A wide-angle outflow with the simultaneous presence of a jet in the high-mass protostar Cepheus A HW2

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- Disk-YSO-Jet system in HW2
- Multi-epoch VLBA water maser observations

Collaborators

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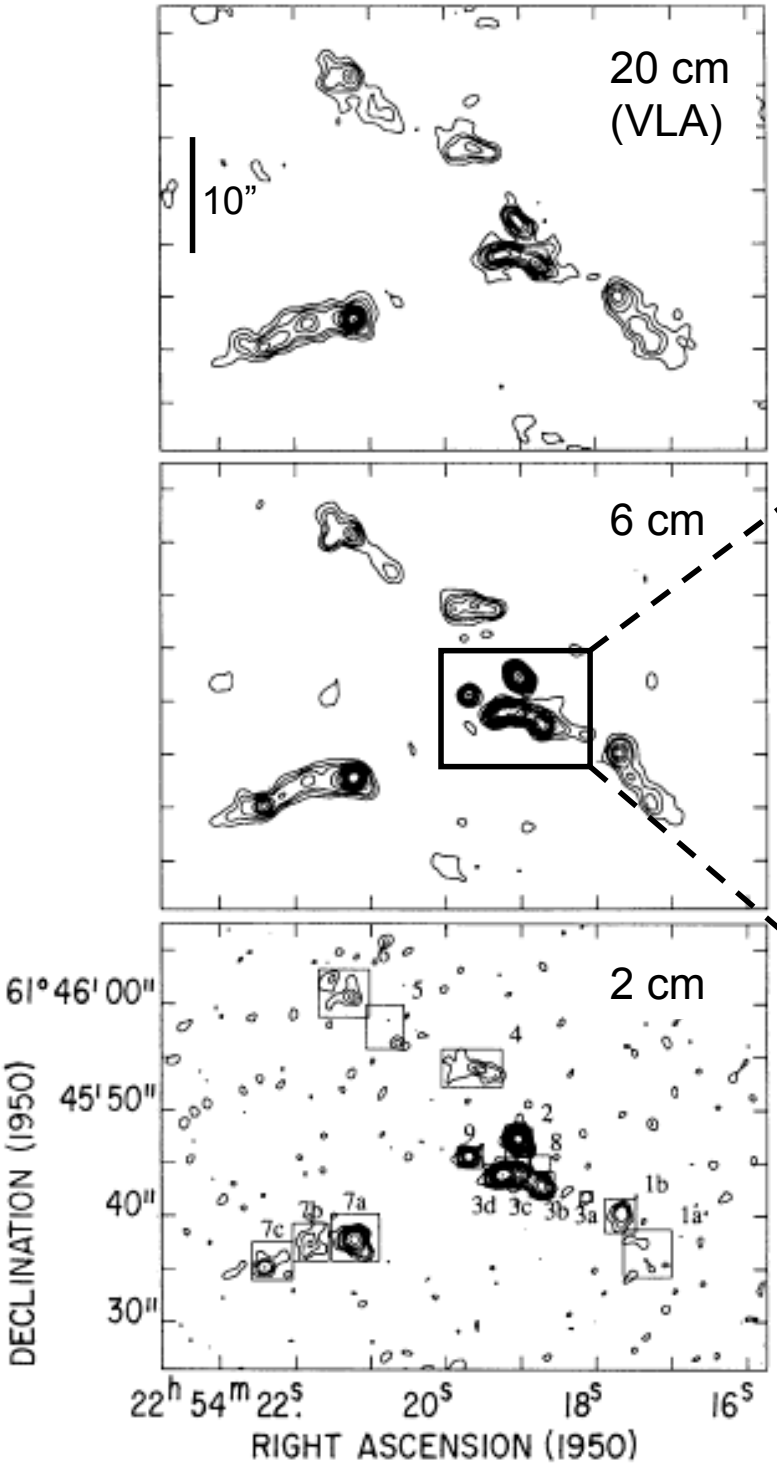
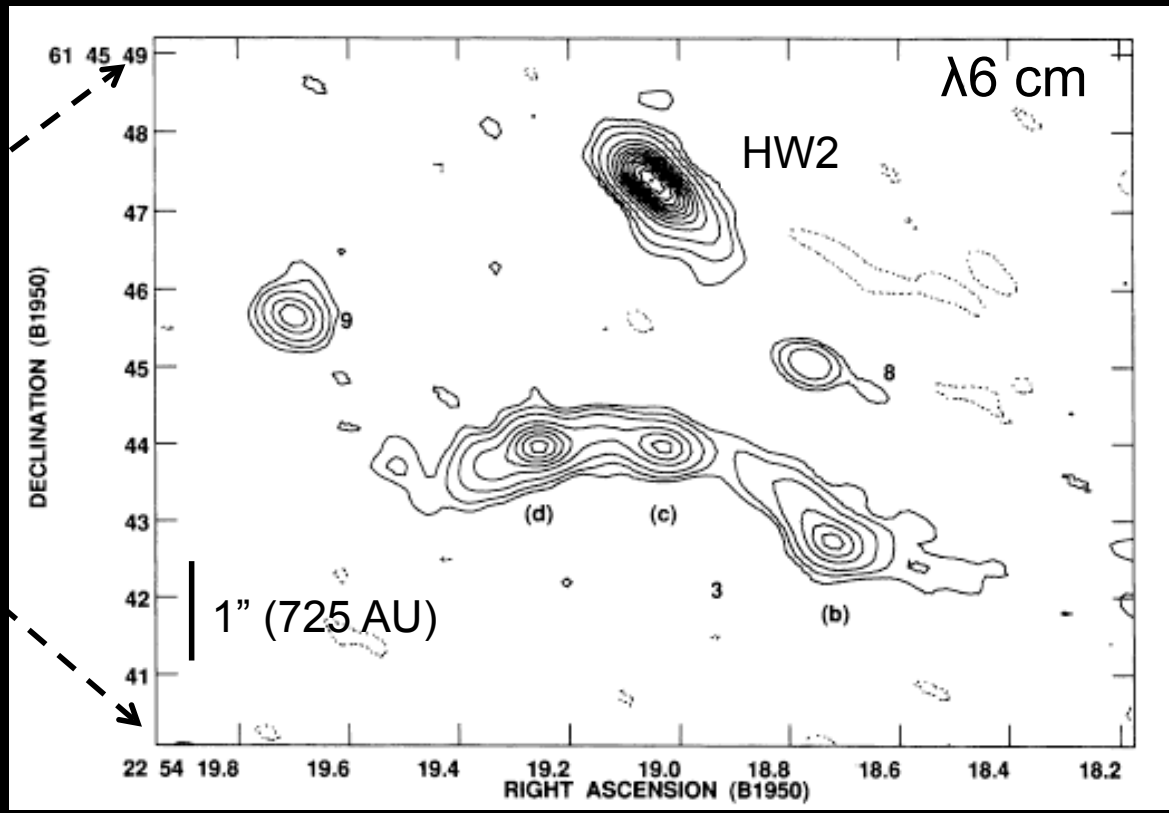
(2010, MNRAS in press)

HW Radio Continuum Sources

(Hugues & Wouterloot 1984)

(16 sources in a region of ≈ 30” size)



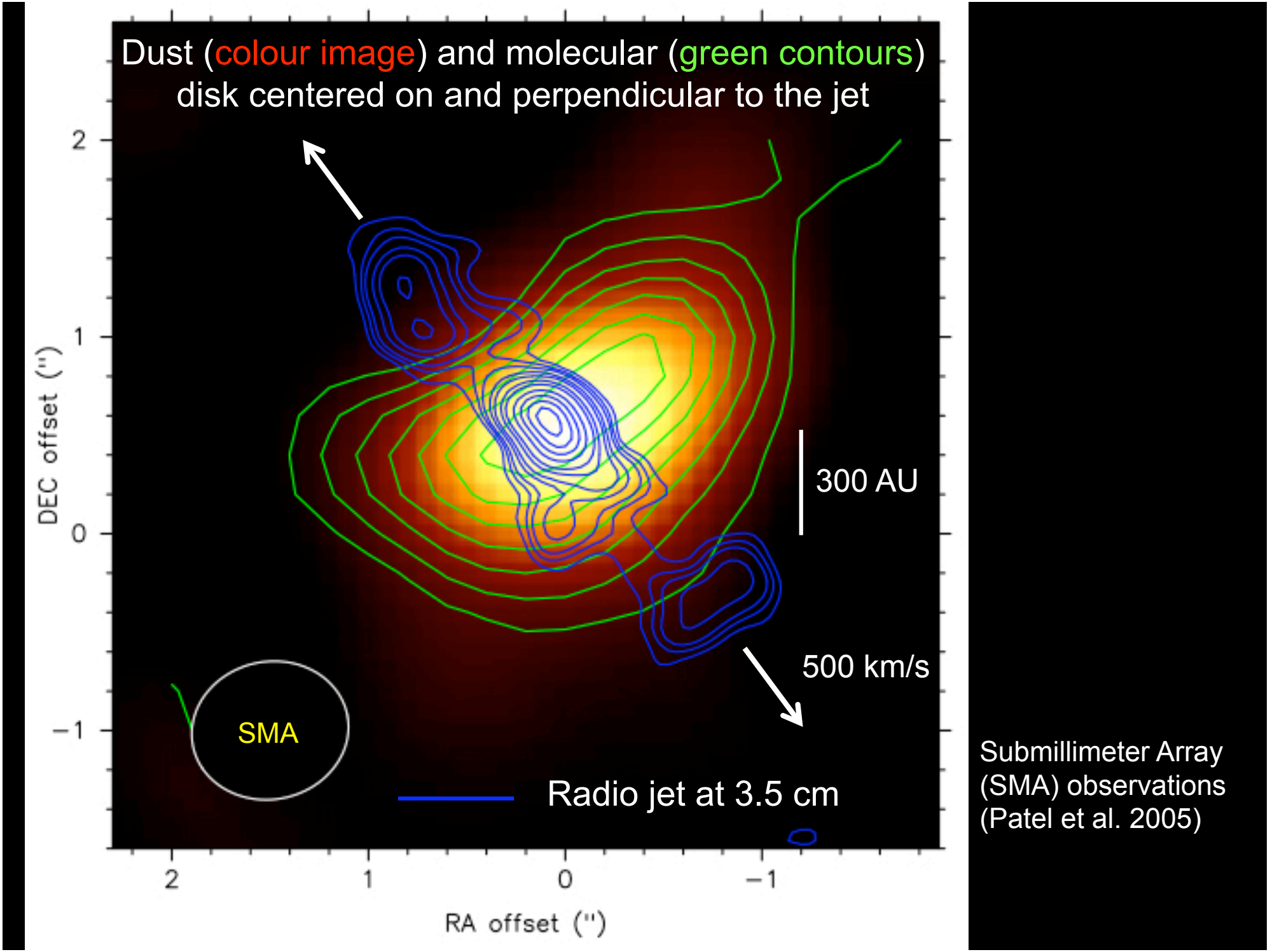


Hugues, Cohen, & Garrington (1995), Garay et al. (1996)

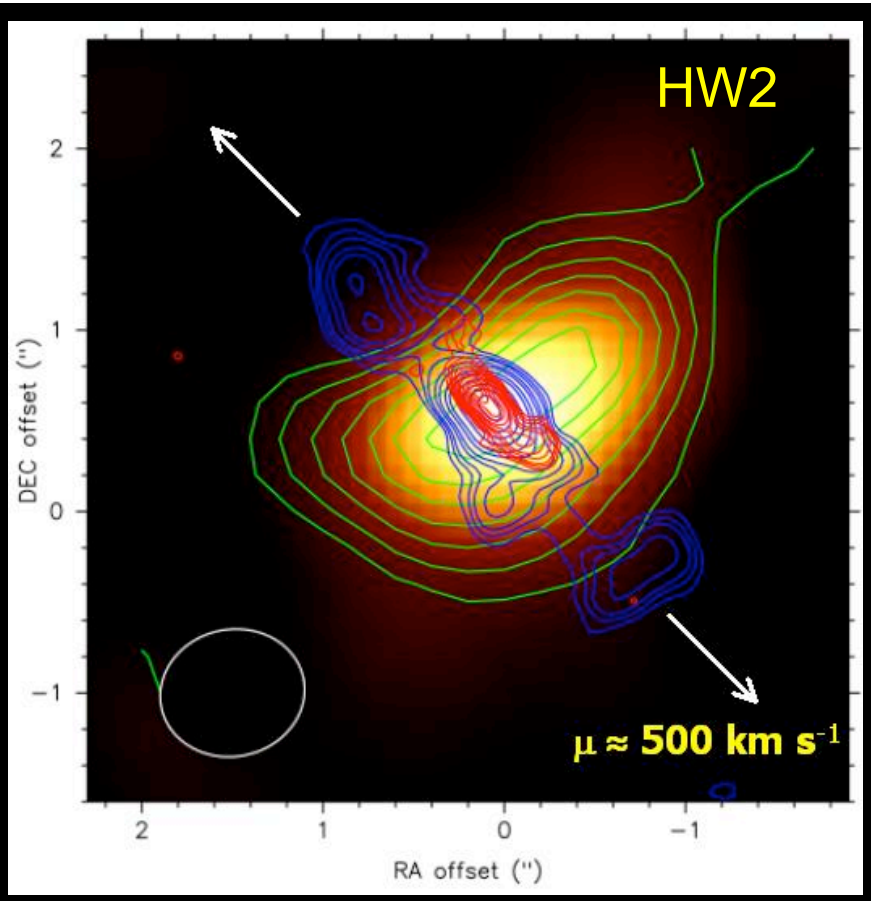
HW2 is a radio jet powered by a massive star

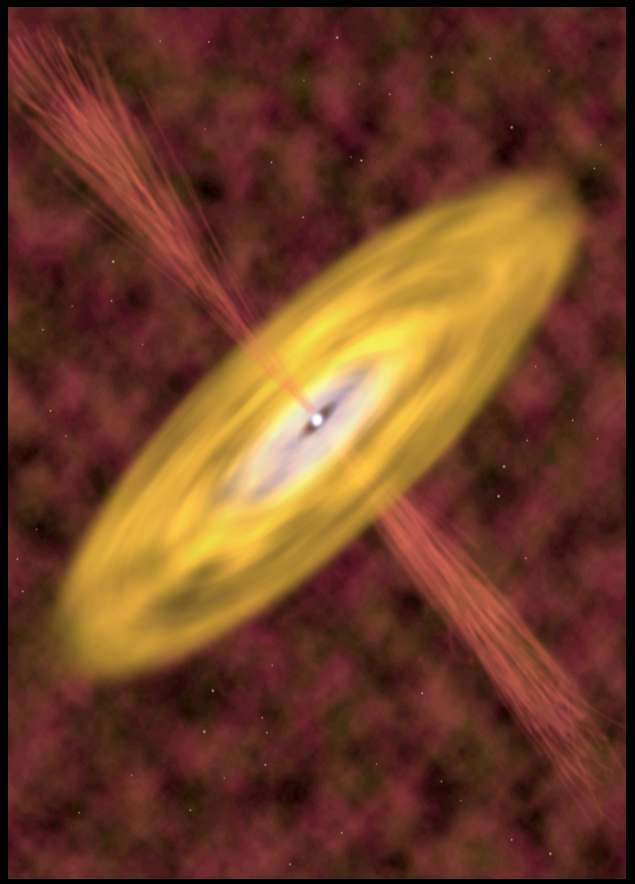
(15-20 Msun; Rodríguez et al. 1994)

$A_V \sim 10^3$ mag (Torrelles et al. 1985)



Submillimeter Array (SMA) observations (Patel et al. 2005)



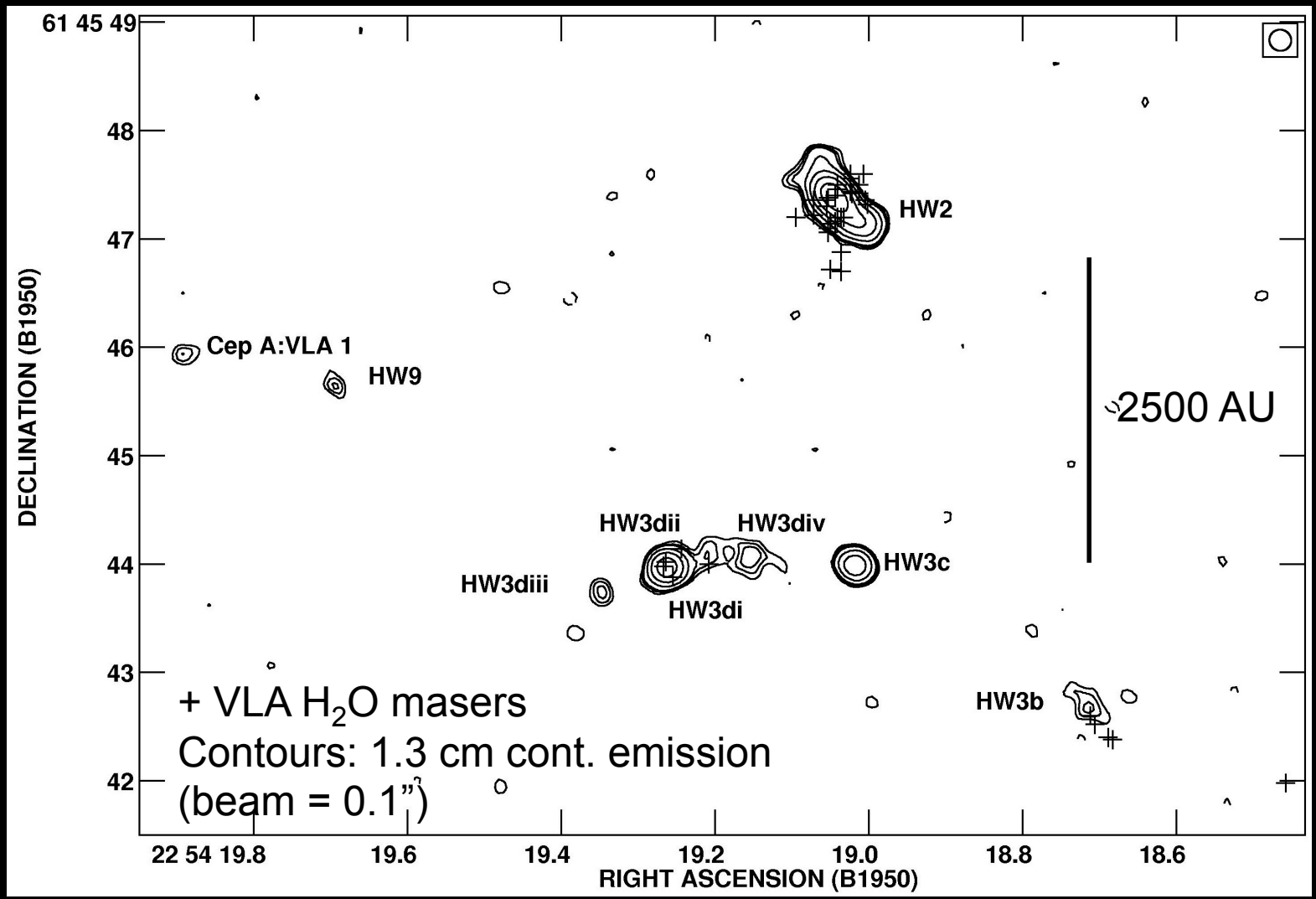


Radius (disk) = 325 AU
Mass (disk) = 1-8 M_{sun}
Mass (star) = 15-20 M_{sun}

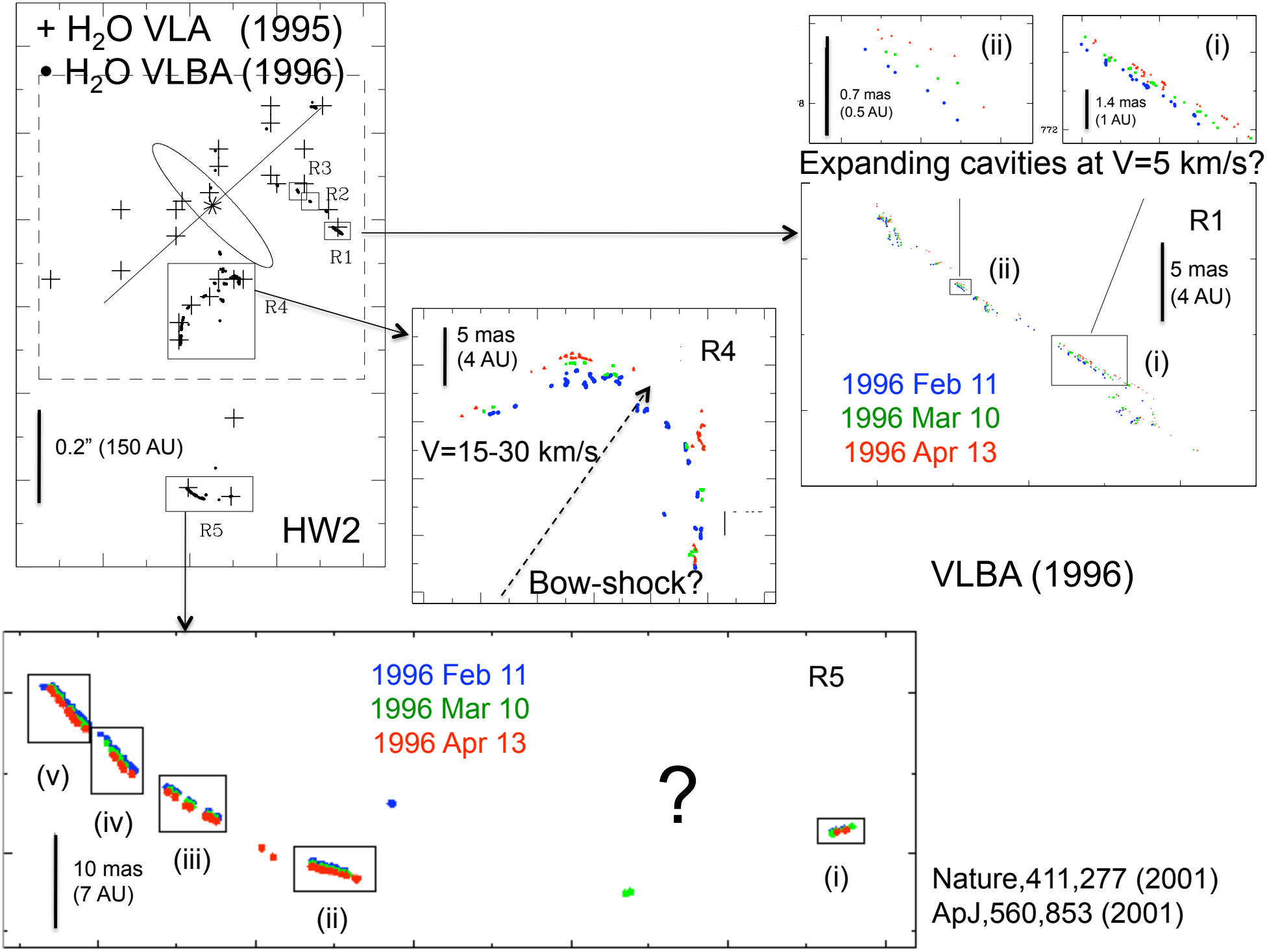
The SMA and VLA results on Cepheus A HW2 support that massive stars form via accretion as low-mass stars do

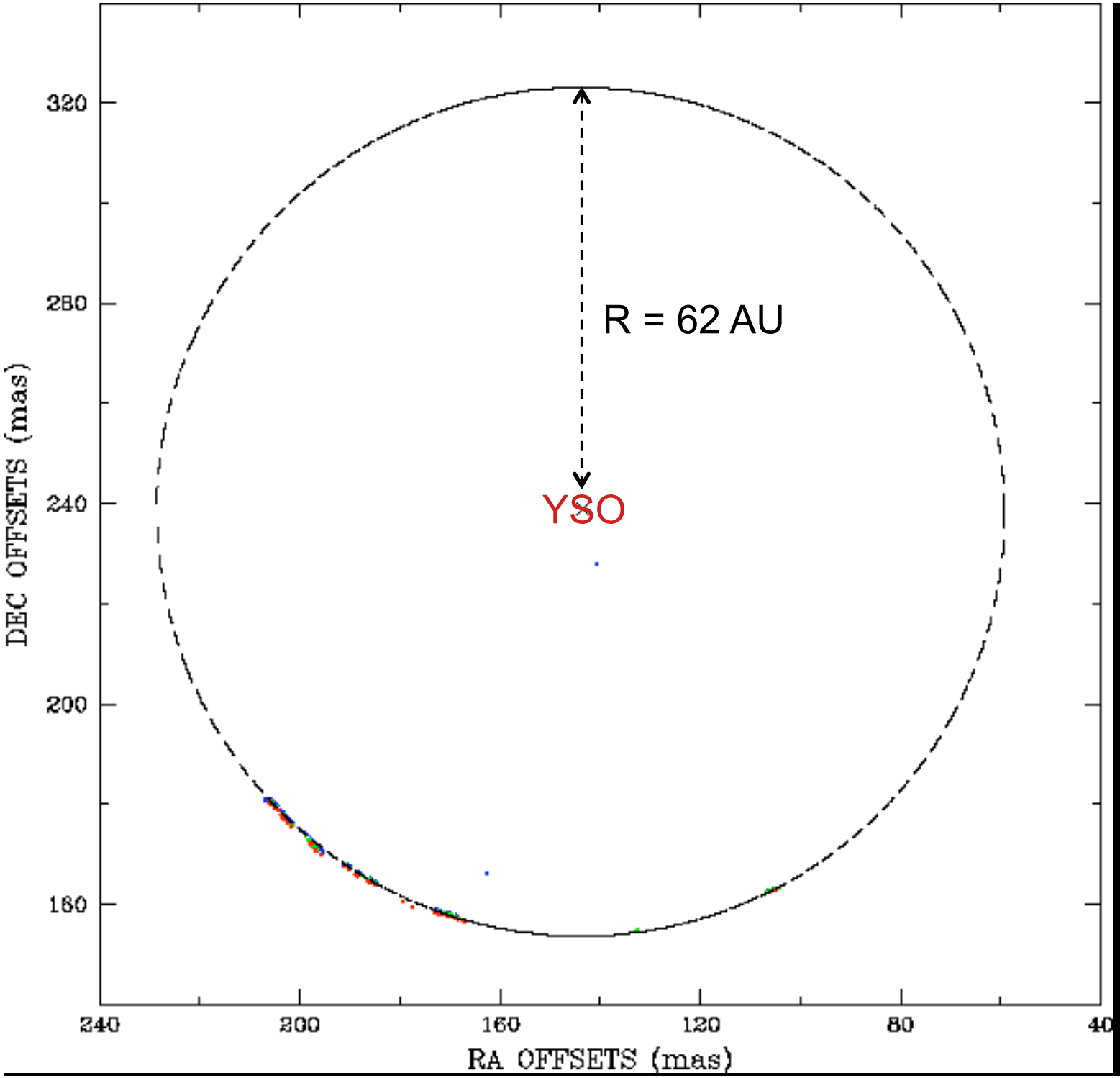
(van Langevelde's talk)

Clusters of strong water maser emission



Torrelles et al. (1996)


+ H2O VLA (1995)
• H2O VLBA (1996)
R3
R2
R1
R4
R5
0.2" (150 AU)
HW2
5 mas
(4 AU)
R4
V=15-30 km/s
Bow-shock?
0.7 mas
(0.5 AU)
(ii)
1.4 mas
(1 AU)
(i)
Expanding cavities at V=5 km/s?
R1
5 mas
(4 AU)
(ii)
(i)
1996 Feb 11
1996 Mar 10
1996 Apr 13
VLBA (1996)
1996 Feb 11
1996 Mar 10
1996 Apr 13
R5
?
(v)
(iv)
(iii)
(ii)
(i)
10 mas
(7 AU)
Nature,411,277 (2001)
ApJ,560,853 (2001)



The R5 arc structure was extremely well fitted by a circle (R=62 AU) to an accuracy of one part in a thousand

Expanding bubble at ~ 9 km/s excited by a central massive YSO (detected at λcm)

New VLBA multi-epoch water maser observations

Main goal

Evolution of the maser structures found in the earlier (1996) VLBA observations to ascertain their nature

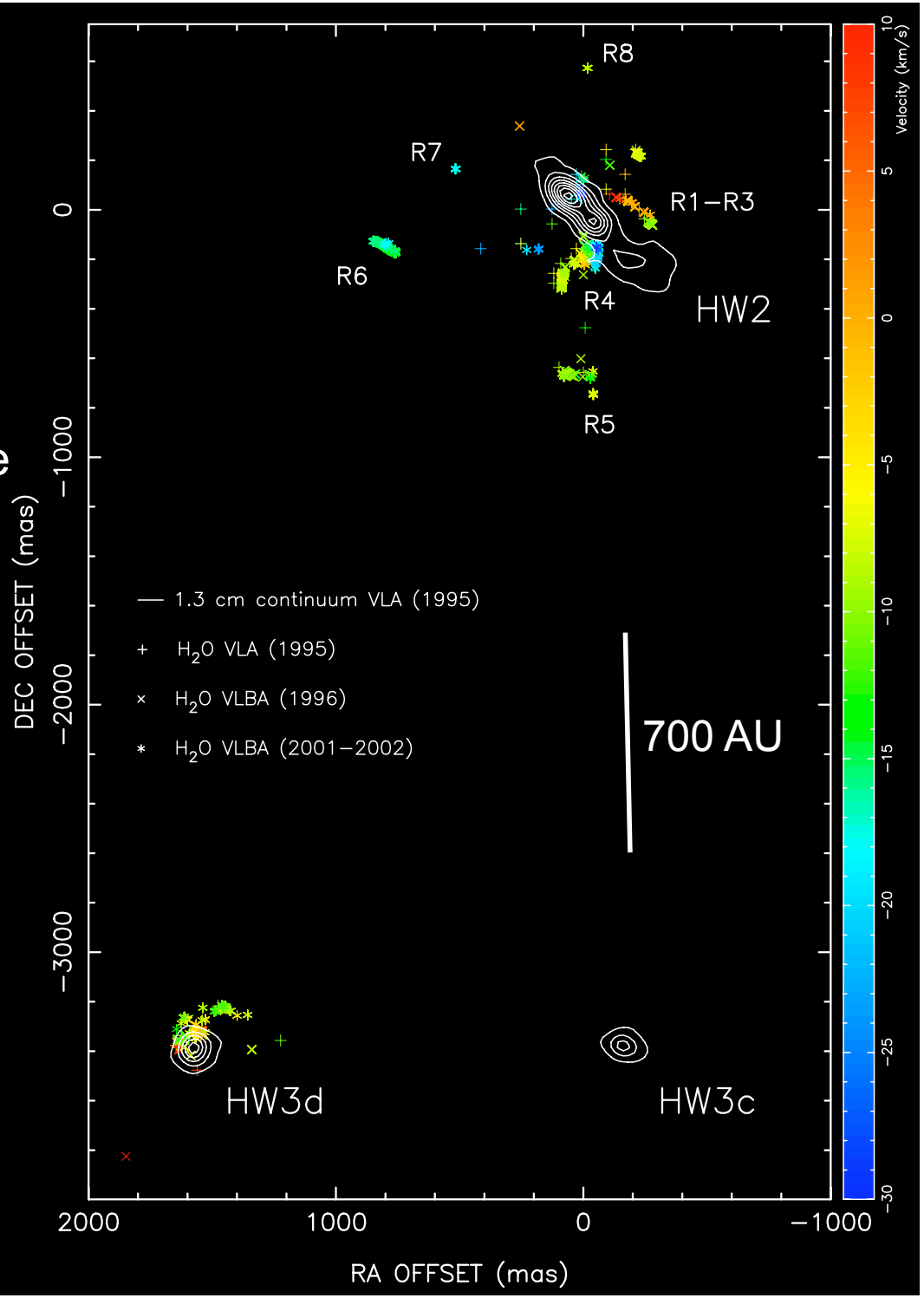
Five observed epochs

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

Beam = 0.4 mas (0.3 AU)

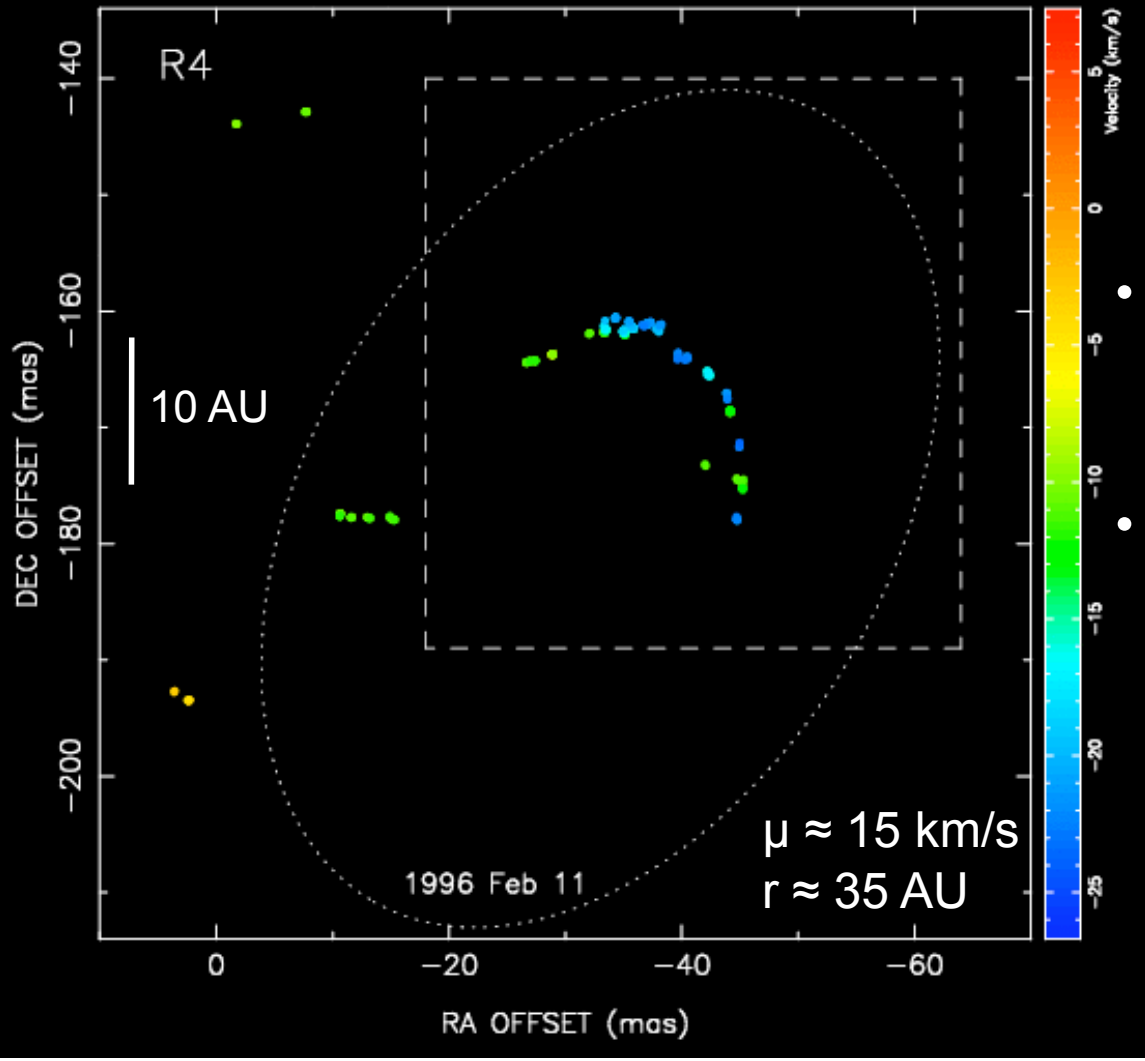
~ 1800 maser spots detected in each epoch

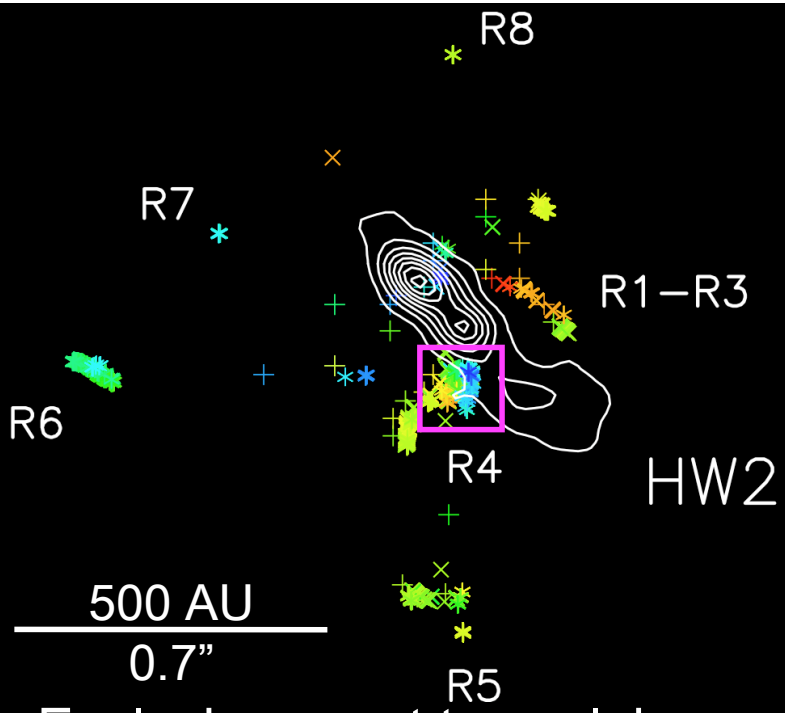
(2010, MNRAS in press)



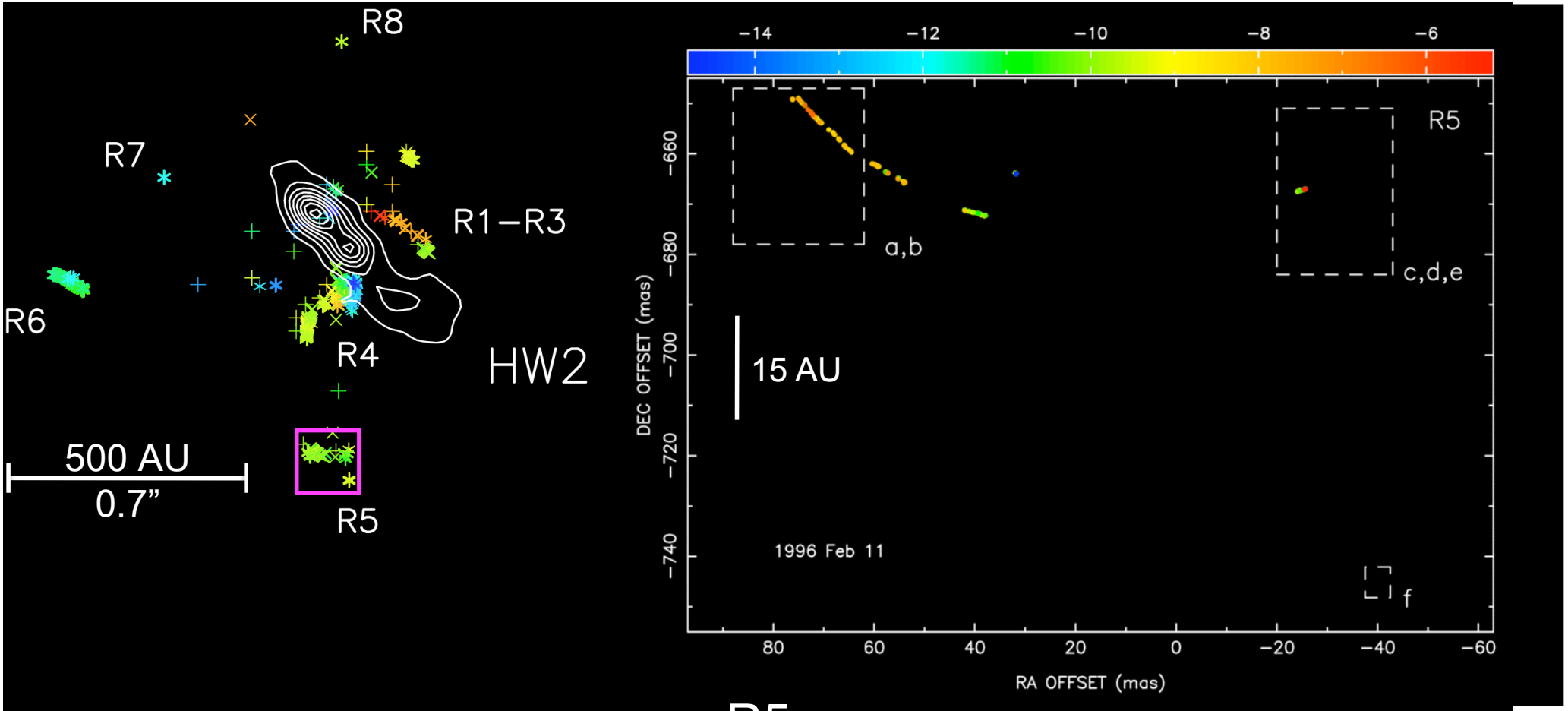
R4

Expanding elliptical ring (35 AU) rather than a simple bow-shock





- Explosive event to explain the high velocity dispersions (dynamical time ~ 10 yr)
- Driving massive YSO (still unidentified) predicted to be located at the center of the ring, (-0.03”,-0.18”) from HW2



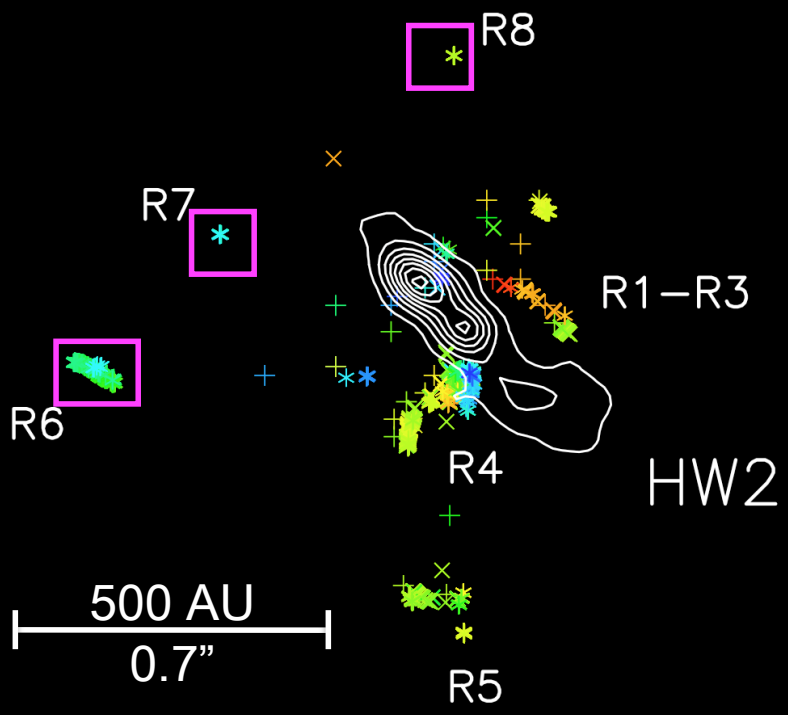
R5

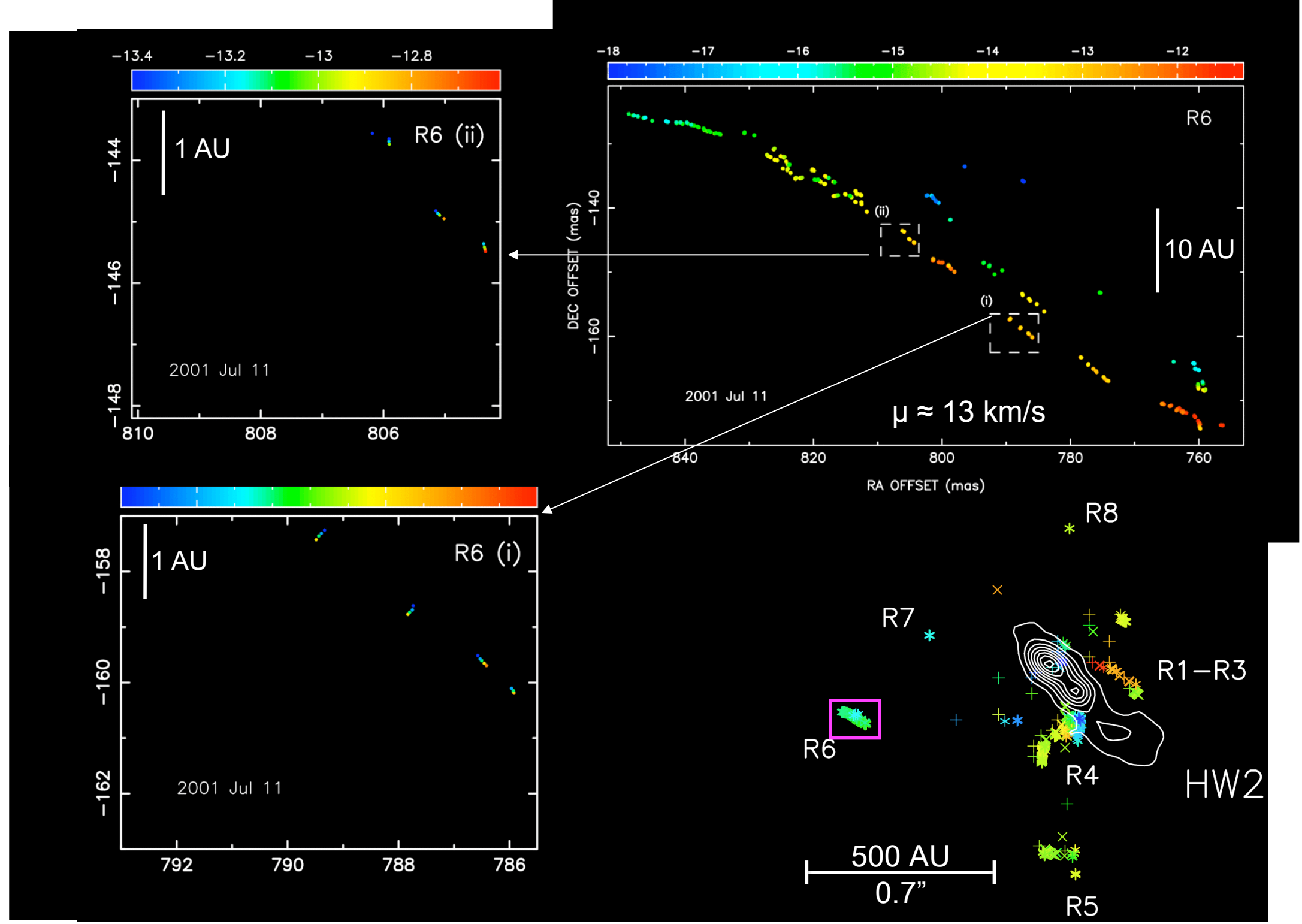
Expanding (~ 10 km/s) bubble (~ 60 AU) currently dissipating in the circumstellar medium, losing its degree of symmetry

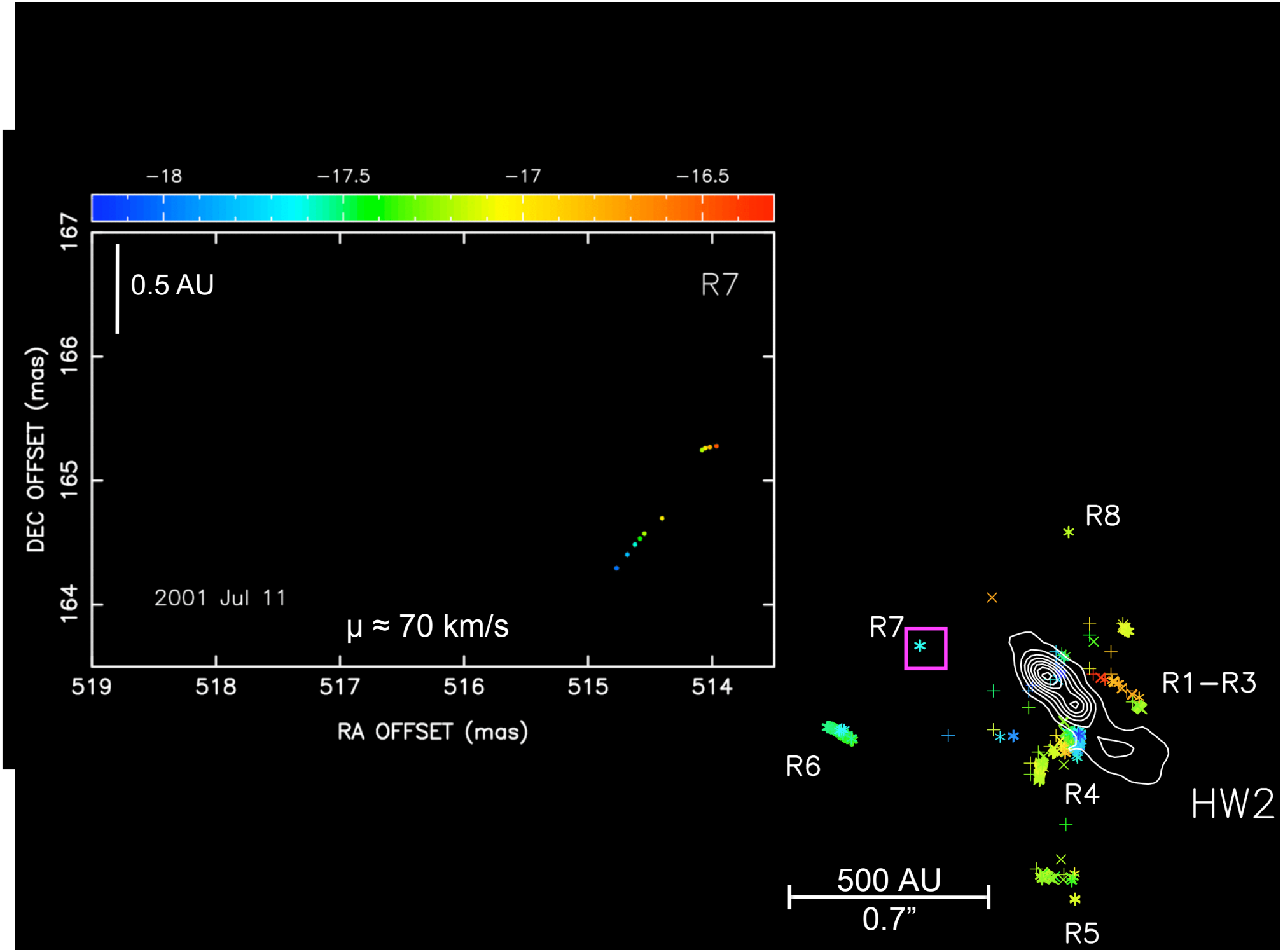
Short-lived (few ten of years) nature (unknown) event

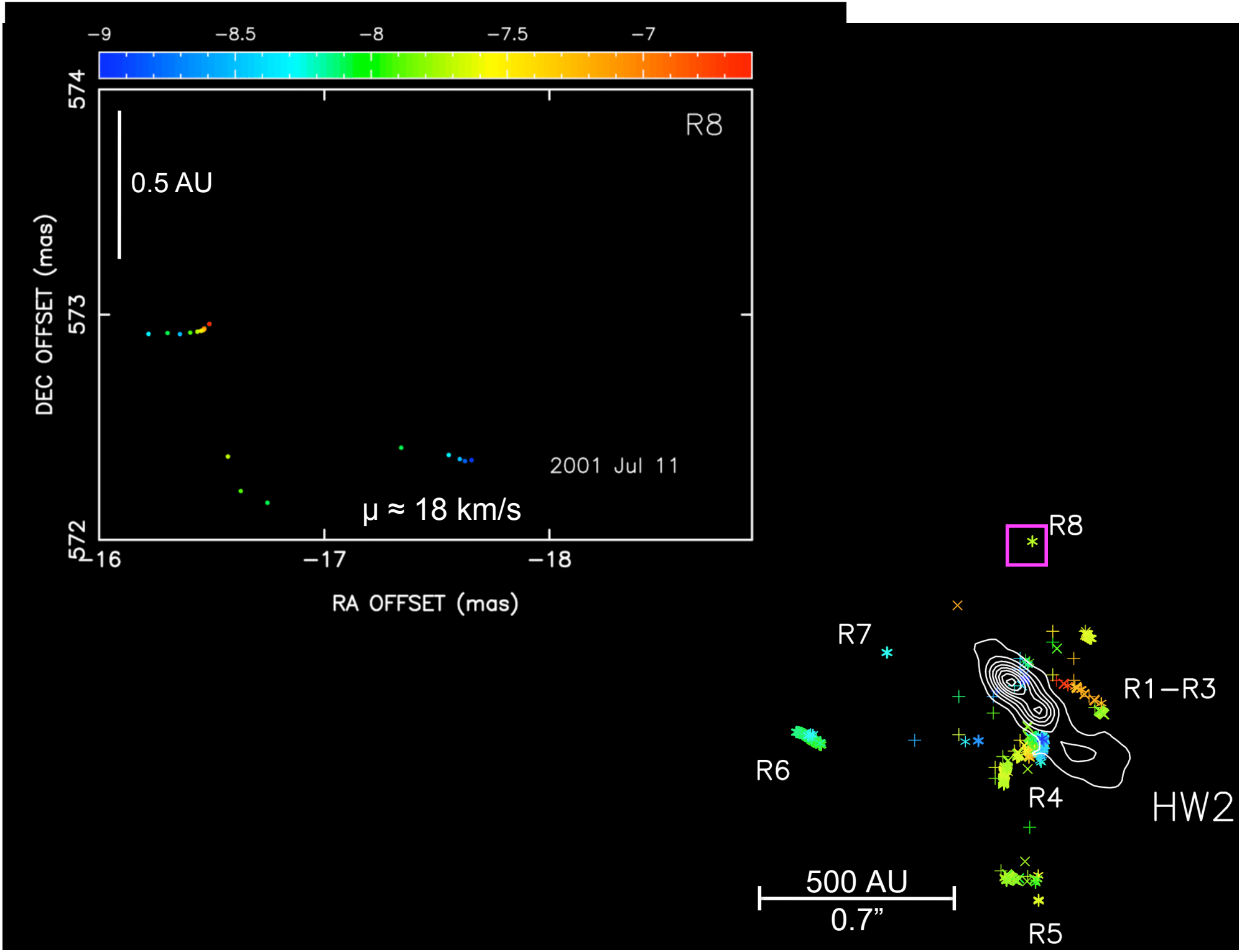
Driving YSO of ~ 10 M_{sun} (detected)

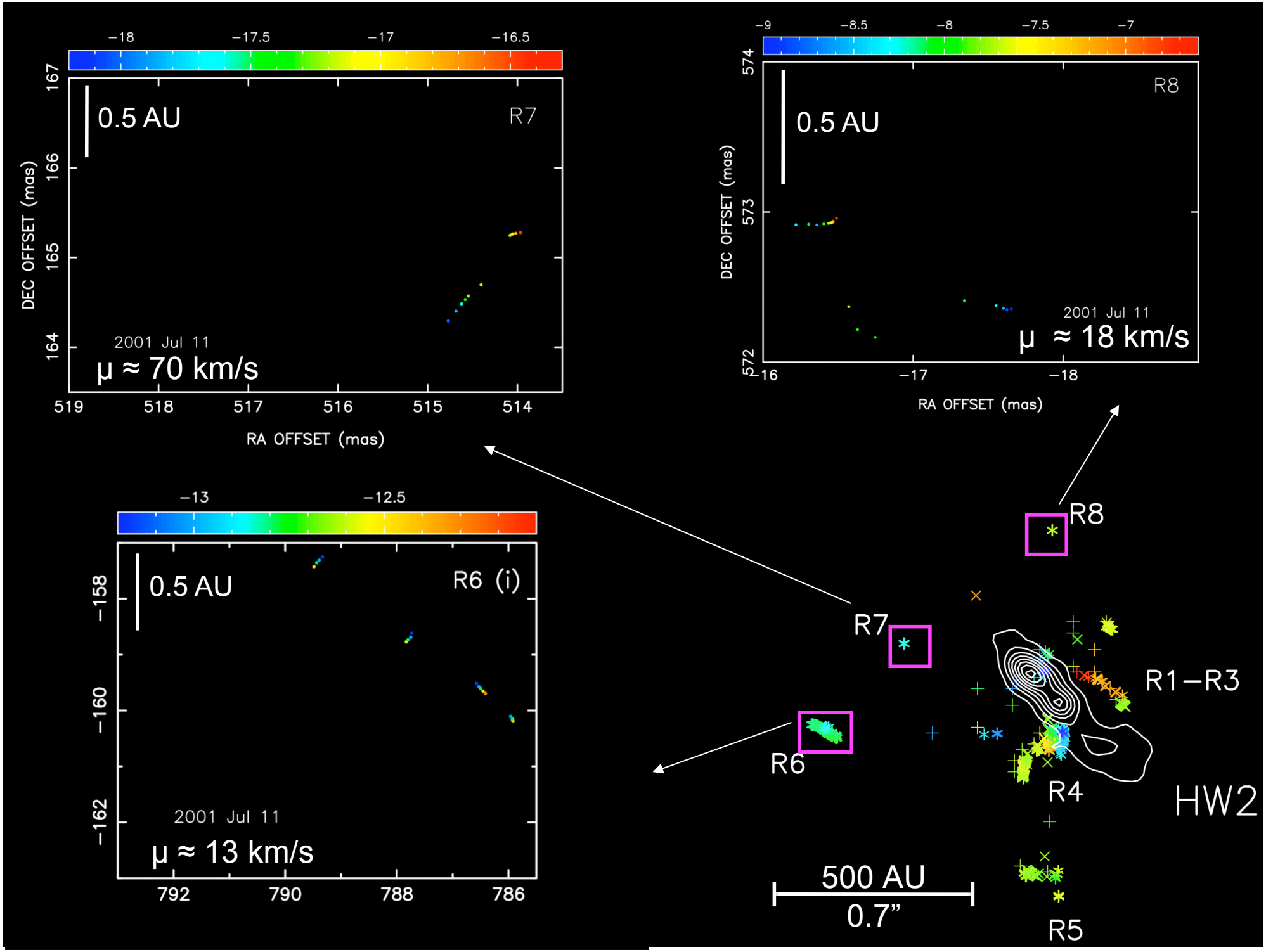
New detected water maser structures
R6, R7, R8

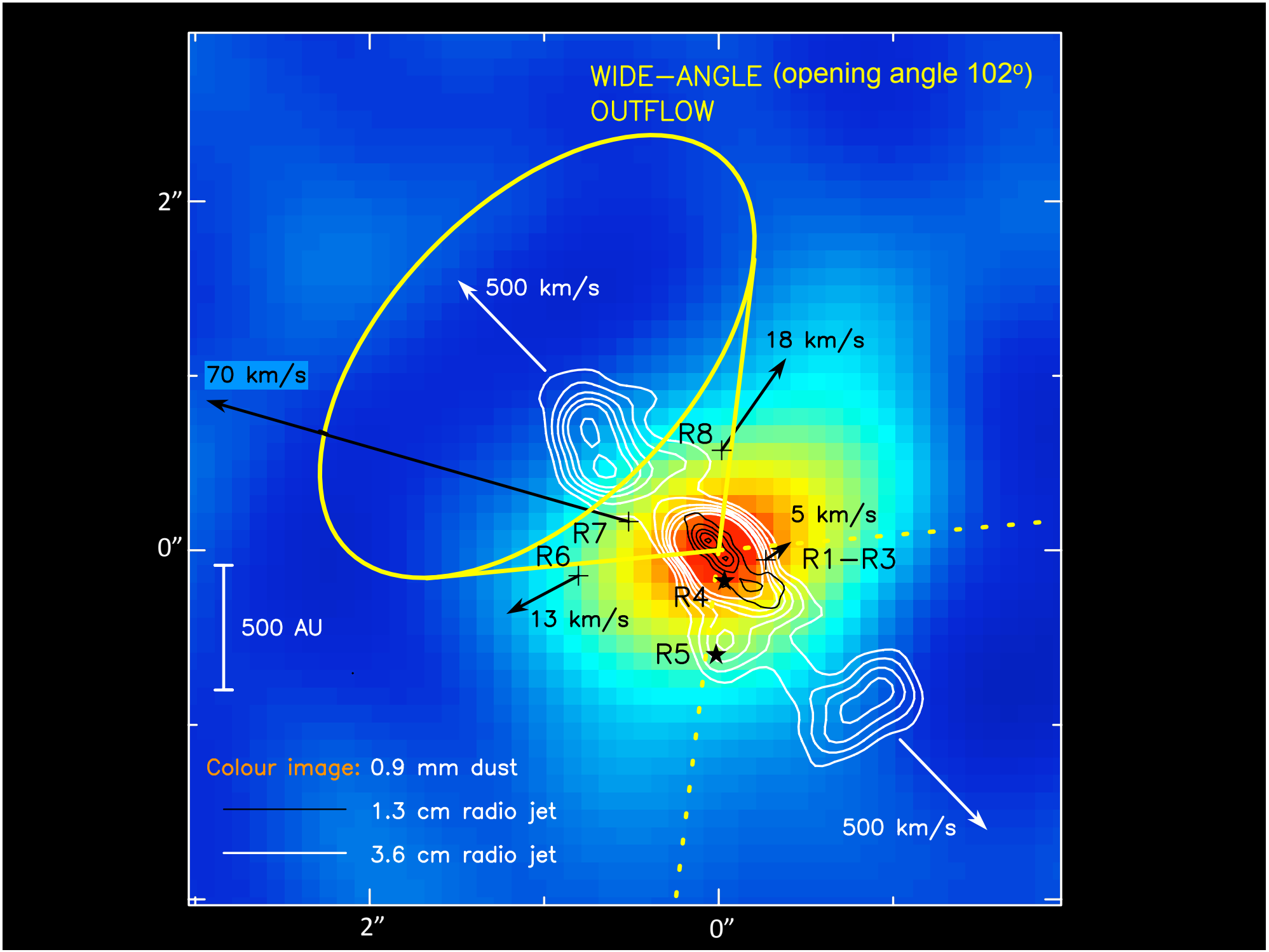



−13.4
−13.2
−13
−12.8
1 AU
R6 (ii)
2001 Jul 11
−144
−146
−148
810
808
806
−18
−17
−16
−15
−14
−13
−12
R6
(ii)
(i)
10 AU
DEC OFFSET (mas)
−140
−160
2001 Jul 11
μ ≈ 13 km/s
840
820
800
780
760
RA OFFSET (mas)
1 AU
R6 (i)
−158
−160
−162
2001 Jul 11
792
790
788
786
R8
R7
R1−R3
R6
R4
HW2
500 AU
0.7”
R5

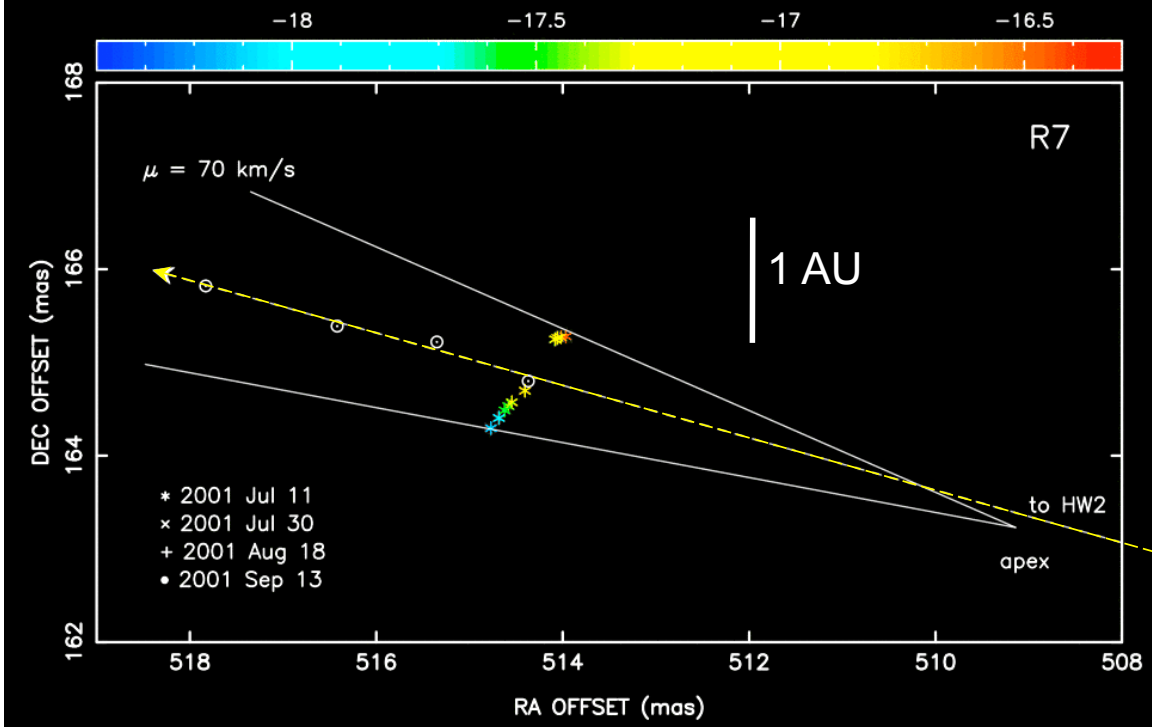

−18
−17.5
−17
−16.5
167
166
165
164
DEC OFFSET (mas)
0.5 AU
R7
2001 Jul 11
μ ≈ 70 km/s
519
518
517
516
515
514
RA OFFSET (mas)
R8
R7
R1−R3
R6
R4
HW2
500 AU
0.7”
R5

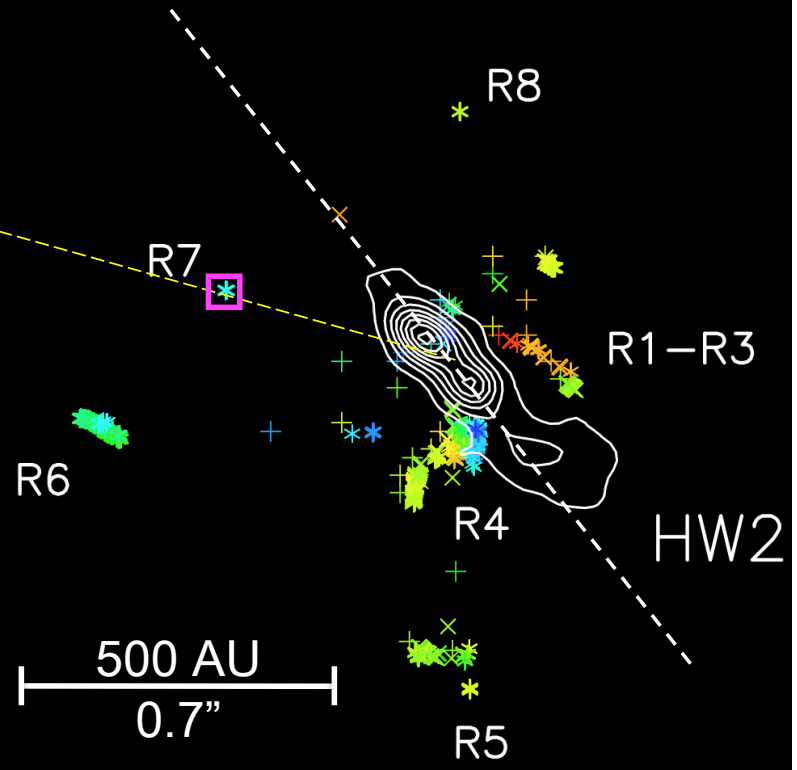

−9
−8.5
−8
−7.5
−7
574
573
572
−16
−17
−18
DEC OFFSET (mas)
RA OFFSET (mas)
R8
0.5 AU
2001 Jul 11
μ ≈ 18 km/s
R8
R7
R1−R3
R6
R4
HW2
500 AU
0.7”
R5


−18
−17.5
−17
−16.5
167
166
165
164
0.5 AU
R7
DEC OFFSET (mas)
2001 Jul 11
μ ≈ 70 km/s
519
518
517
516
515
514
RA OFFSET (mas)
−9
−8.5
−8
−7.5
−7
574
573
572
R8
0.5 AU
DEC OFFSET (mas)
2001 Jul 11
μ ≈ 18 km/s
−16
−17
−18
RA OFFSET (mas)
−13
−12.5
−158
−160
−162
0.5 AU
R6 (i)
2001 Jul 11
μ ≈ 13 km/s
792
790
788
786
R8
R7
R6
R1−R3
R4
R5
HW2
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”

Masers excited, accelerated and beginning to expand via a wide-angle wind from HW2





- The expanding motions define a fan-like structure of few mas (AU) size
- Dynamical time ~ 0.3 yr
- Radial velocity gradient of ~ 2 km/s along the water maser linear structure

CONCLUSIONS

- Three massive YSOs in a region of 0.3” (200 AU) radius: HW2, and the driving sources of the R5 (VLA R5) and R4 (undetected yet) maser structures

- Wide-angle outflow and jet occurring simultaneously at a similar physical scale of 1” (700 AU) in a massive YSO. Important constraints for future models when trying to reproduce different outflow opening angles (not yet developed for high-mass stars)

- The VLBA water maser observations have revealed very short-lived events (0.3 to 30 yr). They are providing new insights in the study of the dynamic scenario of the formation of high-mass stars