Atacama Large Millimeter/submillimeter Array

Understanding Massive Star Formation Activities: Joint Role of ALMA and VLBI (VERA/KVN)

James Chibueze

East Asian ALMA Regional Center, NAOJ.

3rd October, 2013.

In search of our Cosmic Origins

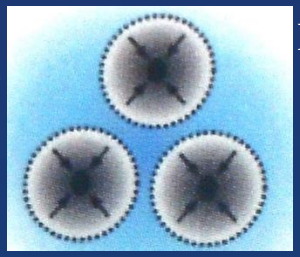
Atacama Large Millimeter/submillimeter Array

Massive Stars: Known and Unknown

Dense molecular cloud

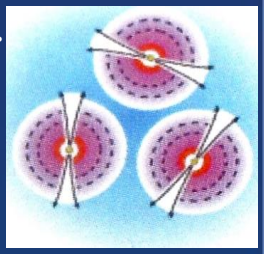
Missing link?

Gravitational collapse



Maser conditions reached, and pumped.

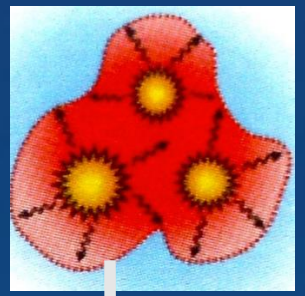
Periodic ejections



Hot core formation [NGC 6334IN SM2 Hot Core]

Disk formation

(Beltran et al. 2006)

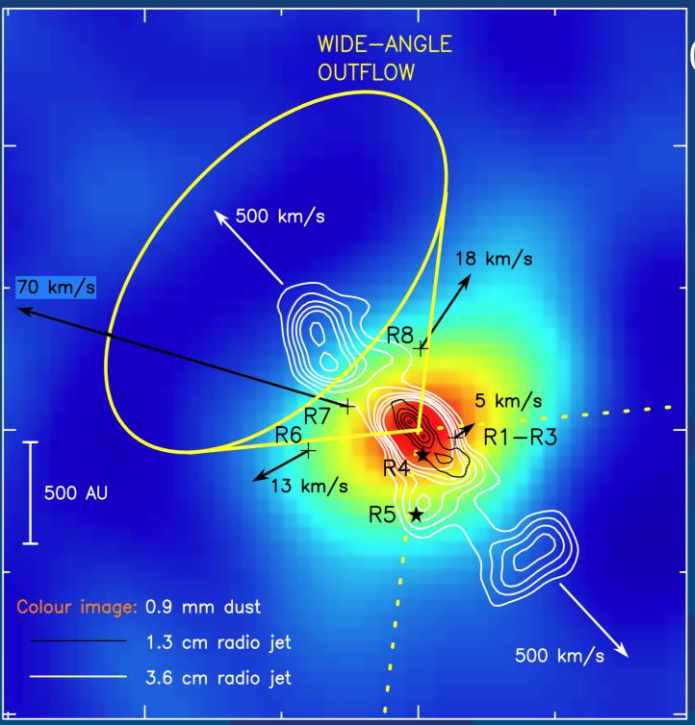


Ultra-compact HII region [100 K, ~ 0.1 pc in size] (keeps expanding as the MYSO evolves and emits more energetic photons).

High-velocity jet formation

Low-velocity bipolar outflow (collimated; Chibueze et al. 2012.)

[Cepheus A HW3d & NGC 6334IN SMA 1 bipolar outflow]



(Torrelles et al. 2011.)

In search of our Cosmic Origins

Atacama Large Millimeter/submillimeter Array

Massive Stars: Known and Unknown

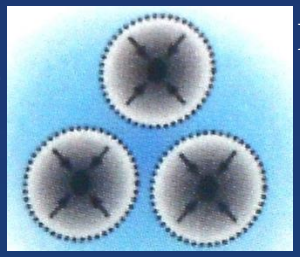
Dense molecular cloud

Missing link?

Gravitational collapse

and/or

Magnetic field



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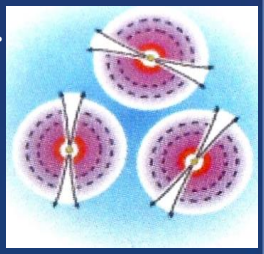
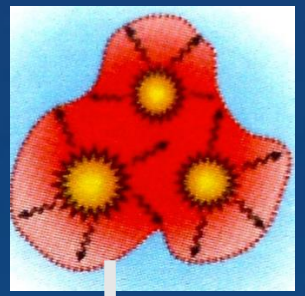


mation [NGC

M2 Hot Core]

nation

al. 2006)



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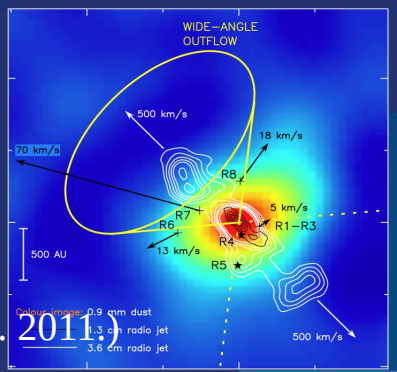


(Torrelles et al. 2011.)

VLBI observations alone (which traces only a small fraction of the region) cannot give us the full picture of how massive stars form.

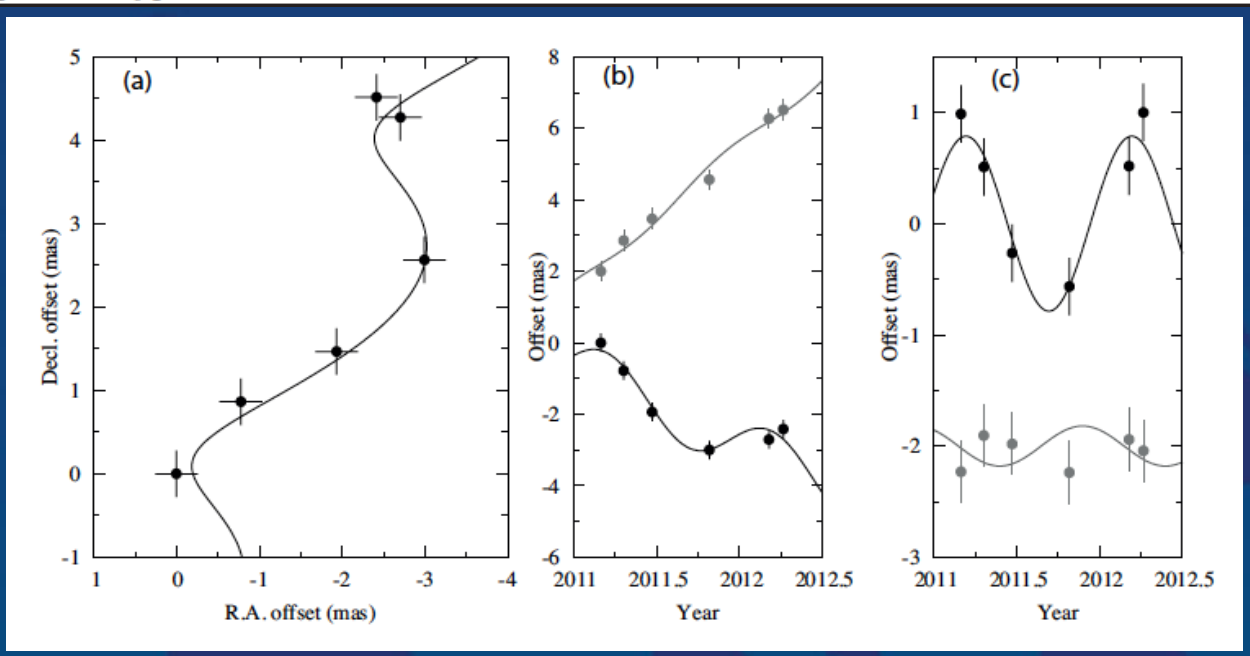
VLBI + ALMA!

Accurate distance (only a small fraction of the distance to MSF regions is known, especially in the southern sky) Needed to constrain MSF physical parameters

Do massive stars form from filamentary structures? If so, how do the filamentary structures form?

	Values at the Kinematic Distance of $D = 3.7$ kpc				Values at Our Distance of $D = 1.56$ kpc				Reference
Millimeter Core	MM1	MM2	MM3	MM4	MM1	MM2	MM3	MM4	
Virial Mass	1130	1510	1370	···	476	637	578	···	(1)
LTE Mass	330	1460	···	···	59	260	···	···	(1)
Dust Mass	1187	1284	301	253	211	228	54	45	(2)
L_{bol}	32000	···	9000	12000	5700	···	1600	2100	(3)
Spectral Type	O9.5	···	B0.5	B0.5	B1	···	B3	B2	(3)

MSXDC G034.43+00.24
Kurayama et al. (2011)



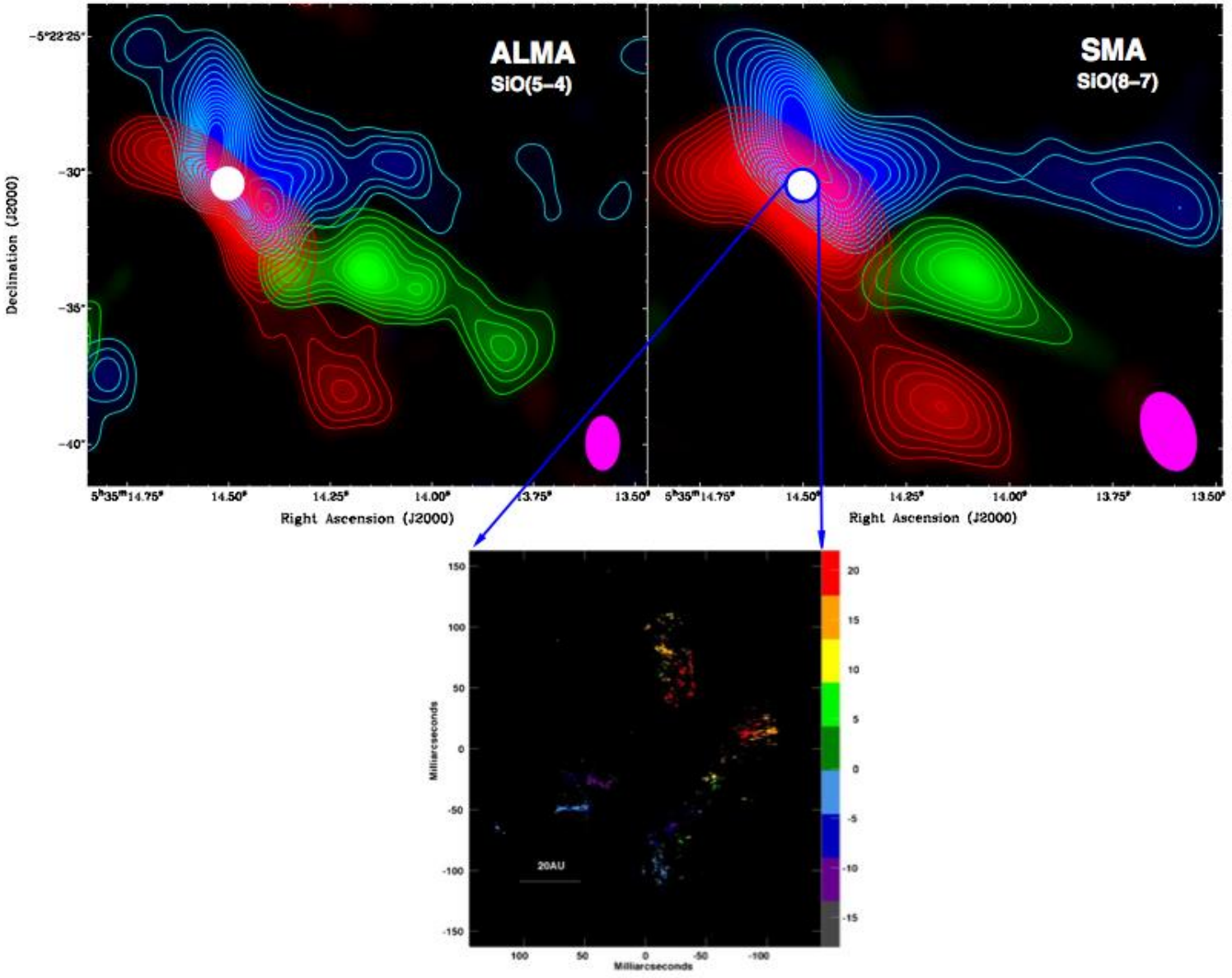
NGC 6334I(North)
Chibueze et al. (submitted)

0.79+/-0.16 mas

1.26 +/- 0.31 kpc

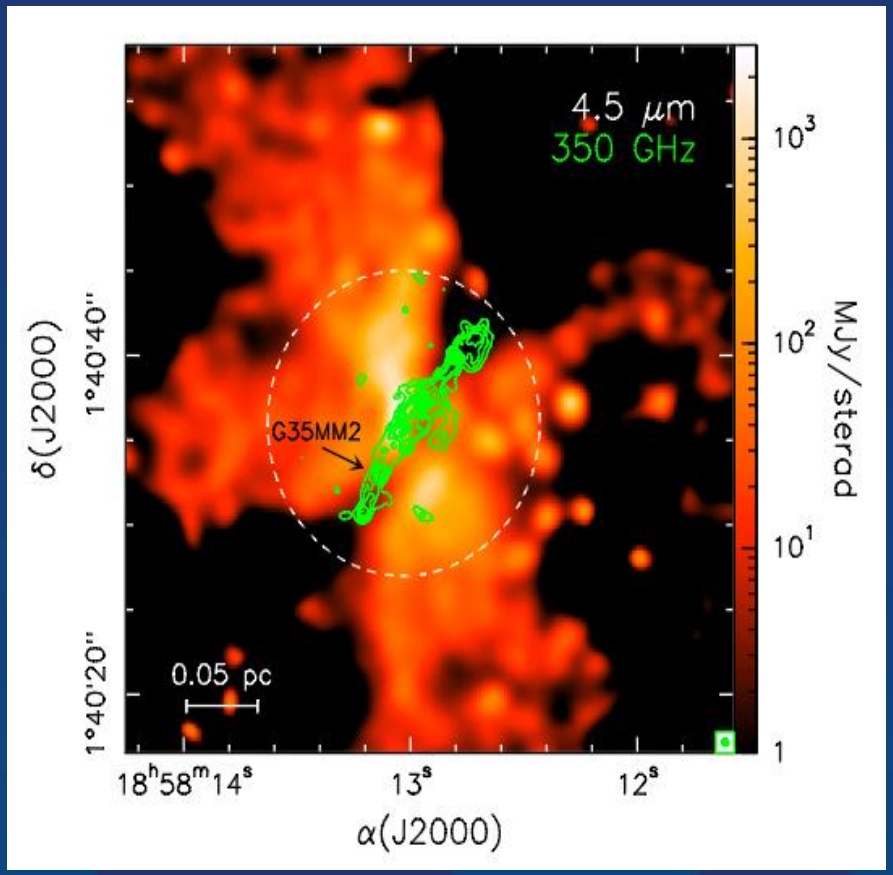
Atacama Large Millimeter/submillimeter Array

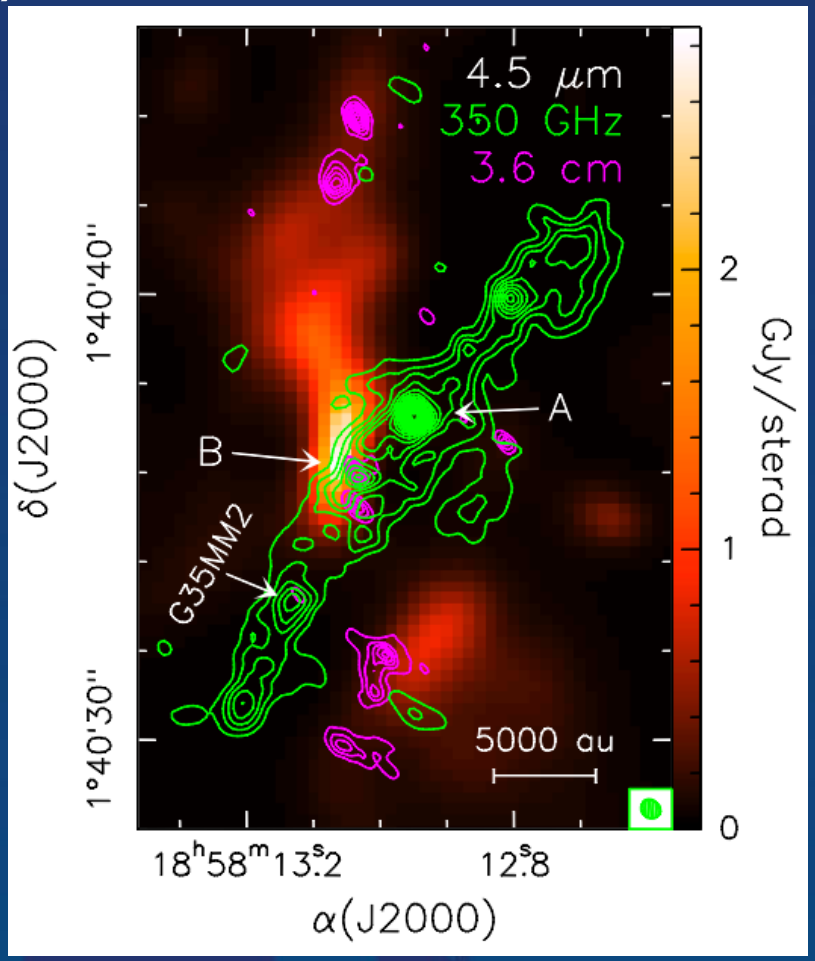
ALMA contributes the needed large-scale view

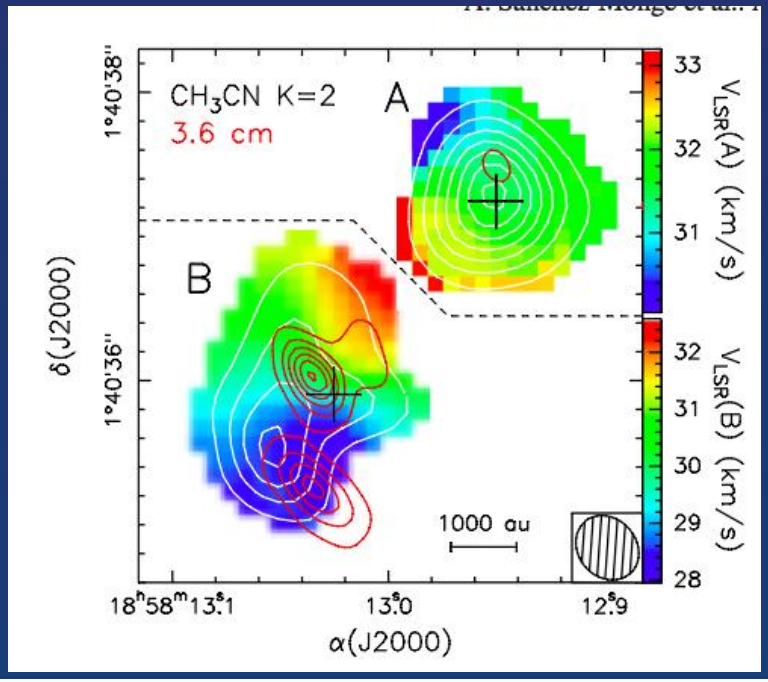


Circumbinary Keplerian Disk Candidate: G35.20-0.74N (MSF)

Sanchez-Monge et al. (2013)







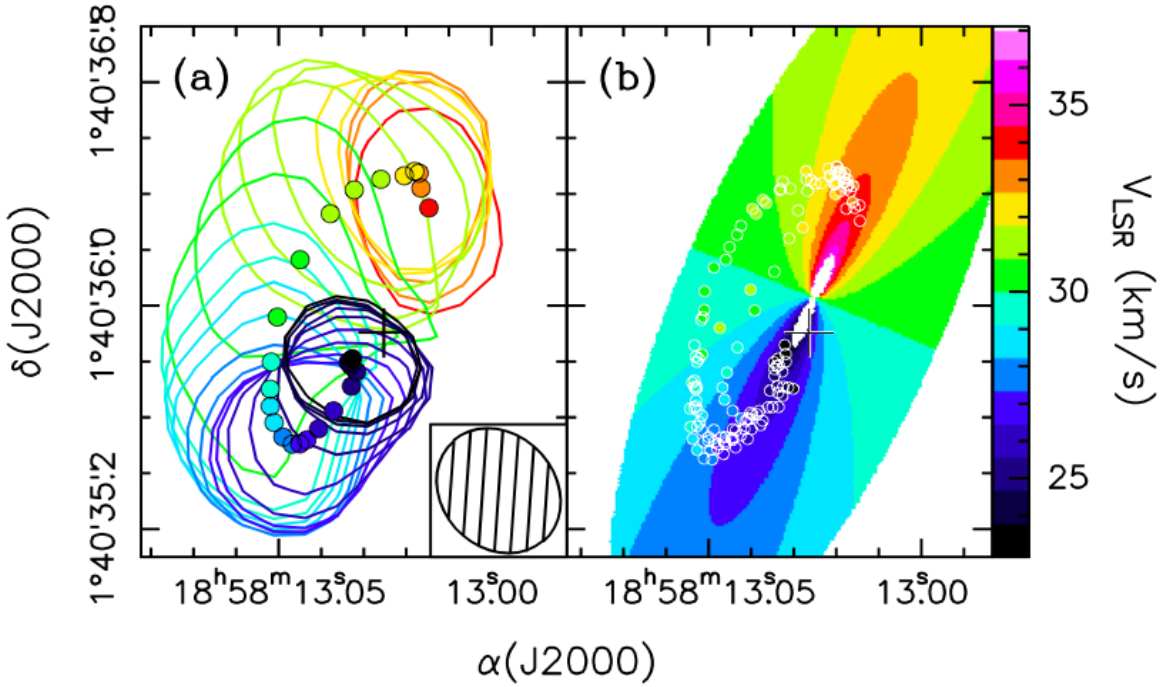
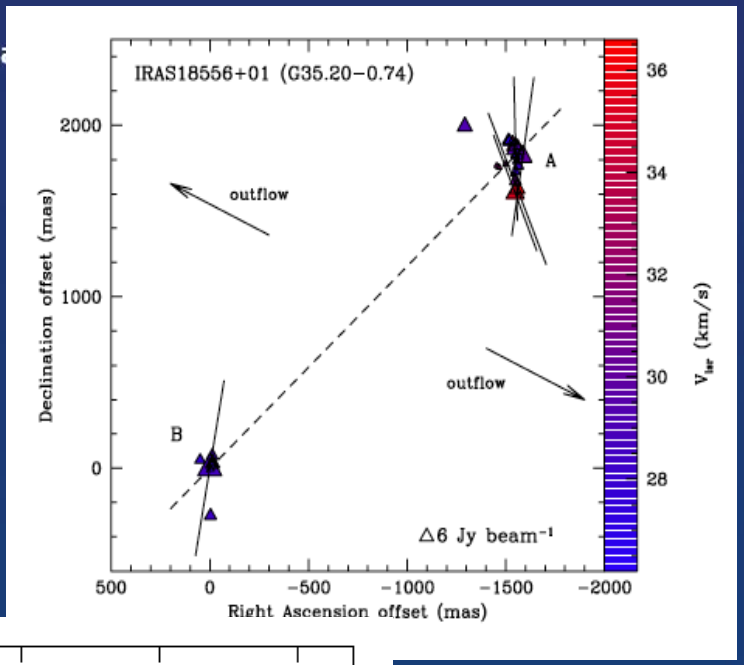


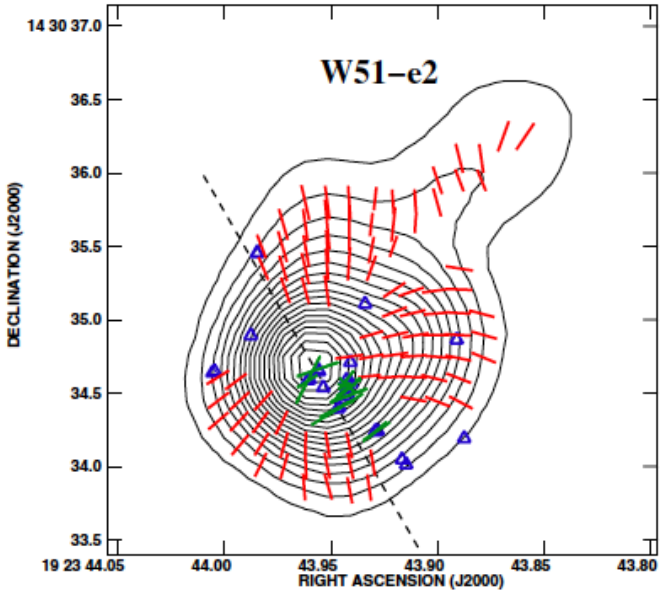
Fig. 4. **a)** Peaks of the $CH_3CN(19–18)$ $K = 2$ line emission (solid circles) obtained with a 2D Gaussian fit channel by channel. For each peak the corresponding 50% contour level is also drawn (using the same color as the peak). The color corresponds to the line-of-sight velocity, according to the scale displayed to the right. The ellipse in the bottom right denotes the synthesized beam. **b)** Comparison between the velocity of the best-fit Keplerian disk (color map) and the emission peaks at different velocities (solid circles) obtained for the following lines: $CH_3CN(19–18)$ $K = 2, 3, 4$, $CH_3OH(7_{1,6}–6_{1,5})$ $v_t = 1$, $CH_3OH(14_{1,13}–14_{0,14})$, and $HC_3N(37–36)$. The crosses mark the position of the continuum peak.

Polarization in MSF

6.7 GHz CH3OH maser (EVN) & 870 μm continuum (SMA)

Cycle 2で可能です。





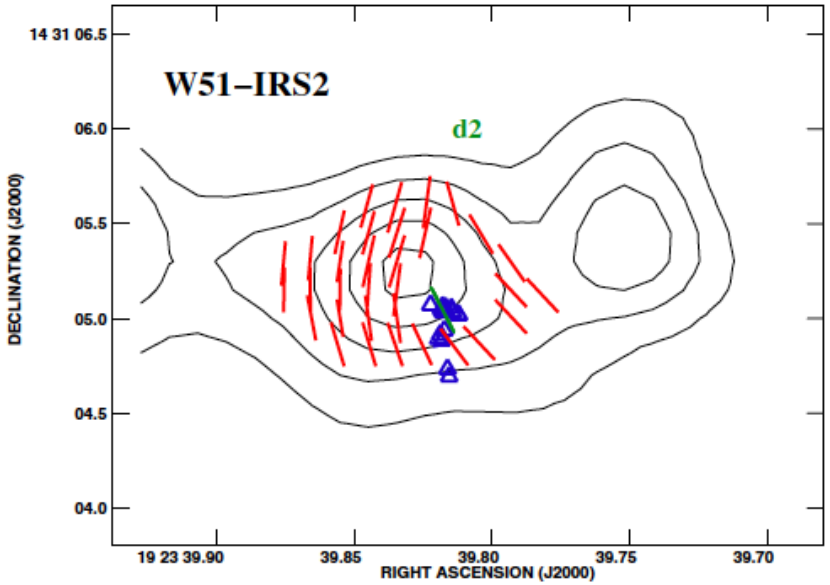
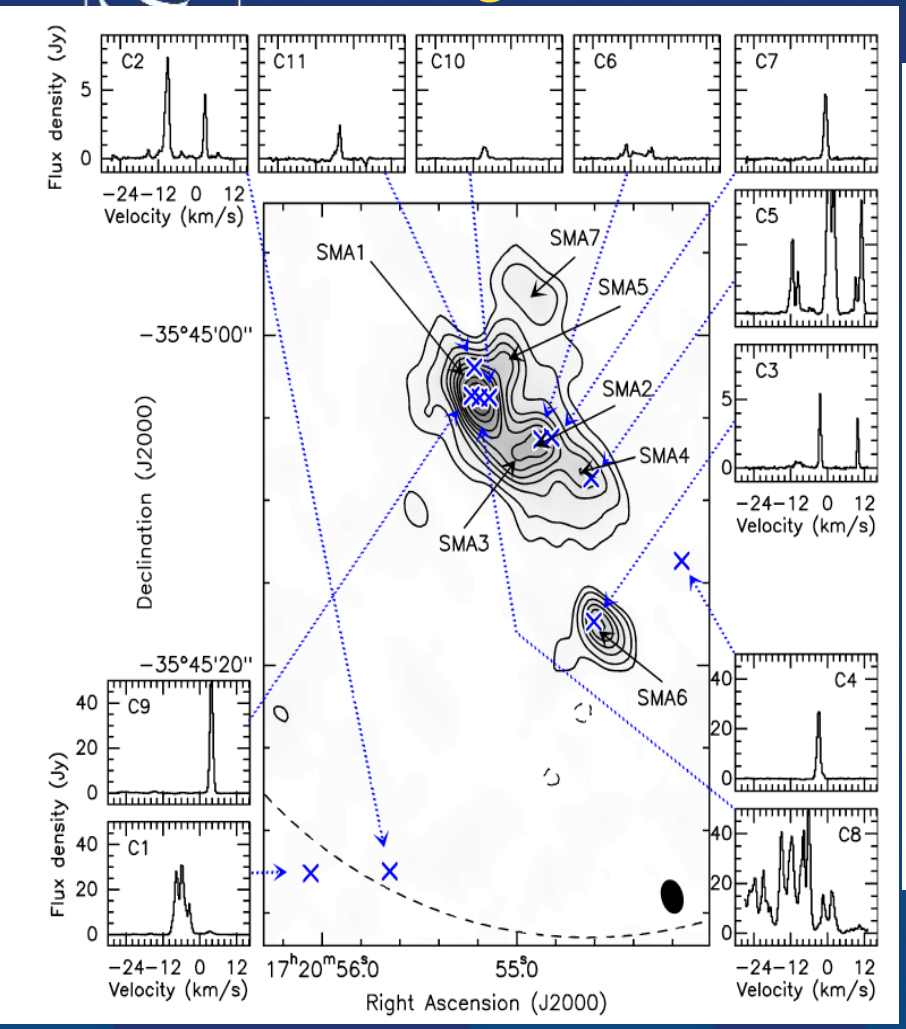


Fig. 10. *Left*: modified version of Fig. 5a of Tang et al. (2009). The magnetic field (red segments) detected with the SMA (angular resolution 0.″7 that at 5.4 kpc corresponds to ~4000 AU) is superimposed on the 870 μm continuum contour map of W51–e2. The dashed black line indicates the direction of the ionized accreting flow by Keto & Klaassen (2008). *Right*: the magnetic field (red segments) detected with the SMA is superimposed on the 870 μm continuum contour map of W51–e2 (Tang et al., priv. comm.). In both images the green segments, which are scaled logarithmically according to polarization fraction P_1, mark the direction of the magnetic fields as derived from the linearly polarized emission of the CH_3OH masers (blue triangles; angular resolution 0.″001 corresponding to ~5 AU).

Exciting Source Confirmation



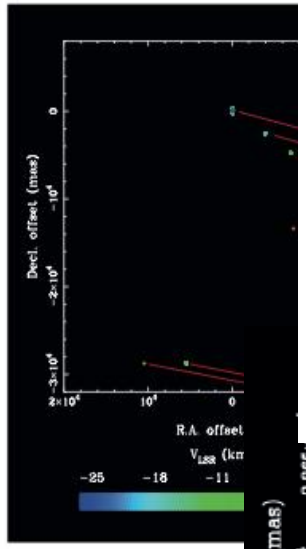
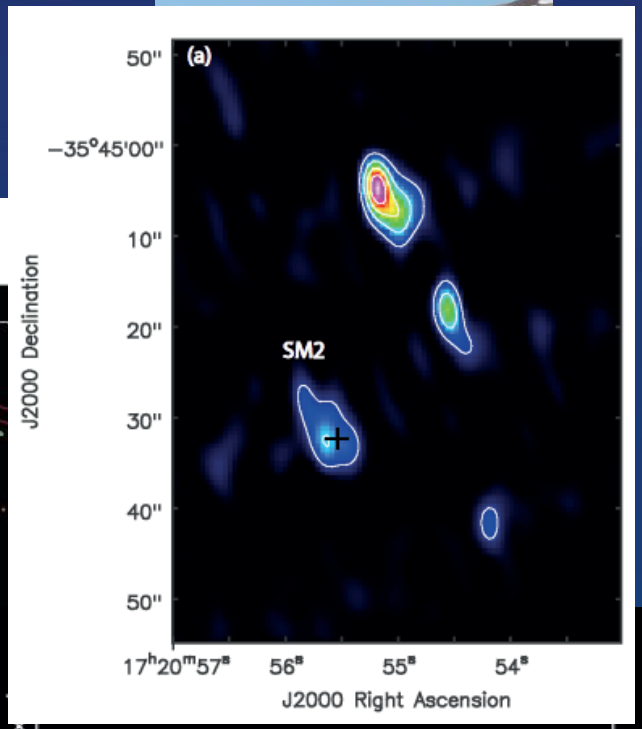
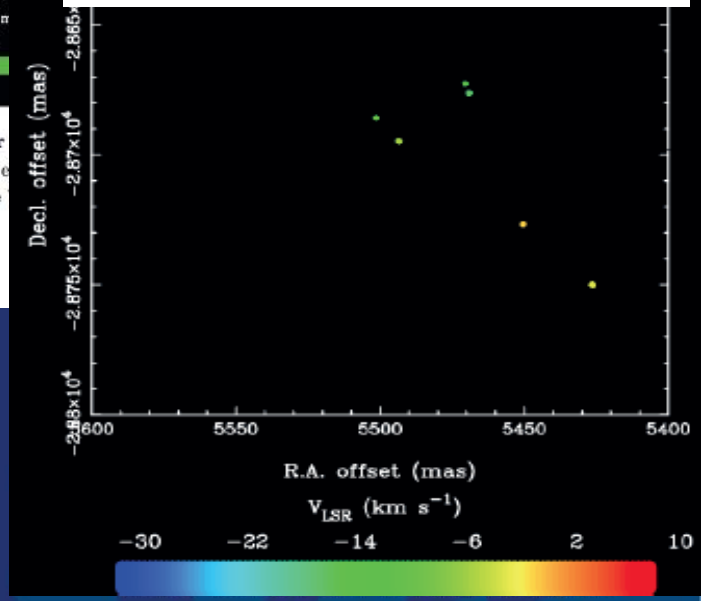


Figure 4.7: H_2O maser
maser map of our R10137
clusters obtained with the





Nature of sources in a region

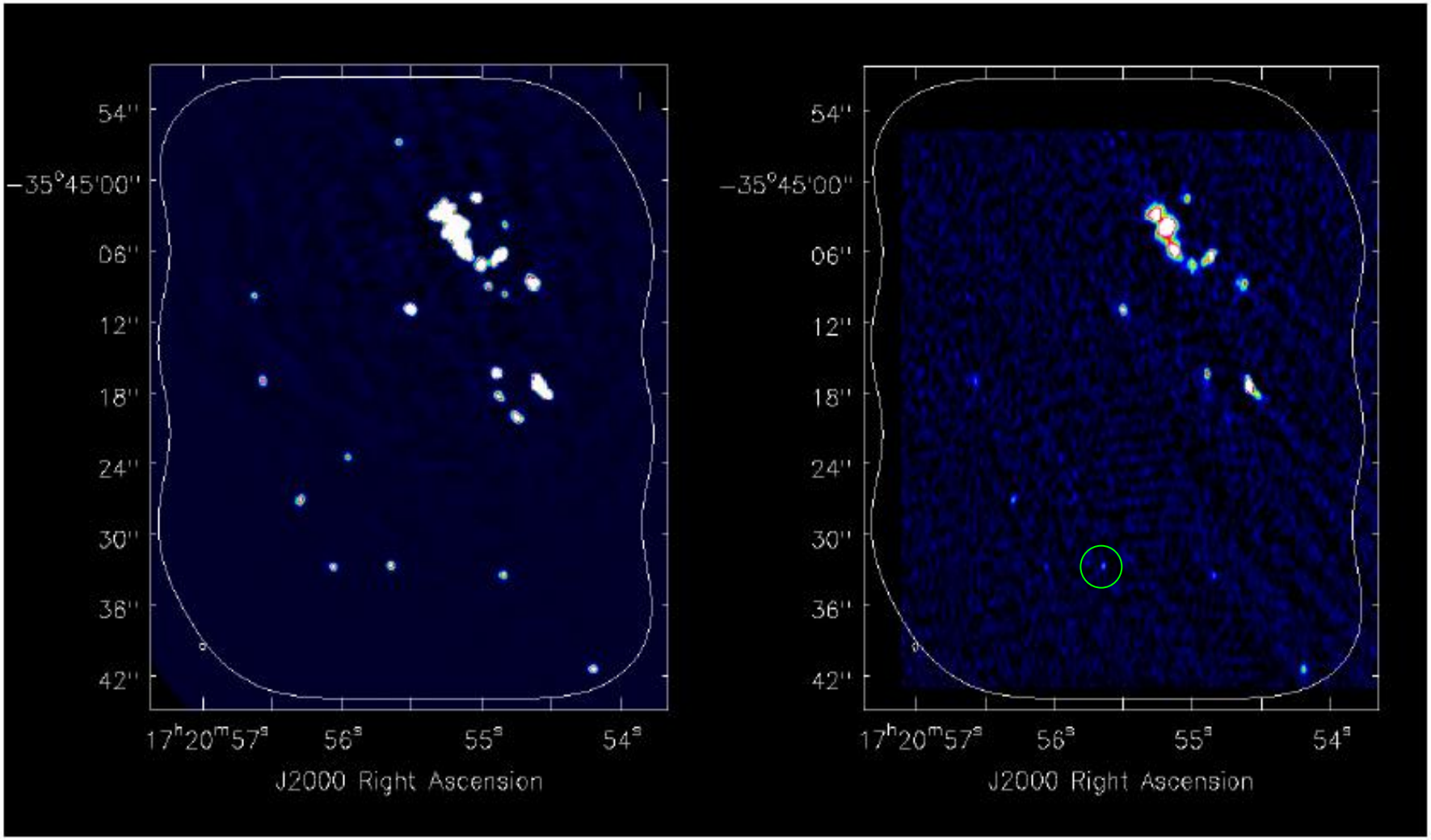
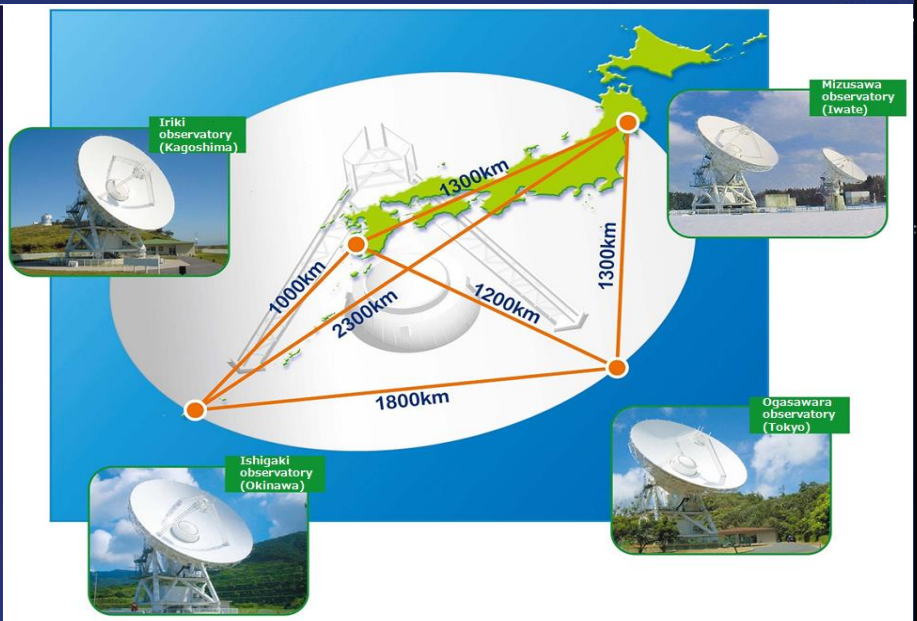
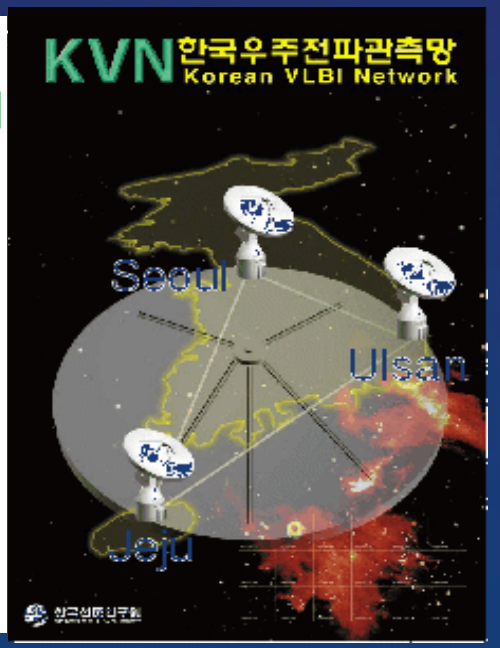


Figure 2: *SMA 218 GHz clean image (right panel) of NGC 6634I(N) and the simulated clean image (left panel) of the ALMA 345 GHz (band 7) based of the SMA clean image.*

ALMA
ATACAMA LARGE MILLIMETER ARRAY





Looking forward to MANY cycle 2 proposal from the Japan/Korea VLBI community!!!

The Atacama Large Millimeter/submillimeter Array (ALMA), an international astronomy facility, is a partnership of Europe, North America and East Asia in cooperation with the Republic of Chile. ALMA is funded in Europe by the European Organization for Astronomical Research in the Southern Hemisphere (ESO), in North America by the U.S. National Science Foundation (NSF) in cooperation with the National Research Council of Canada (NRC) and the National Science Council of Taiwan (NSC) and in East Asia by the National Institutes of Natural Sciences (NINS) of Japan in cooperation with the Academia Sinica (AS) in Taiwan. ALMA construction and operations are led on behalf of Europe by ESO, on behalf of North America by the National Radio Astronomy Observatory (NRAO), which is managed by Associated Universities, Inc. (AUI) and on behalf of East Asia by the National Astronomical Observatory of Japan (NAOJ). The Joint ALMA Observatory (JAO) provides the unified leadership and management of the construction, commissioning and operation of ALMA.