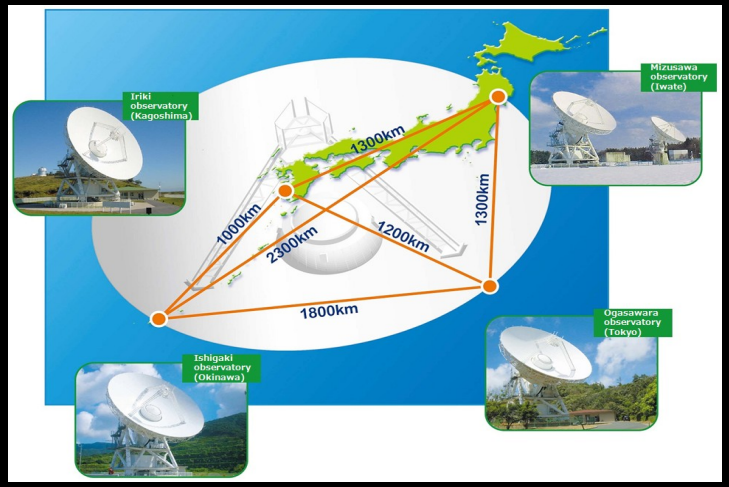
A Highly Collimated Water Maser Bipolar Outflow in the Cepheus A HW3d Massive Young Stellar Object



Chibueze James Okwe
Radio Astronomy Group,
Graduate School of Science & Engineering,
Kagoshima University, Japan.

East Asian Collaboration SKA Workshop Nov 30th ~ Dec 2nd, 2011.

Abridged Outline

Introduction of the entire Cepheus A massive star-forming region

Observations and Data Analysis

VERA & VLA Results

Future Research Prospect with the SKA

Research goal:

Understanding massive star formation by conducting a statistical study of the maser spatio-kinematics in as many massive star-forming region as possible.

Introduction

* Massive star formation unlike its low-mass counterpart is yet poorly understood

* Complex formation environment caused by closeness of high-mass stars (complicated interactions)

* Short formation timescale & observation sensitivity issues.

Introduction – Recent Results

Main goal

Evolution and nature of the maser structures found in the earlier (1996) VLBA observations

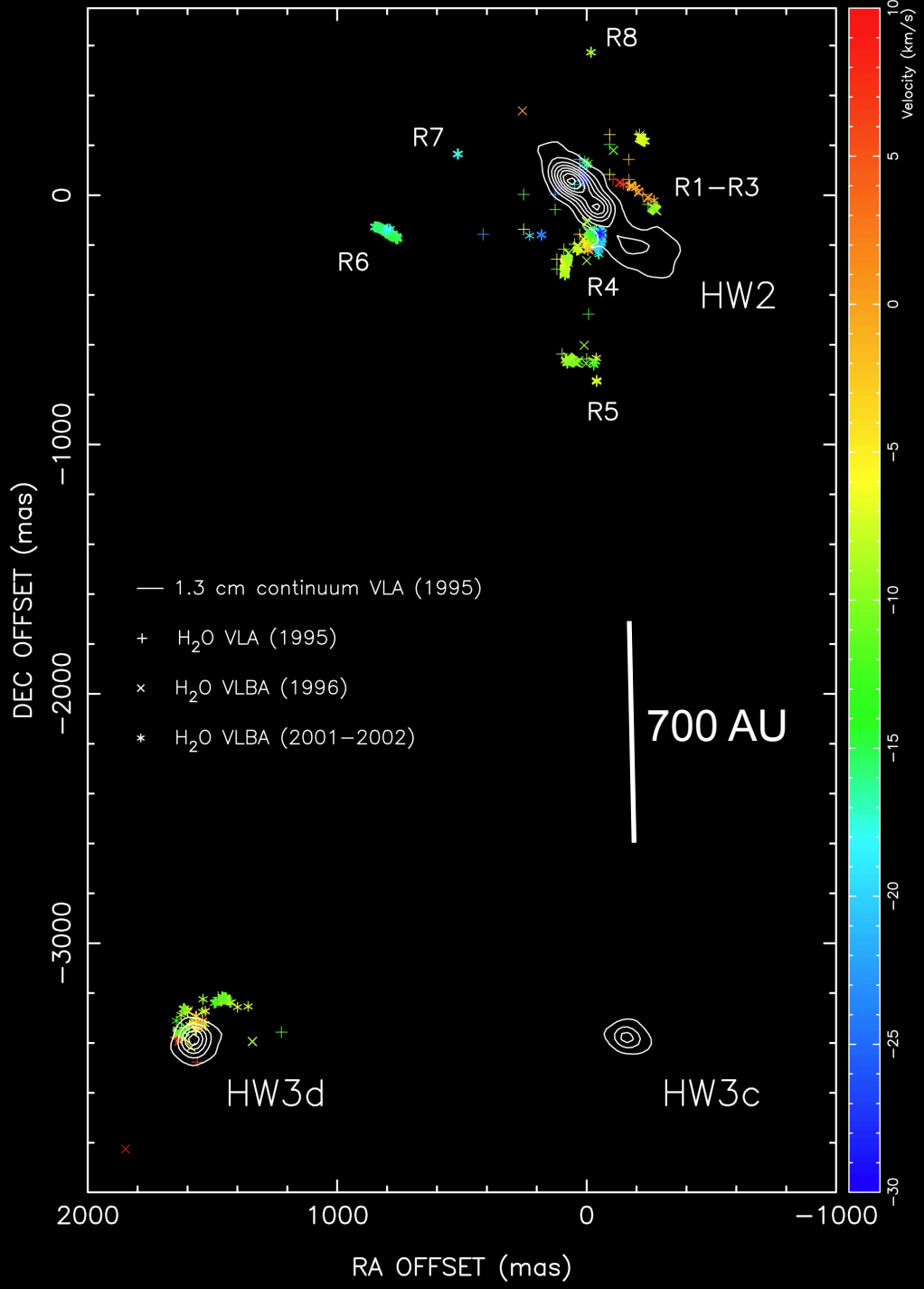
Five observed epochs

2001 Jul 11
2001 Jul 30
2001 Aug 18
2001 Sep 13
2002 Jan 27

Beam = 0.4 mas (0.3 AU)

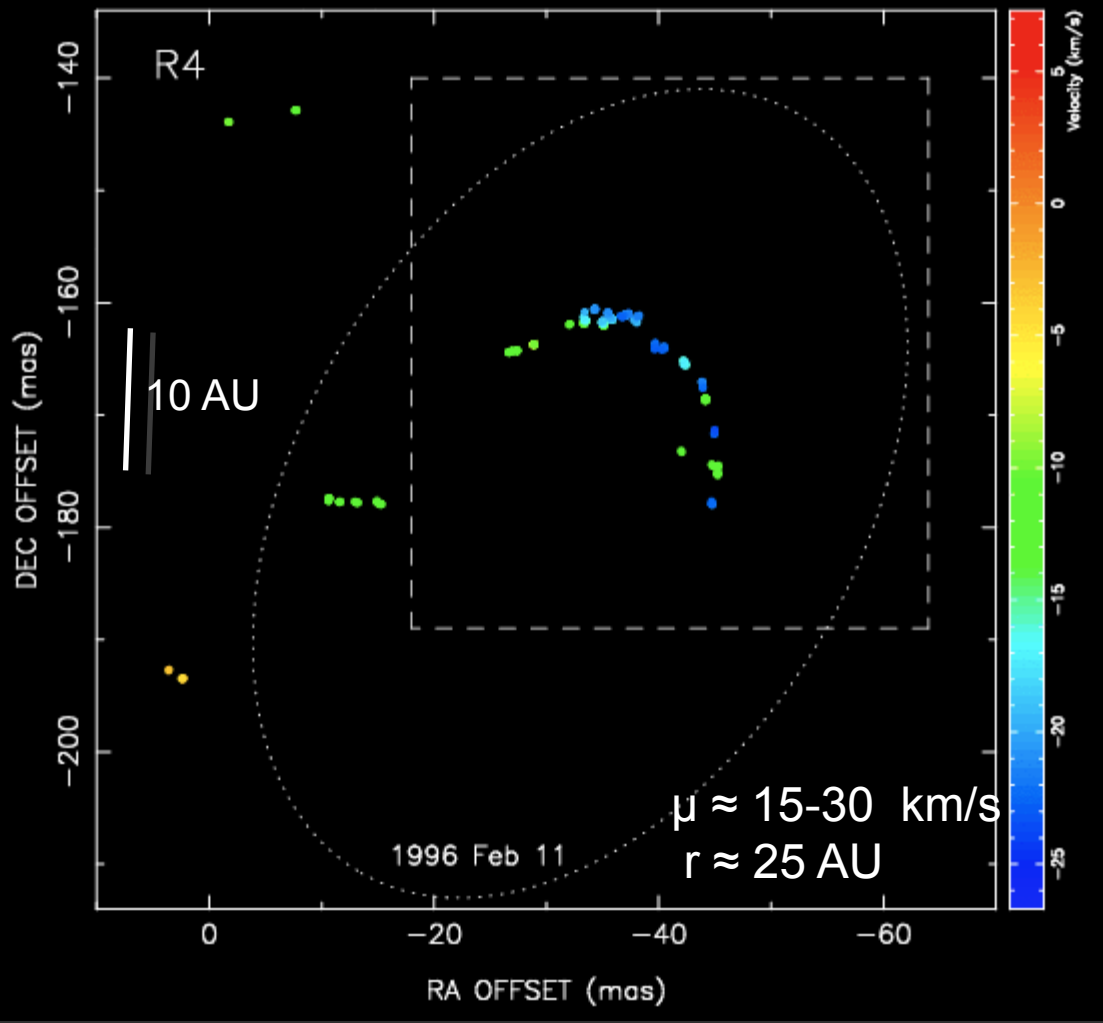
~ 1800 maser spots detected in each epoch

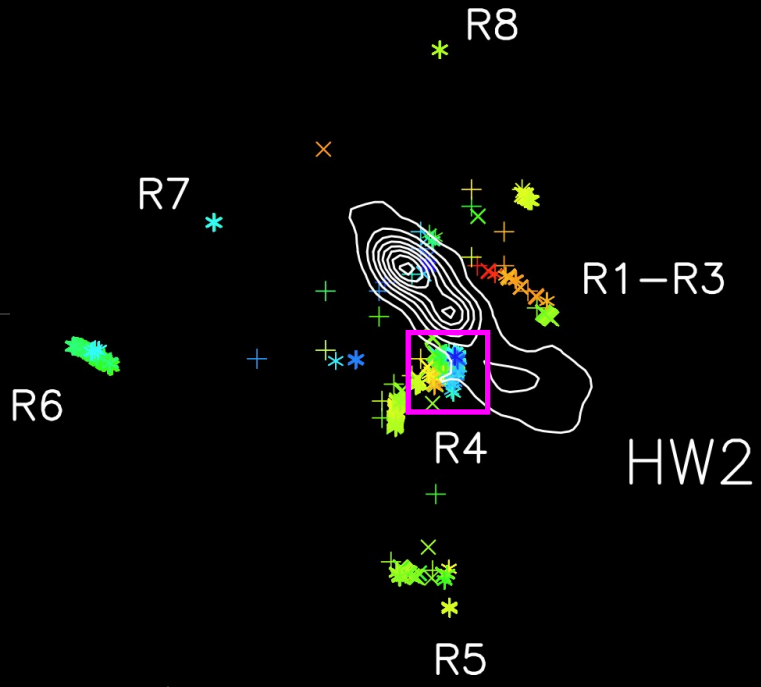
Torrelles et al. (2011)



R4

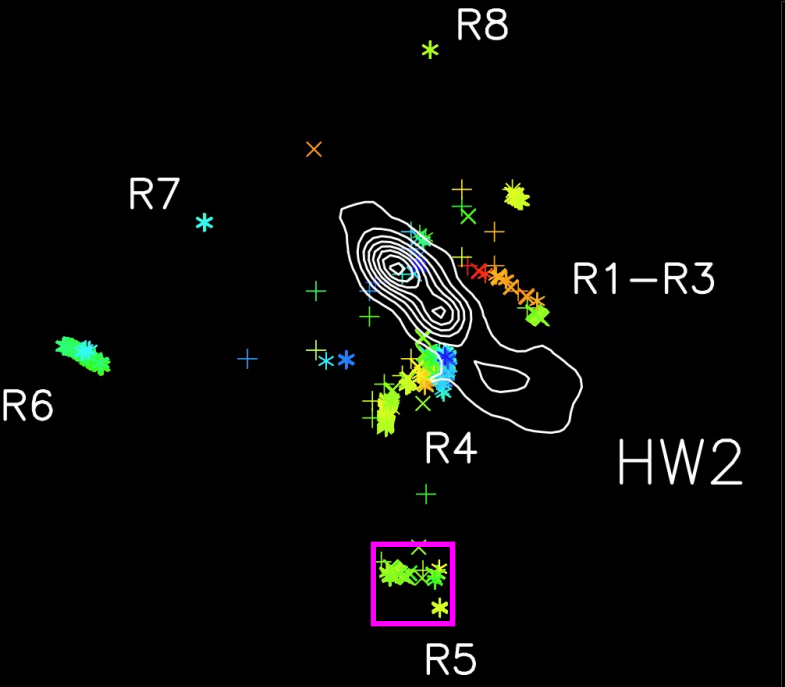
Expanding elliptical ring (r ≈ 35 mas, 25 AU)
rather than a simple bow-shock

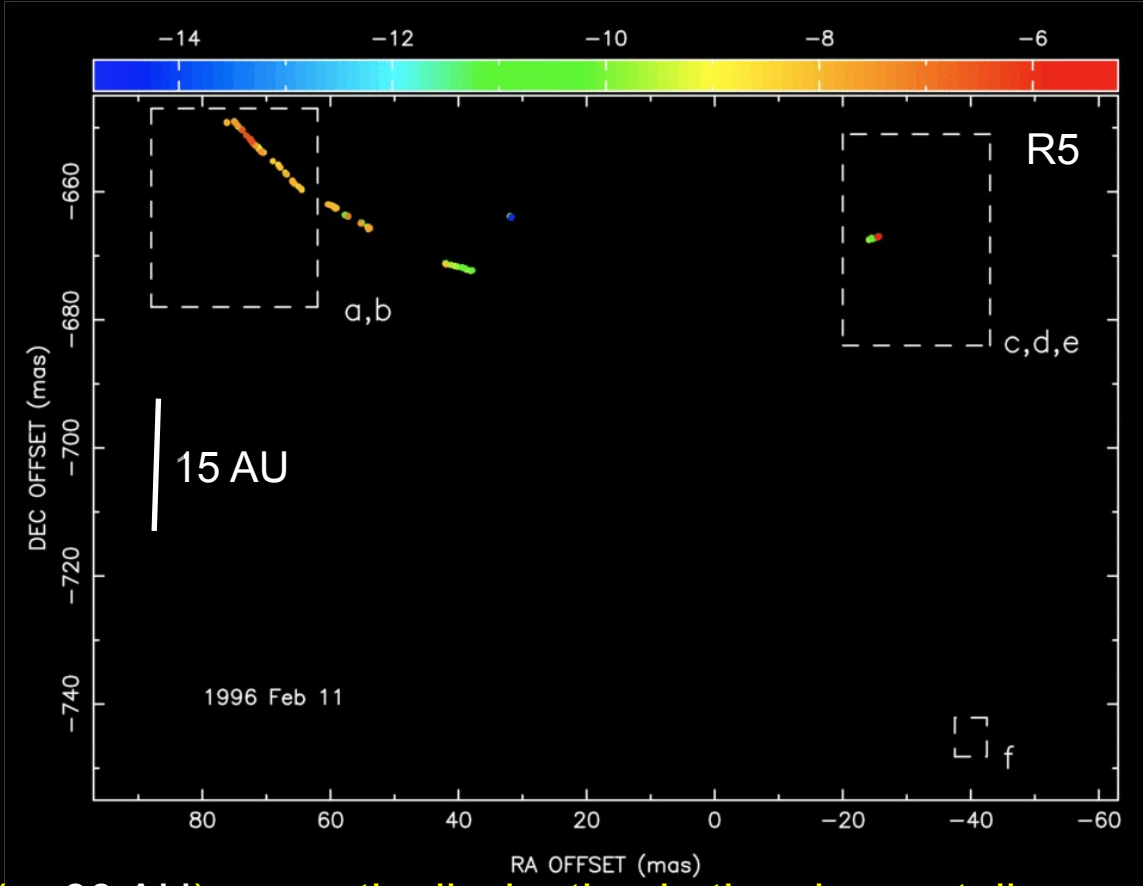




Violent ejection(s) (dynamical time ~ 10 yr) from a massive YSO (still unidentified), predicted to be located at the center of the ring,(-0.03”, -0.18”) from HW2.

To be tested with EVLA/e-MERLIN continuum observations

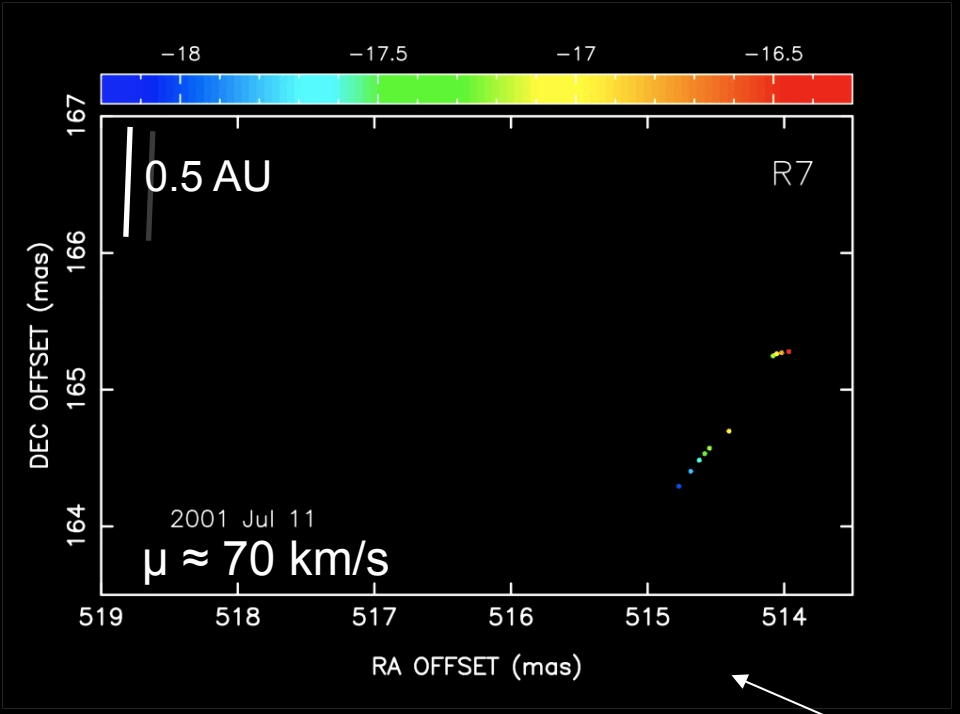


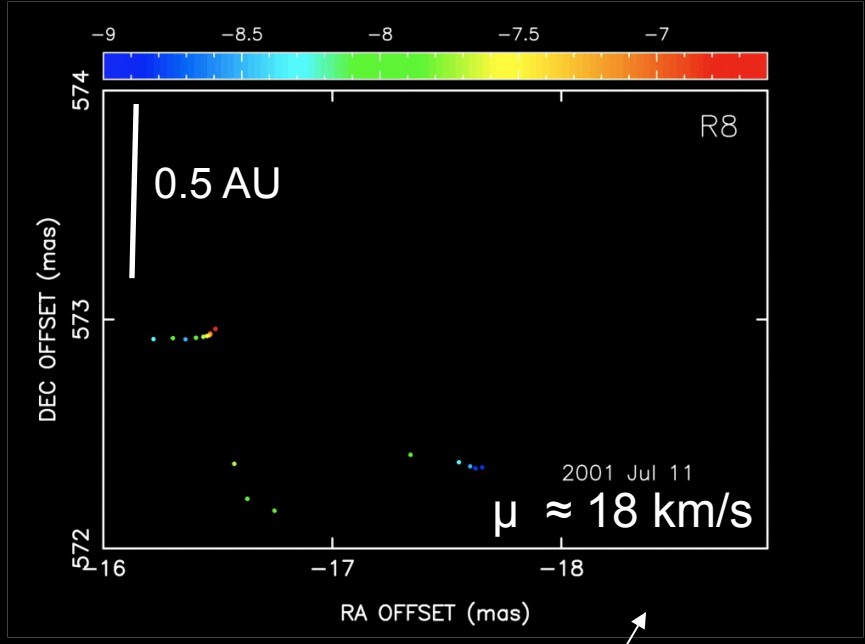


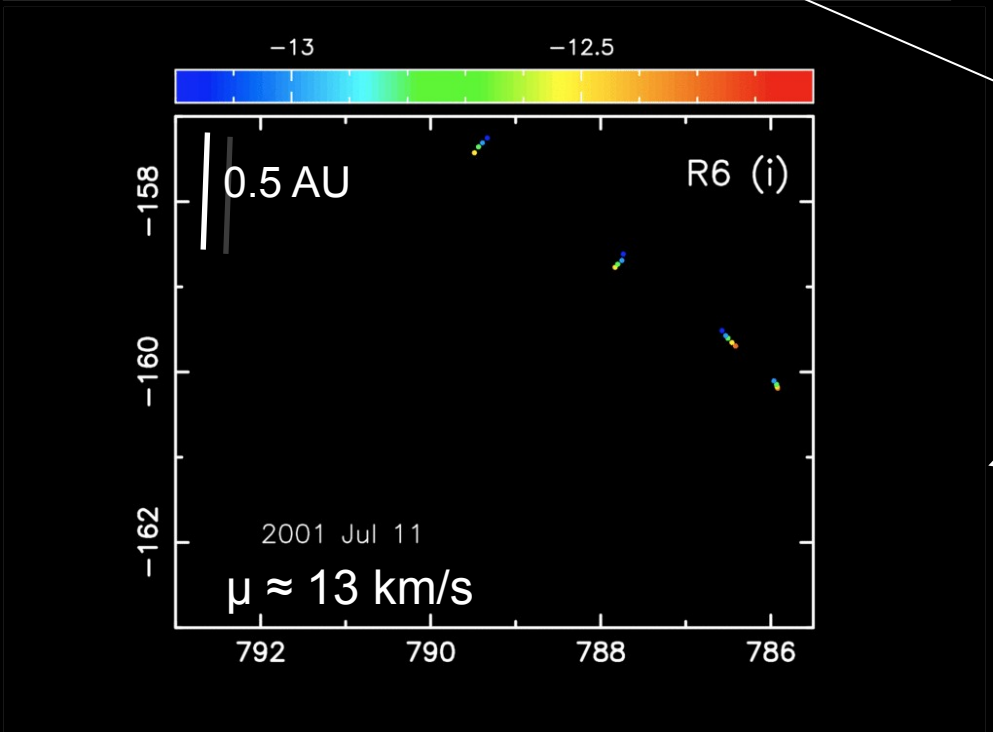
Expanding (~ 10 km/s) bubble (~ 60 AU) currently dissipating in the circumstellar medium, losing its degree of symmetry

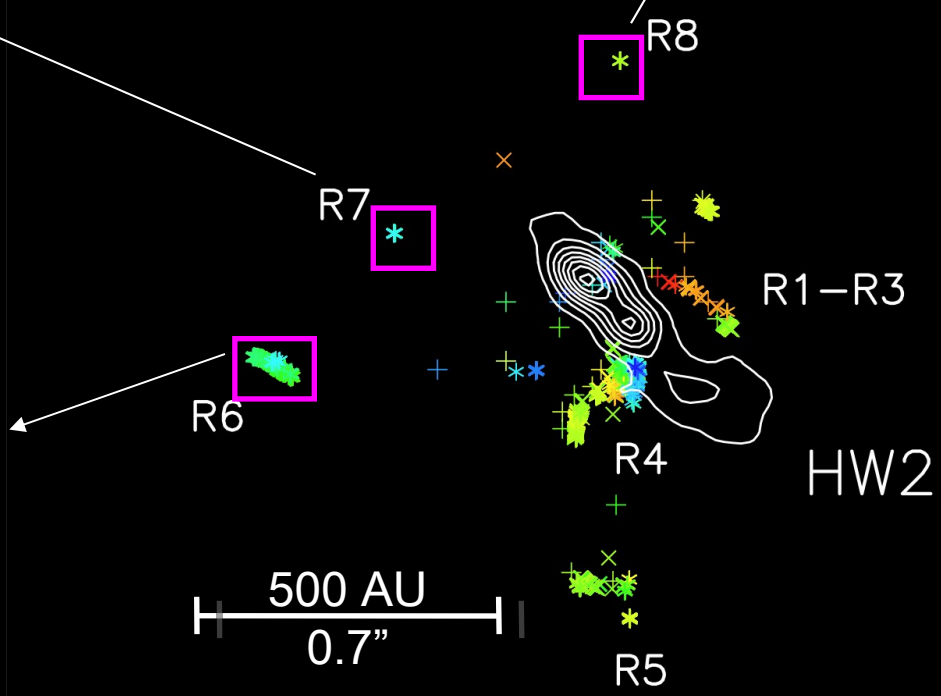
Short-lived isotropic ejection event (dynamical time ~ tens of years), excited by a massive YSO of ~ 10 $M_{\odot}$ (already detected)

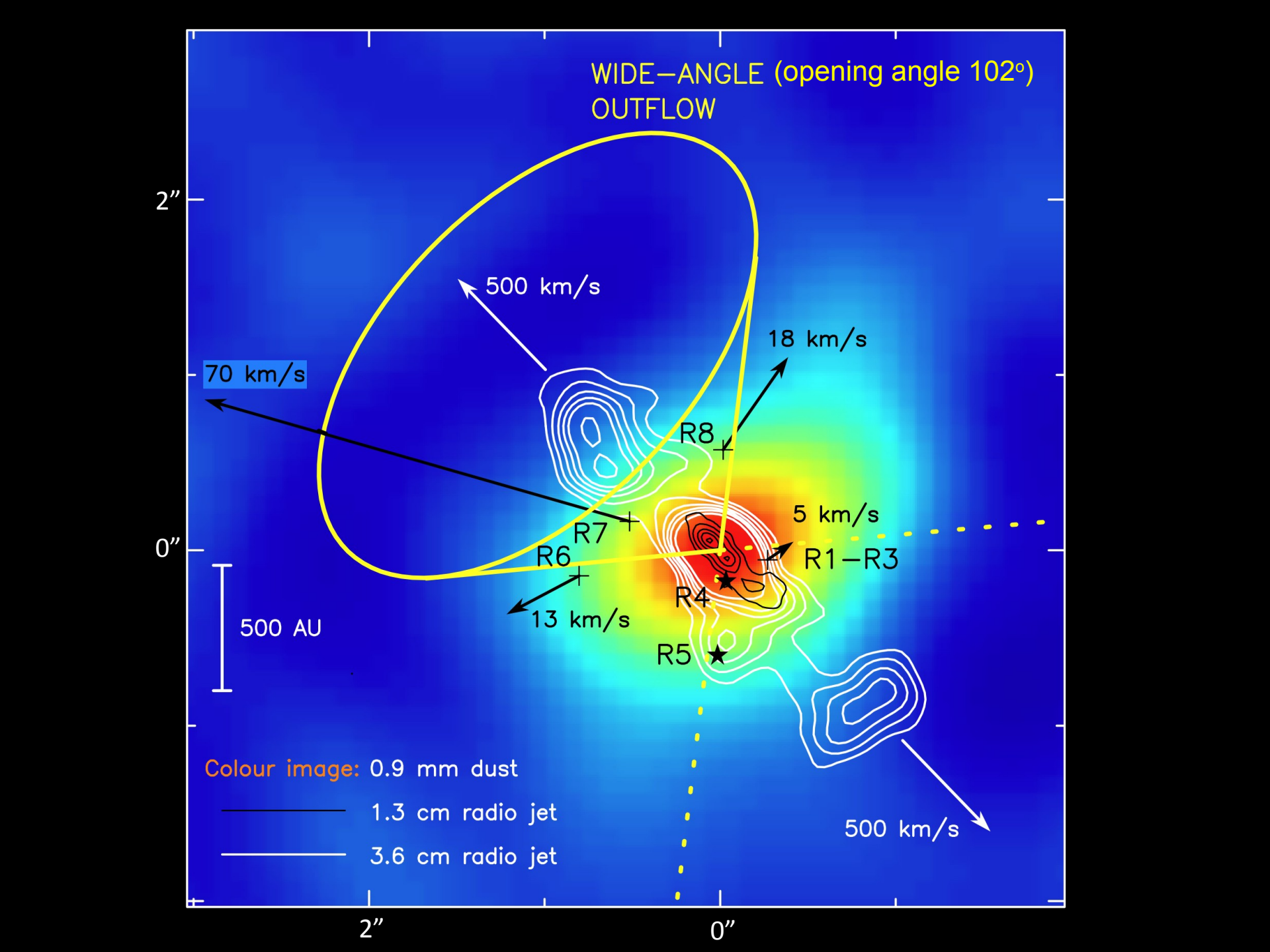
After R5, other similar examples have been identified in massive YSOs with “isotropic ejections” (e.g., W75N, G24.78; see Surcis et al. 2011), indicating that the very first stages of massive protostars could have these kind of outflows


−18
−17.5
−17
−16.5
0.5 AU
R7
2001 Jul 11
μ ≈ 70 km/s
DEC OFFSET (mas)
RA OFFSET (mas)
167
166
165
164
519
518
517
516
515
514


−9
−8.5
−8
−7.5
−7
0.5 AU
R8
2001 Jul 11
μ ≈ 18 km/s
DEC OFFSET (mas)
RA OFFSET (mas)
574
573
572
−16
−17
−18


−13
−12.5
0.5 AU
R6 (i)
2001 Jul 11
μ ≈ 13 km/s
−158
−160
−162
792
790
788
786


R8
R7
R6
R1−R3
R4
HW2
R5
500 AU
0.7”


WIDE–ANGLE (opening angle 102°)
OUTFLOW
500 km/s
18 km/s
70 km/s
R8
5 km/s
R7
R6
R1–R3
R4
13 km/s
R5
500 AU
500 km/s
Colour image: 0.9 mm dust
1.3 cm radio jet
3.6 cm radio jet
2″
0″
2″
0″

Observations & Data Analysis

VERA Observation

K-band, 22GHz

Target source: Cepheus A

Phase reference source: J2302+6405

Number of epochs: 9

Epoch codes: r06133b, r06208an, r06291a, r06310a, r07004a, r07049a, r07103a, r07135a, and r07243a

VLA Observations

1.3cm continuum, 22GHz

Target source: Cepheus A

Observation epochs: 1995 & 2006

Data Analysis

AIPS normal calibration procedures

Self-calibration

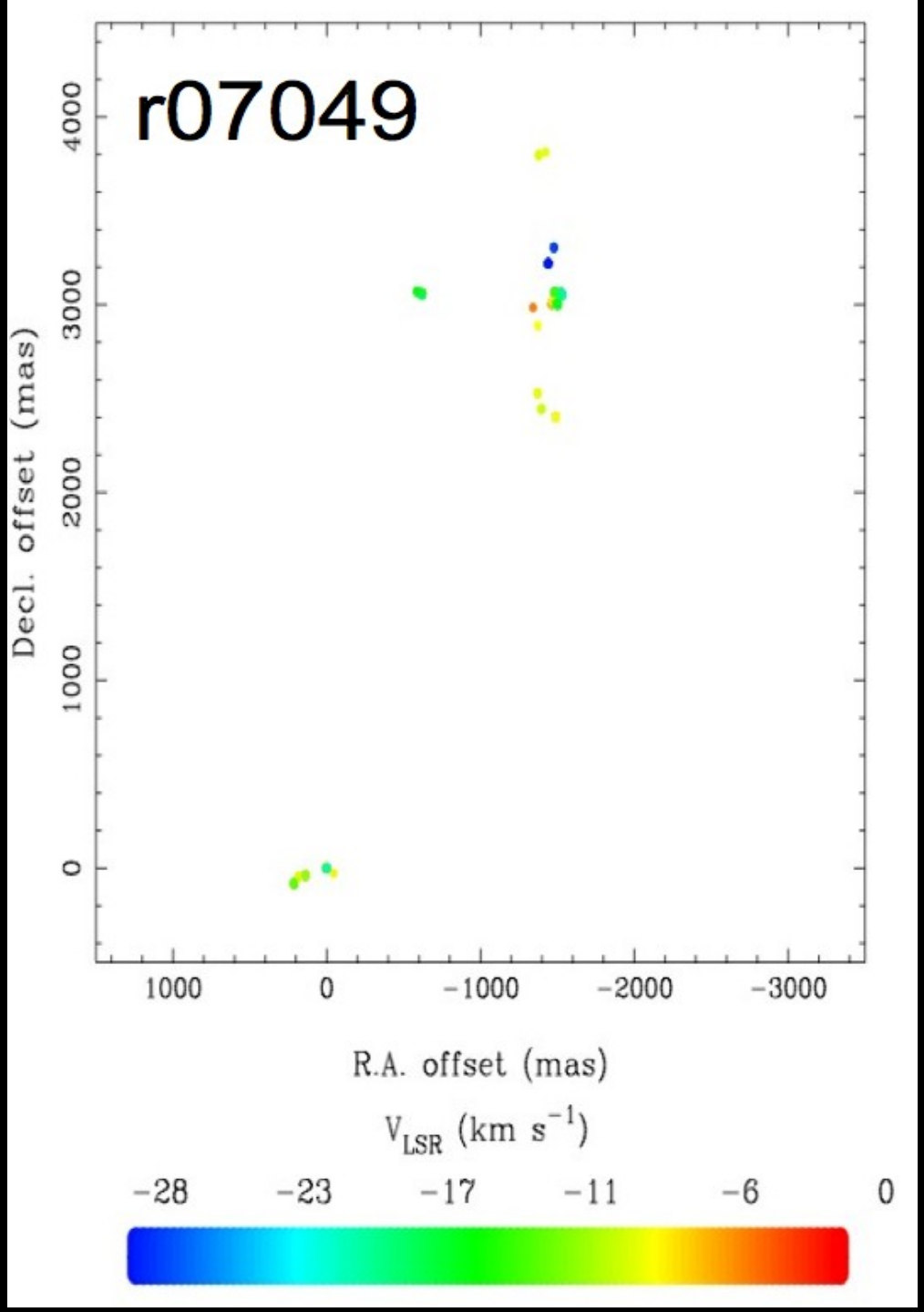
Proper motion identification technique (maser features were used, proper motions were identified in 3 or more epochs and in 2 epochs for cases of velocity or position isolation)

VERA Result

* Detected water (H_2O)masers corresponding to the R1, R2, R3, R4, R5, R6, and R8 maser clusters of the HW2 region as well as the maser cluster associated with the HW3d region.

* Focused on the HW3d

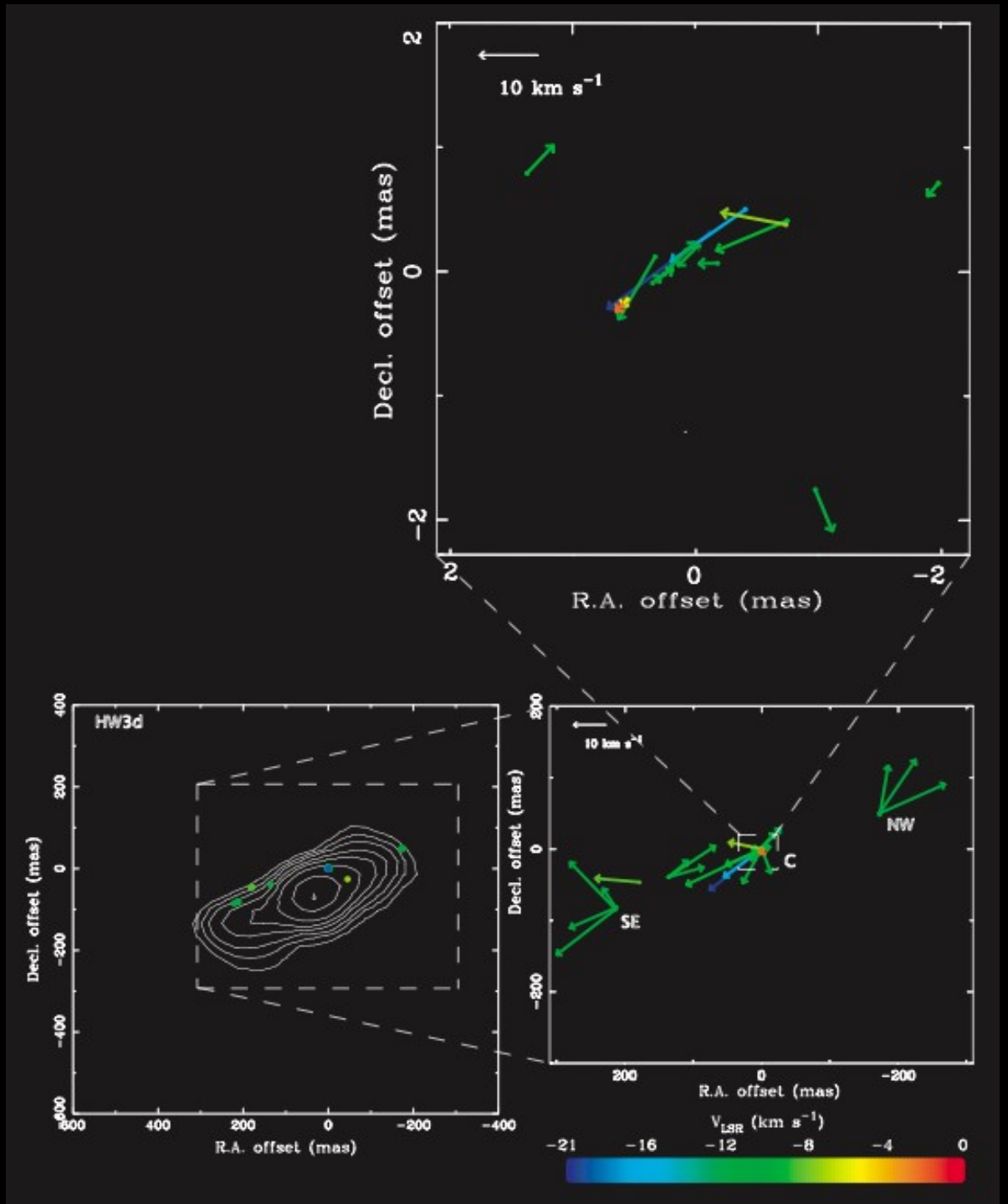
* Obtained 30 maser proper motions in HW3d



* Water maser proper motions trace a bipolar outflow in the direction of elongation of the 1.3cm VLA continuum.

* Outflow extends over ~400 mas (280 AU) with a typical proper motion of ~12 km/s

* Dynamical timescale of ~100 years



VLA Results

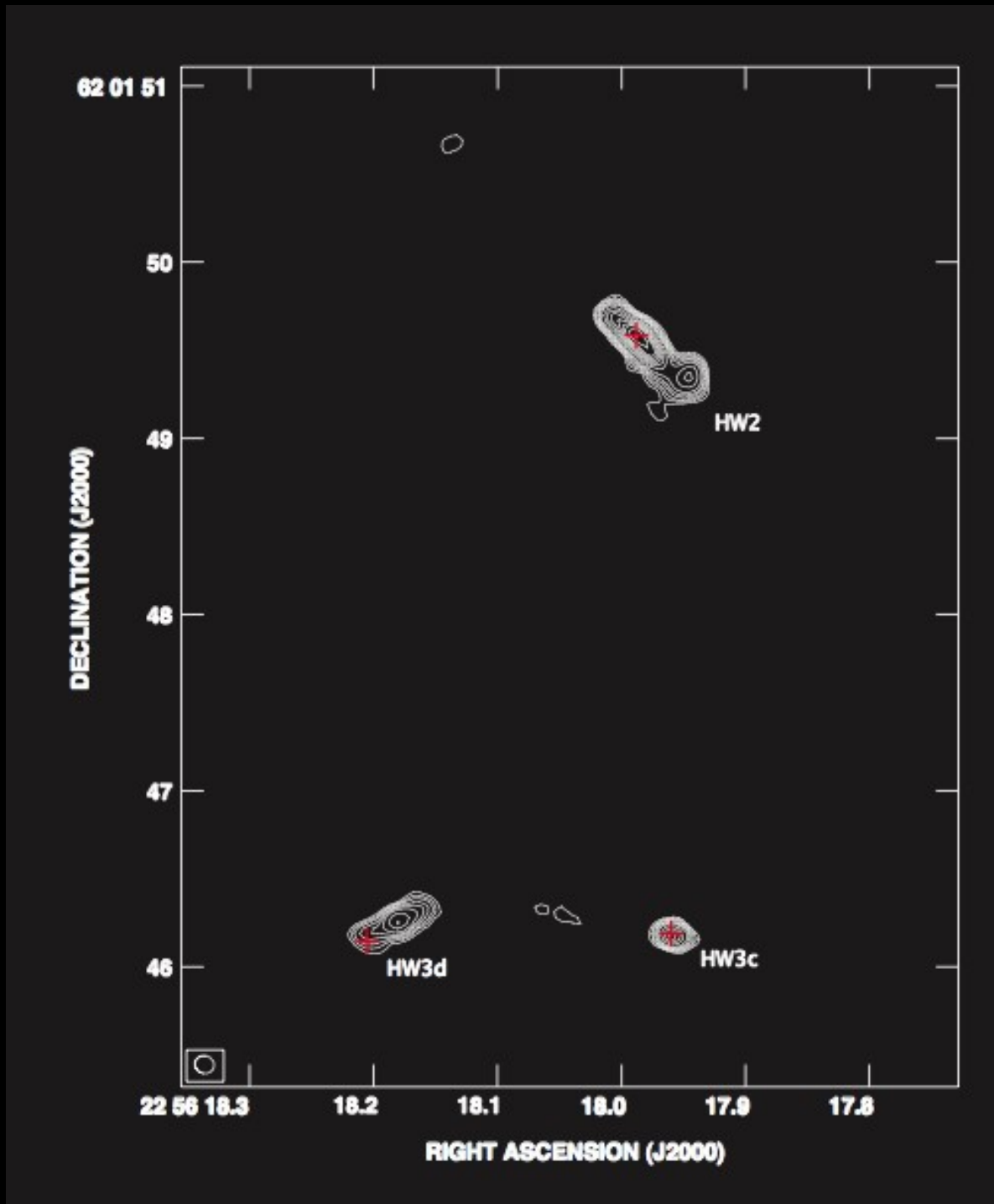
* Comparing VLA Maps

1.3cm continuum map from VLA archive data of 1995 and 2006

* Red crosses represent the position of the continuum peaks in 1995 epoch. HW3d has a shift in its peak position.

* Estimated proper motion velocity of the peak (for the case of same source) per year shielded ~65 km/s.

* Possibility of a single very fast moving object? Or the presence of multiple sources?



Discussions

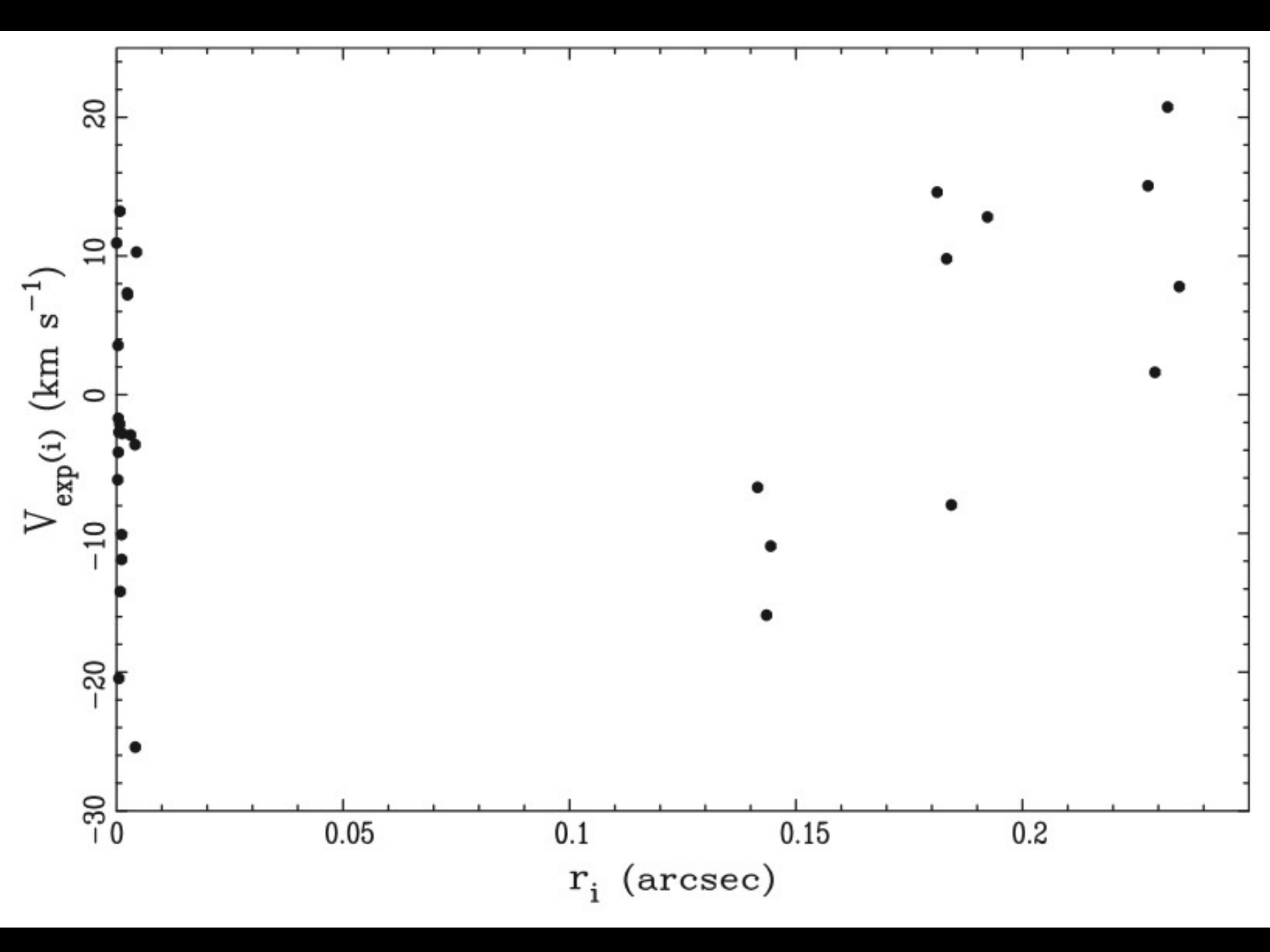
Spatio-kinematics modeling of the maser features. (Non-linear least-square method involving Levenburg-Marquart minimization technique)

Case : Assuming a single exciting source

Since the model assumes expanding (outflow) motion, the model fitting result would show positive data points if outflow exists.

	Systemic proper motion
V_{0x} (km s^{-1})	-2.5 ± 3.0
V_{0y} (km s^{-1})	5.4 ± 2.2
Position offset of the reference maser spot	
x_0 (mas)	20.0 ± 10.5
y_0 (mas)	-17.0 ± 9.0
$\sqrt{S^2}$ [a]	3.3

[a]Mean of the root-mean-square residual of the model fitting (errors at 1σ).


20
10
0
−10
−20
−30
0
0.05
0.1
0.15
0.2
$V_{exp(i)}$ (km s^{-1})
r_i (arcsec)

Summary

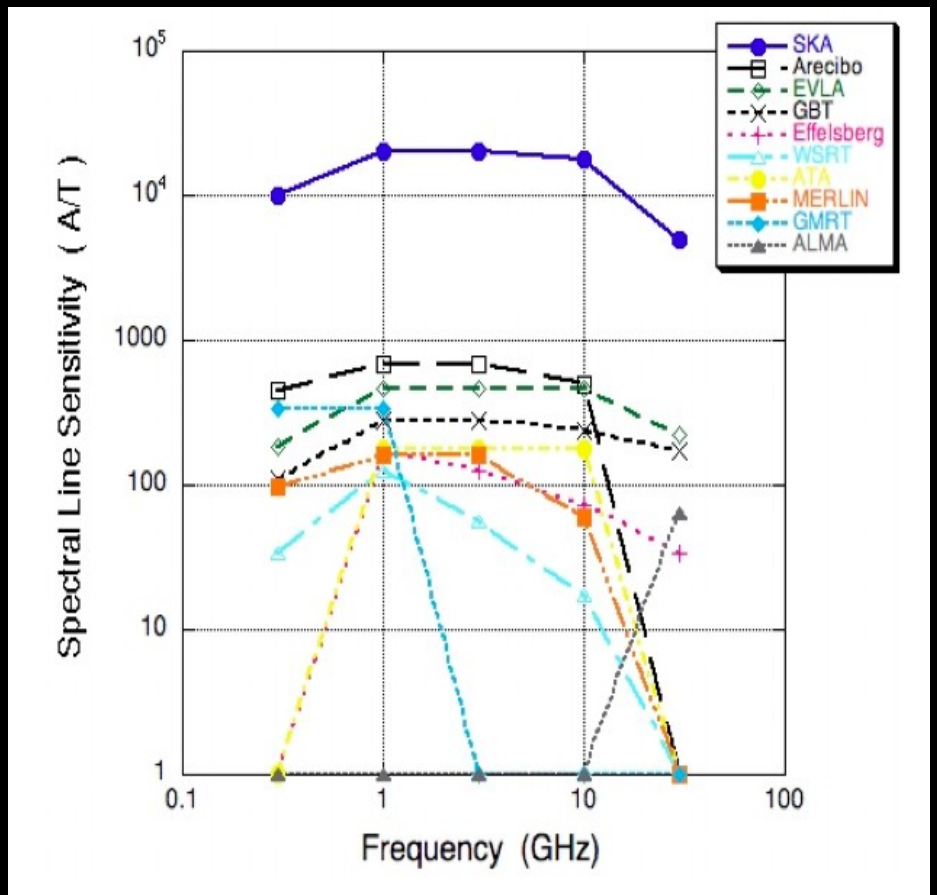
* Our results support the presence of an exciting source (at least one) in the HW3d.

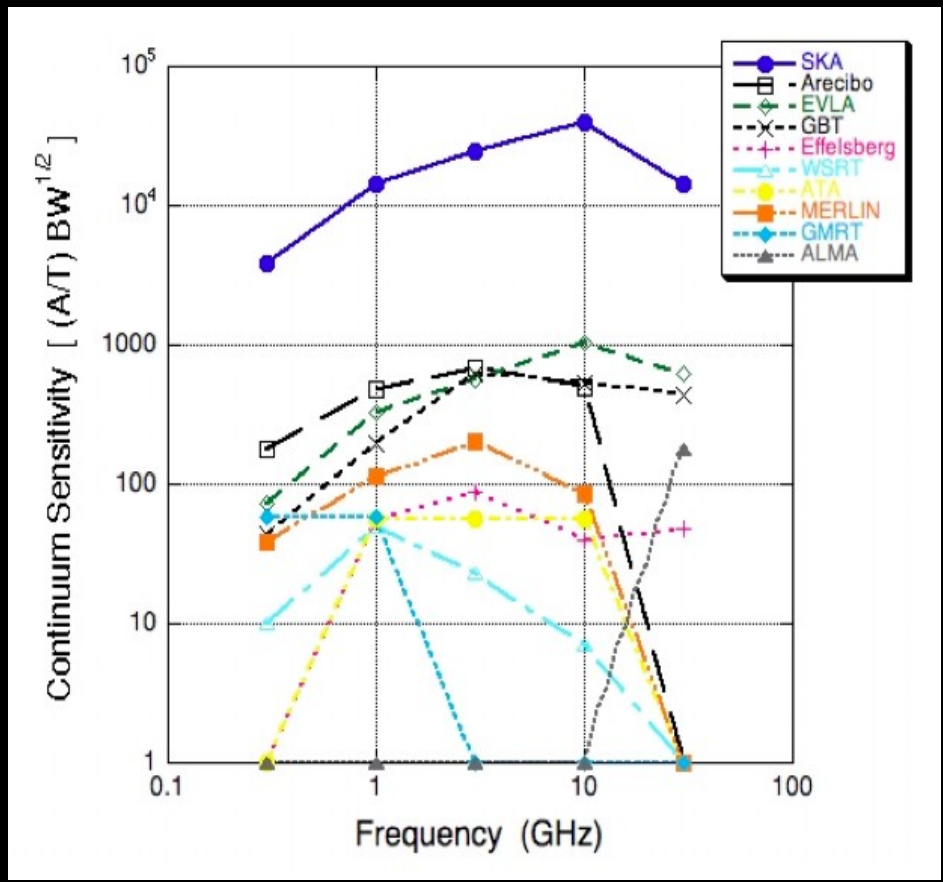
* The bipolar structure suggests that a disk-YSO-jet system has formed in the HW3d

* Maser spatio-kinematic fitting and the shift in the peak position of the HW3d continuum suggest the possibility of multiple source scenario.

Future Research Prospect with the SKA

SKA with its high sensitivity and angular resolution would be vital for testing the singularity or multiplicity of the exciting source(s) in HW3d. (See Memo 66)





Implications;

* More maser detection and tracing of more proper motion, thus clearer picture of internal motions in MSF regions

* This would be helpful in tracing the evolutionary sequence of massive star formation.

Using dynamical timescales;

Violent ejections in elliptical ring structures (~10yrs) >>>>>> Expanding bubbles of isotropic ejections (~ 30yrs) >>>>>> Jets ? >>>>>> Bipolar outflow (~ 100yrs) >>>>>> Wide angle outflow

Very high possibility of finding other intermediary maser activities

* High continuum sensitivity would lead to the detection of weak components which are currently not detect with existing telescopes

SKA AFRICA
SQUARE KILOMETRE ARRAY

While planning to kick-off this study with the EVLA and ALMA, we are looking forward to exciting results in MSF studies with the SKA !!!!!!