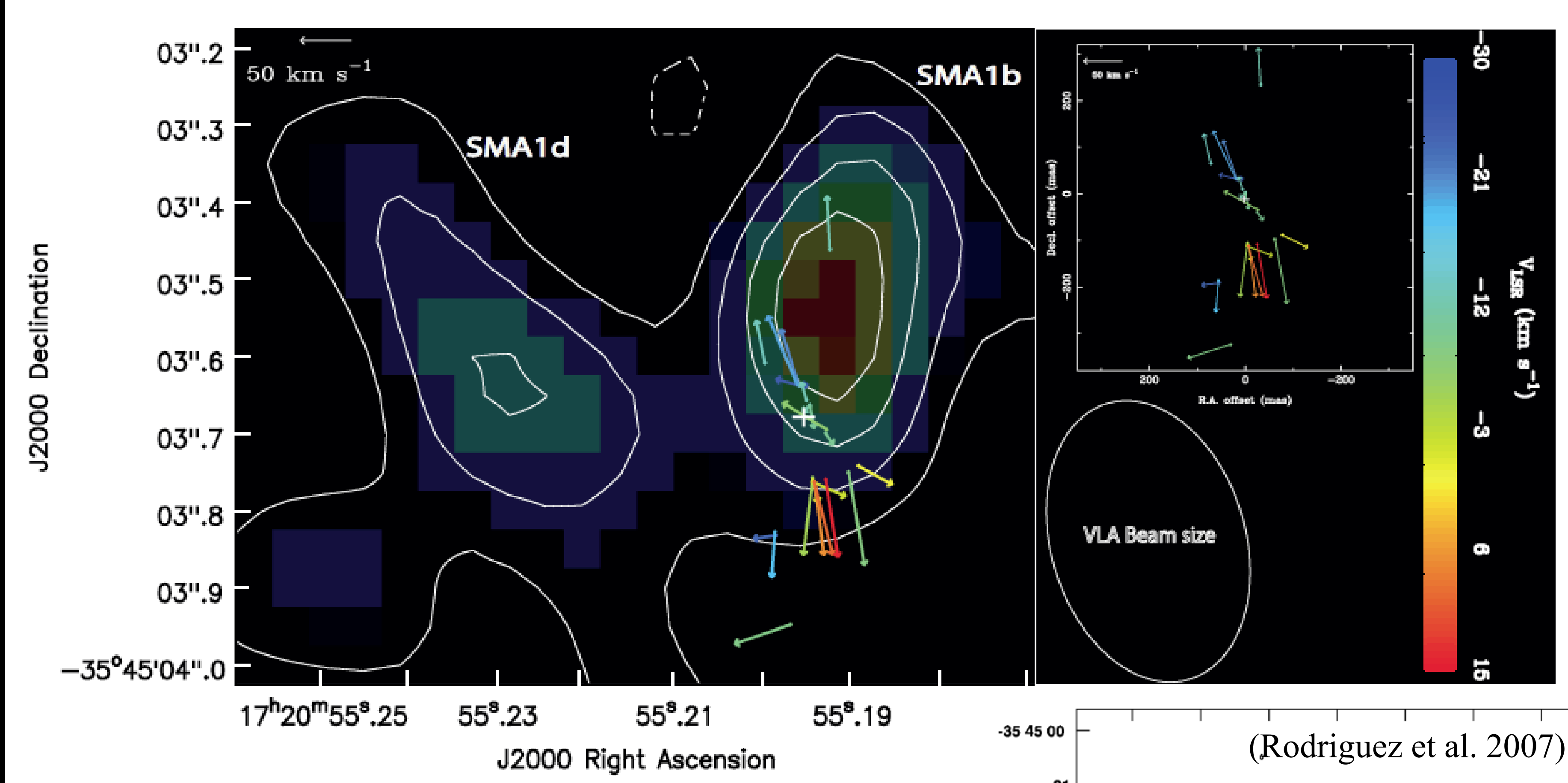
B: VLA 1.7mm continuum (solid lines), 3.6 cm continuum (dashed lines), 1.3 cm continuum (gray scale), CH_3OH masers (yellow ellipse), H_2O masers (colored crosses)

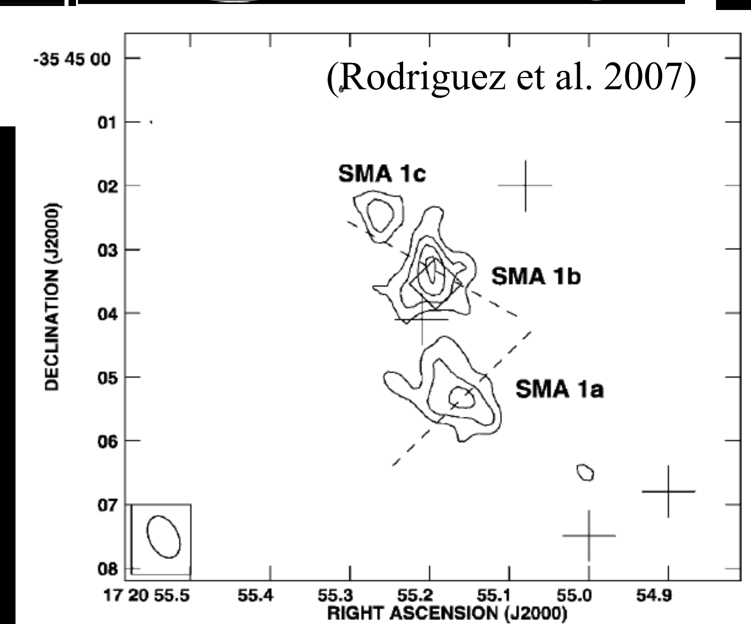
C: JVN H_2O maser map (top), superposed image of the maser distribution in SMA1b on it 1.3 cm VLA continuum map (bottom)





Brogan et al. (2009)





(Rodriguez et al. 2007)

* Maser proper motions in SMA1b tracing a bipolar outflow structure with a driving source most probably located at R.A. (J2000) = 17h 20m 55.195s .1909, and declination (J2000) = − 35d45'03".70 (derive from the model in the next slide)

* Mean proper motion of 11.6 km/s and extending through 720 AU

* Dynamical timescale of ~ 295 years.

* Bipolar structure aligns well with the outflow report in previous papers (Rodriguez et al. 2007: dashed line across SMA1b)

Position/Velocity Variance and Covariance Matrix Analysis

$$\sigma_{ij} = \frac{1}{N-1}\sum_{n=1}^{N}(v_{i,n} - \bar{v_i})(v_{j,n} - \bar{v_j}),$$

(Bloemhof 1993)

$$\begin{pmatrix} 1954.95 & 977.10 & -159.08 \\ 977.10 & 1773.24 & -276.15 \\ -159.08 & -276.15 & 115.64 \end{pmatrix} \Longrightarrow \begin{pmatrix} 2878.83 & 0 & 0 \\ 0 & 894.16 & 0 \\ 0 & 0 & 70.85 \end{pmatrix}$$

PVCM		
ψ_{max} [mas^2]	ψ_{min} [mas^2]	PA_{max}[1] [°]
11689.92	1104.00	-2.7

VVCM						
ψ_{max}	ψ_{mid}	ψ_{min}	PA_{max}	PA_{mid}[2]	ϕ_{max}[3]	ϕ_{mid}
[km^2 s^{-2}]	[km^2 s^{-2}]	[km^2 s^{-2}]	[°]	[°]	[°]	[°]
2878.83	894.16	70.85	44.4±6.7	44.7±4.9	-6.3±0.6	-6.7±5.2

Expanding flow model of the maser spatio-kinematics

$$S^2 = \frac{1}{3N_\mathrm{m} - N_\mathrm{p}} \sum_{i}^{N_\mathrm{m}} \left\{ \frac{[\mu_{ix} - w_{ix}/(a_0 d)]^2}{\sigma^2_{\mu_{ix}}} + \frac{[\mu_{iy} - w_{iy}/(a_0 d)]^2}{\sigma^2_{\mu_{iy}}} + \frac{[u_{iz} - w_{iz}]^2}{\sigma^2_{u_{iz}}} \right\}$$

(Least-square method involving Levenburg-Marquart minimization technique)

N_p: number of free parameters (= 4)

N_m: number of proper motion data (= 23)

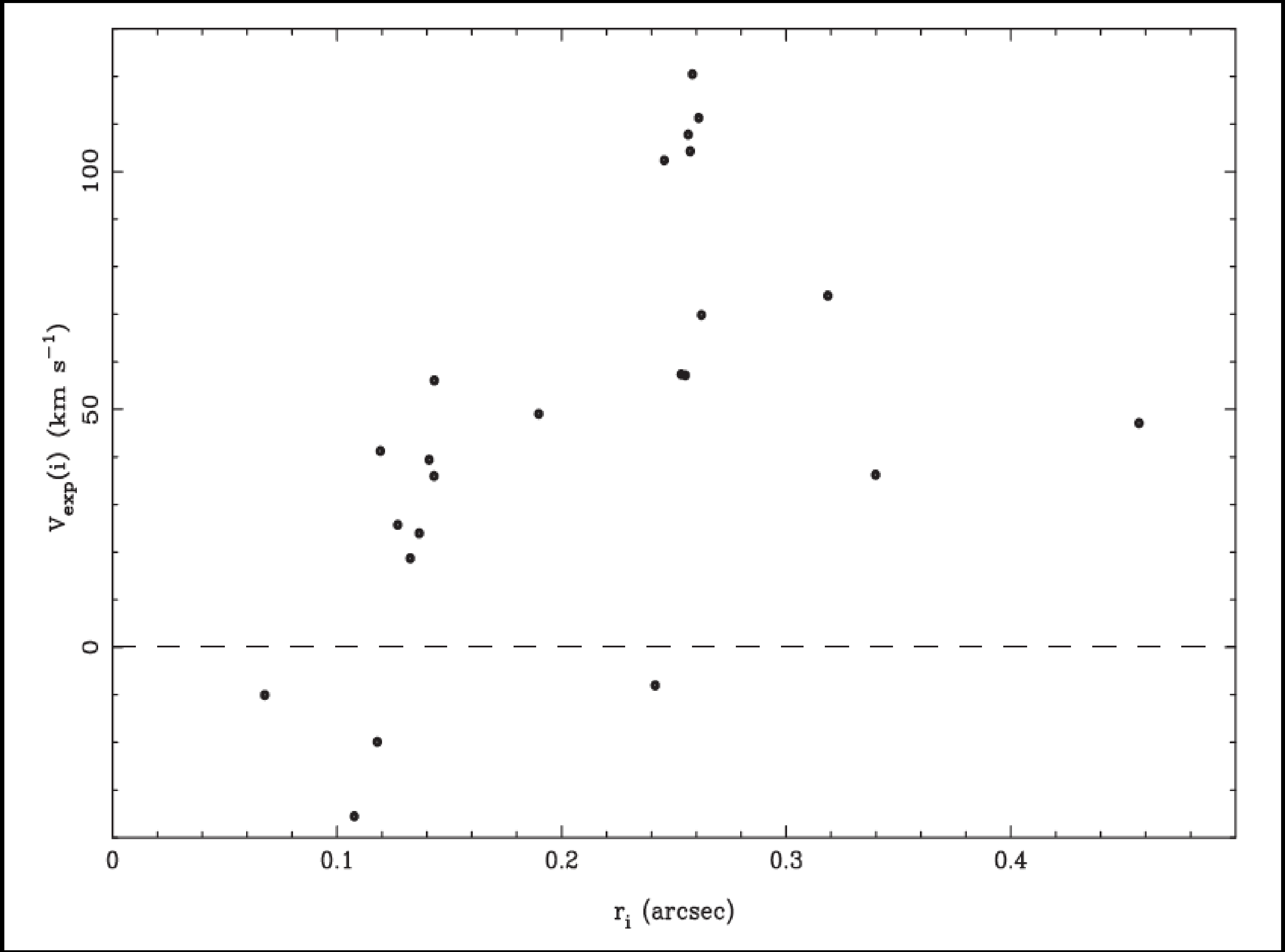
$$\boldsymbol{w_i} = \boldsymbol{V_0} + V_{\mathrm{exp}}(i) \frac{\boldsymbol{r_i}}{r_i},$$

Assumption: Each maser feature is radially moving away from a common originating point (near 0,0) of the outflow with V_{exp} (i).

Radial expanding motion of maser feature

$$V_{exp}(i) = \frac{(u_{ix} - v_{0x})r_{ix} + (u_{iy} - v_{0y})r_{iy} + (u_{iz} - v_{0z})z_{iz}}{r_i}$$

Derived Expansion Velocity of Individual Maser Features



Most of the expansion velocities were positive as espected, 4 negative expansion velocity could be as a result of infall, turbulence or some error in the model fitting.

Summary

1. We detected outflow activity in SMA1b, indicating that this source is internally excited by a massive young stellar object.

2. The bipolar motions of the H2O masers indicate the presence of a YSO-jet system in SMA1b.

4. ALMA & EVLA observations will be helpful to explore the physical conditions of this object.