ALMA Reveals Sequential High-mass Star Formation in the G9.62+0.19 Complex (ApJ, 849, 25)

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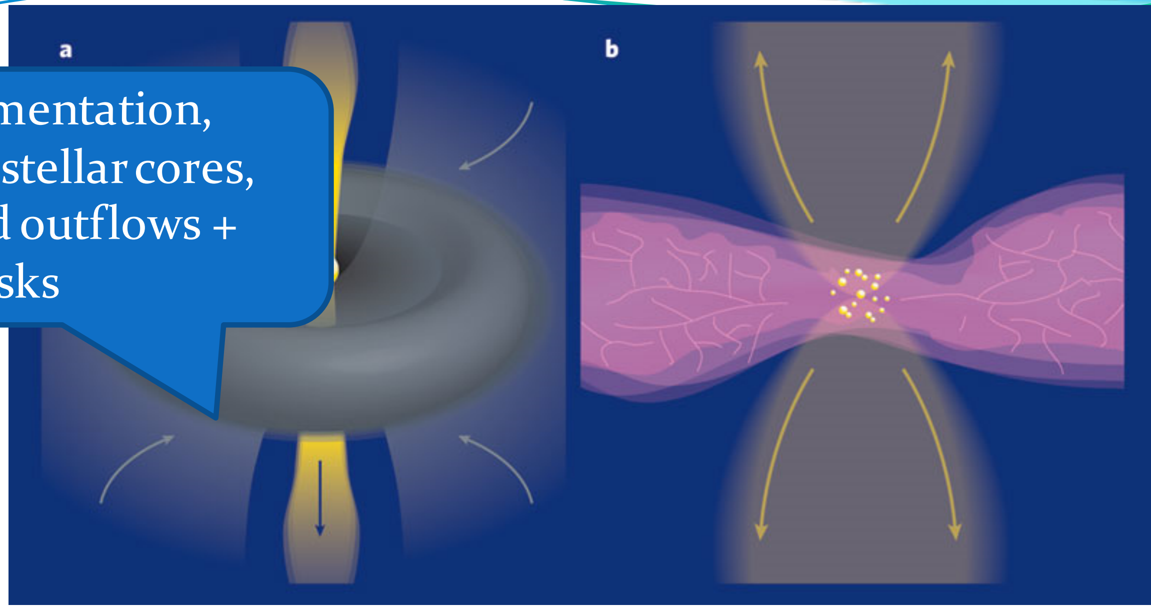
Outline:

- i). Introduction (also see the summary by Hirota-san)
- ii). ALMA Reveals Sequential High-Mass Star Formation in the G9.62+0.19 Complex
- iii). Summary

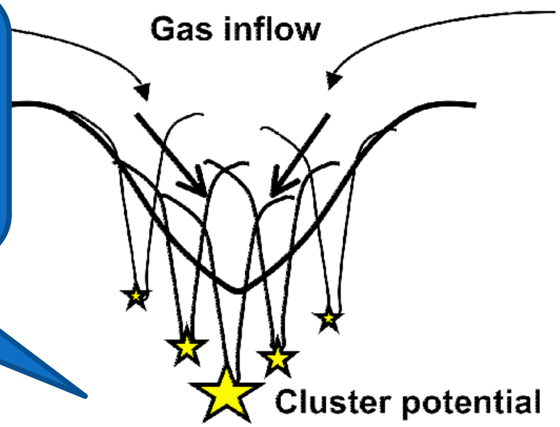
Mechanisms of forming high-mass stars

Low fragmentation,
Massive prestellar cores,
Collimated outflows +
disks

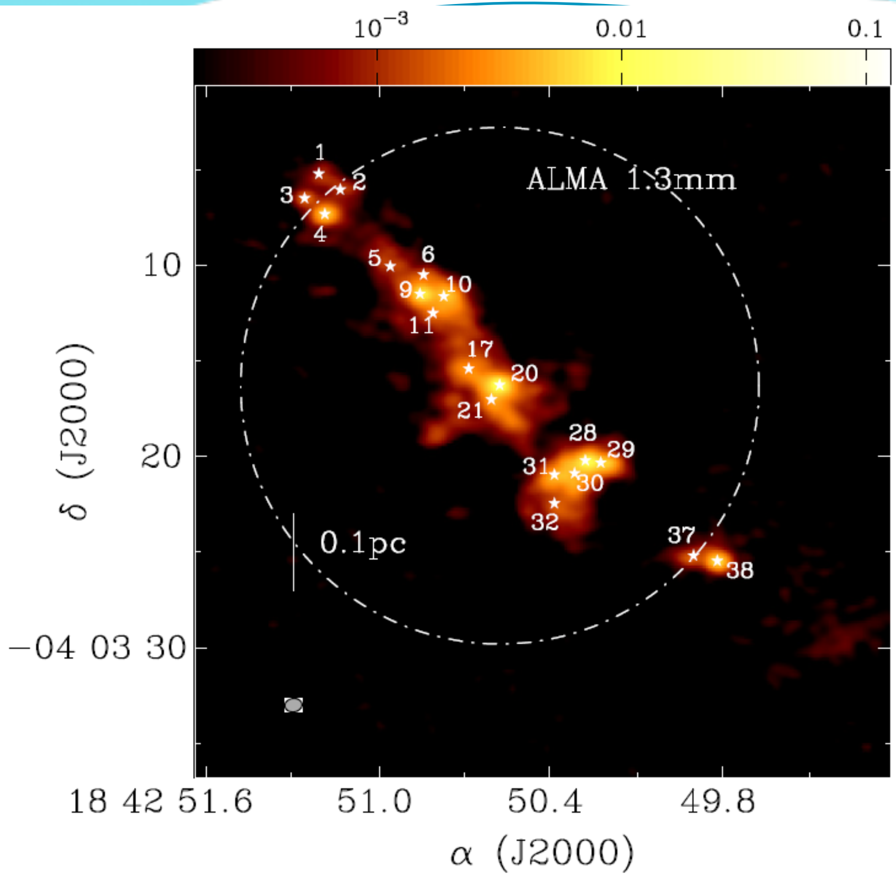


a. Accretion-disk-outflow (McKee & Tan 2002); b. stellar collisions and mergers; Whitney (2005)

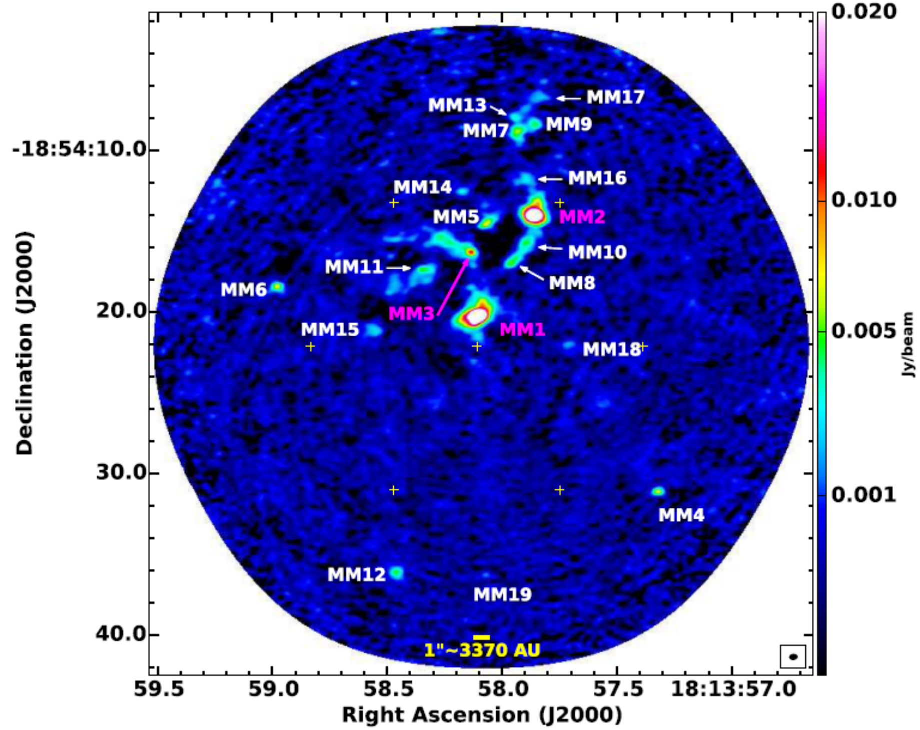
High fragmentation
Jean-mass prestellar cores
Disks?
Global collapsing clumps



c. Competitive accretion. Bonnell et al. (2007)



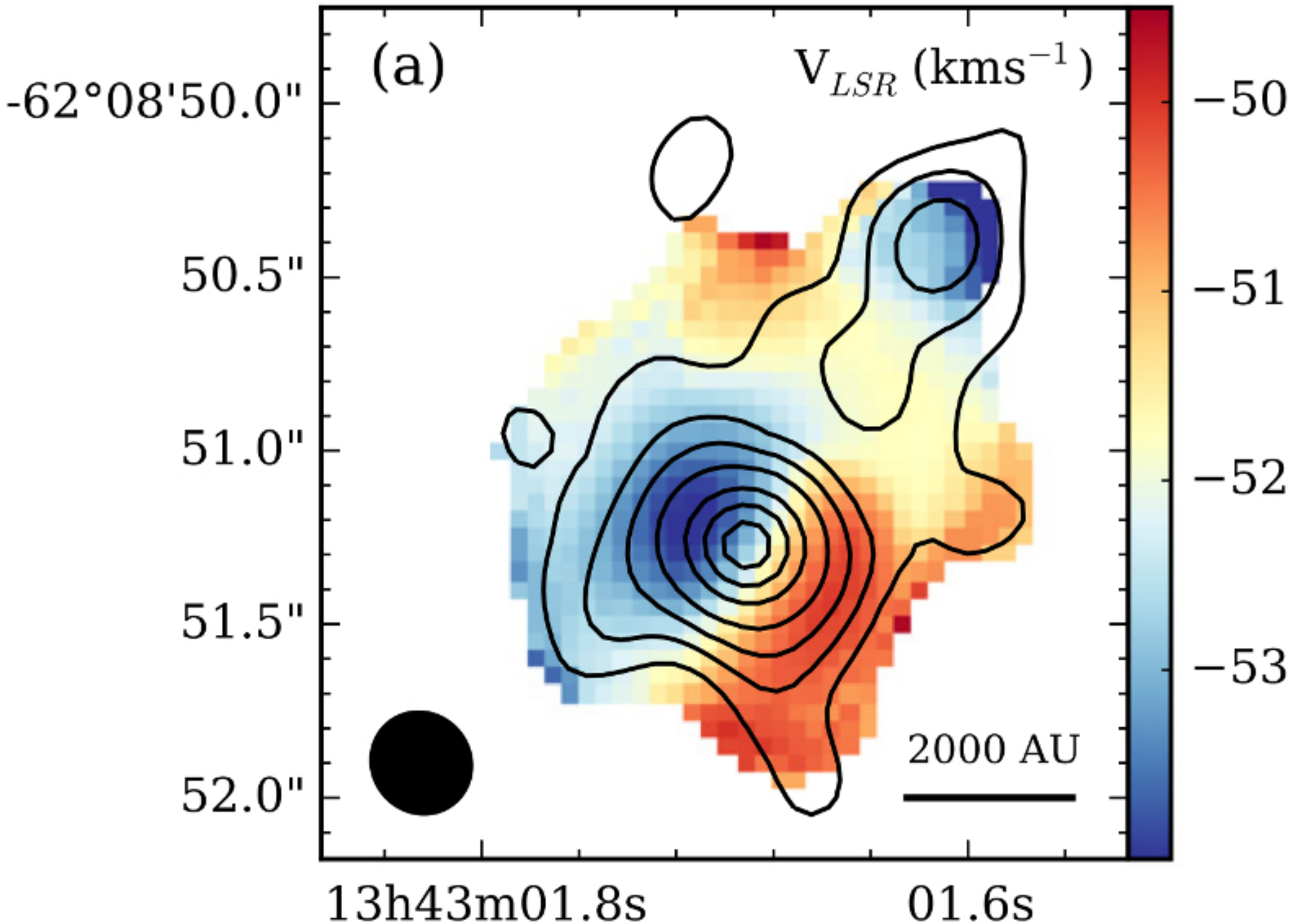
G28.34 P1 (Zhang+2015)



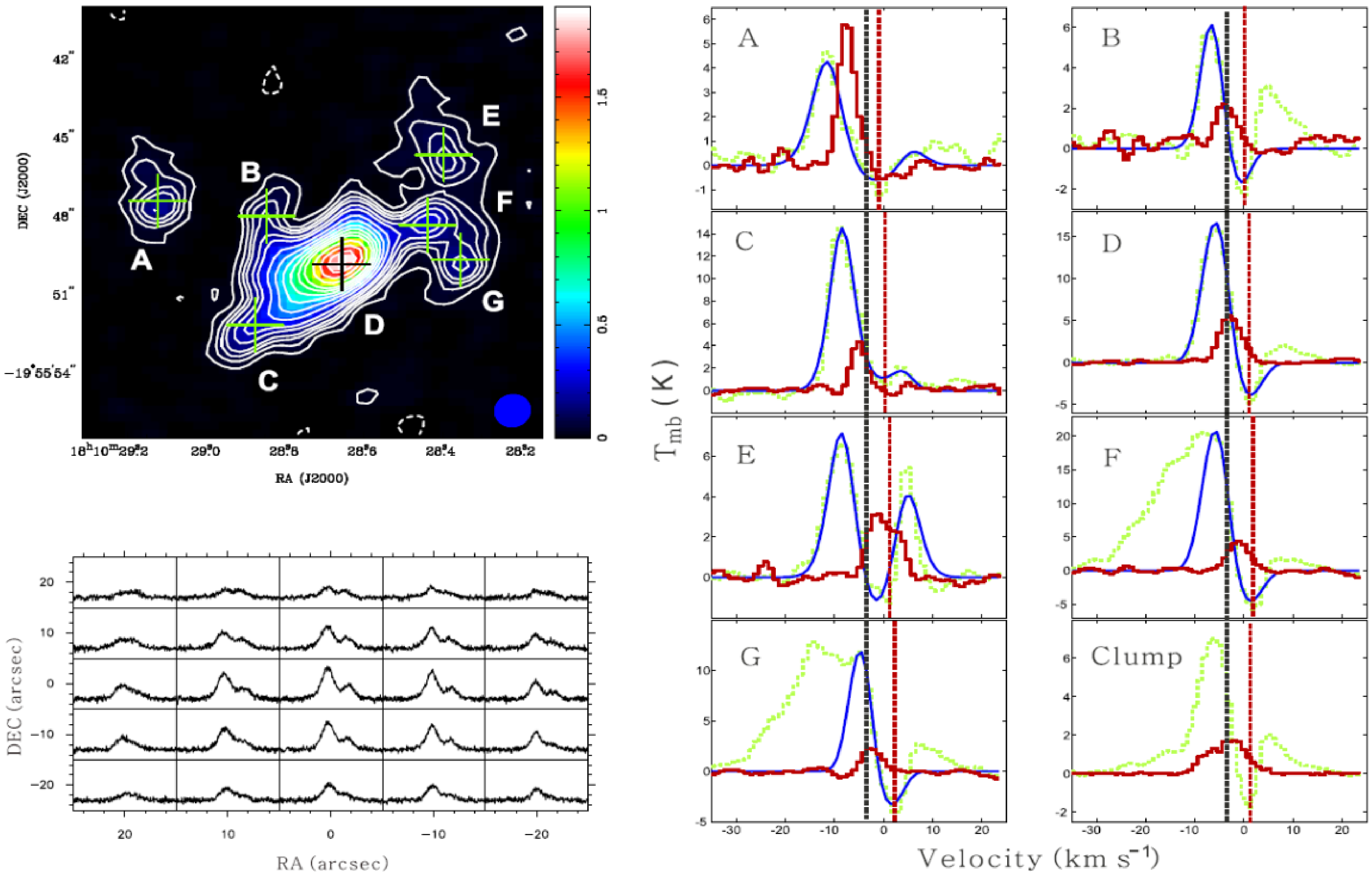
G11.92-0.61 (Cyganowski)

Simultaneous low- and high-mass star formation?

A Keplerian rotation of a disk around an O-type star (Johnston et al. 2015)?



Is global collapse common in cluster formation?



Liu et al. (2013, MNRAS,436, 1335)

How to form high-mass stars in proto-clusters? 2017.1.00545.S

ABSTRACT

Although high-mass stars (M >8 Msun) play a major role in the evolution of galaxies, their formation and evolution are still very unclear. The two particularly promising models of high-mass star formation are "turbulent core accretion" and "competitive accretion" (see reviews in Krumholz & Bonnell 2009; Tan et al. 2014). In order to distinguish from different models for high-mass star formation, we propose to use ALMA 12-m array to mosaic 11 protoclusters. We aim to: (1). Study the spatial distributions of individual cores and their mass assembly in the protoclusters; (2). Study infall motions of individual cores with inverse P-Cygni profiles in HCN (4-3) and HCO+ (4-3) lines (3). Reveal the population of low-mass protostellar cores to see whether low-mass stars form along with their high-mass counterparts.

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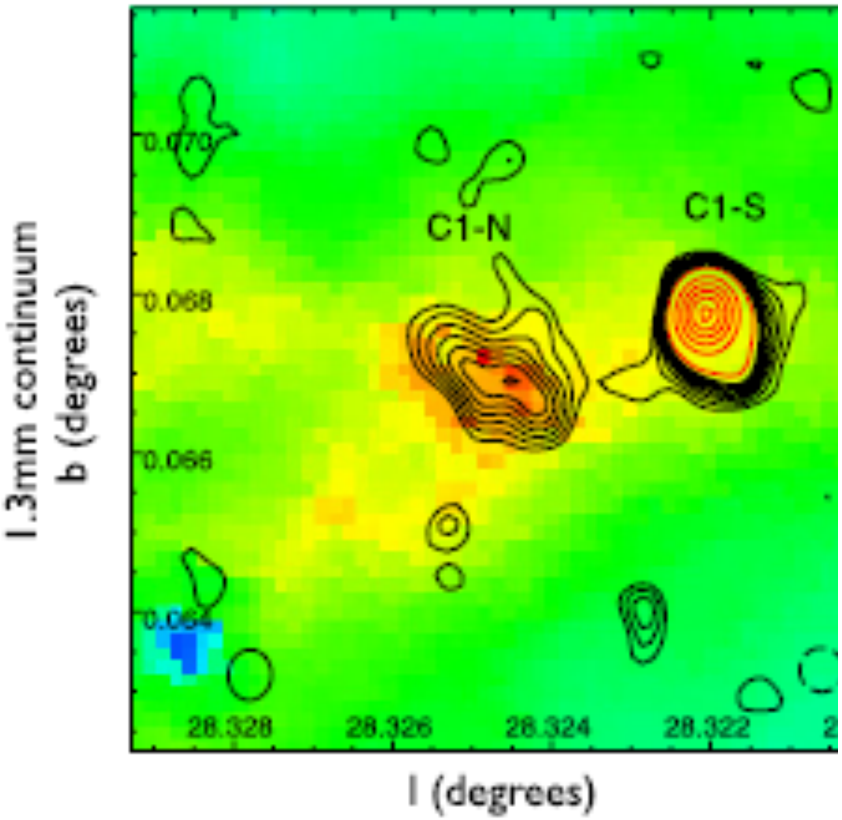
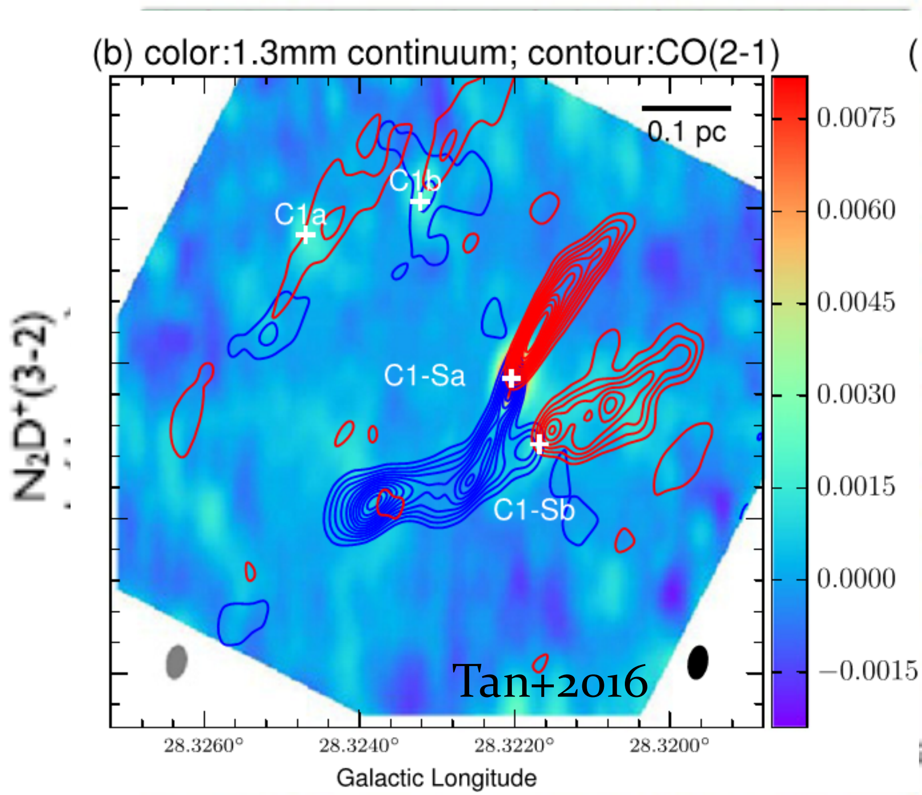
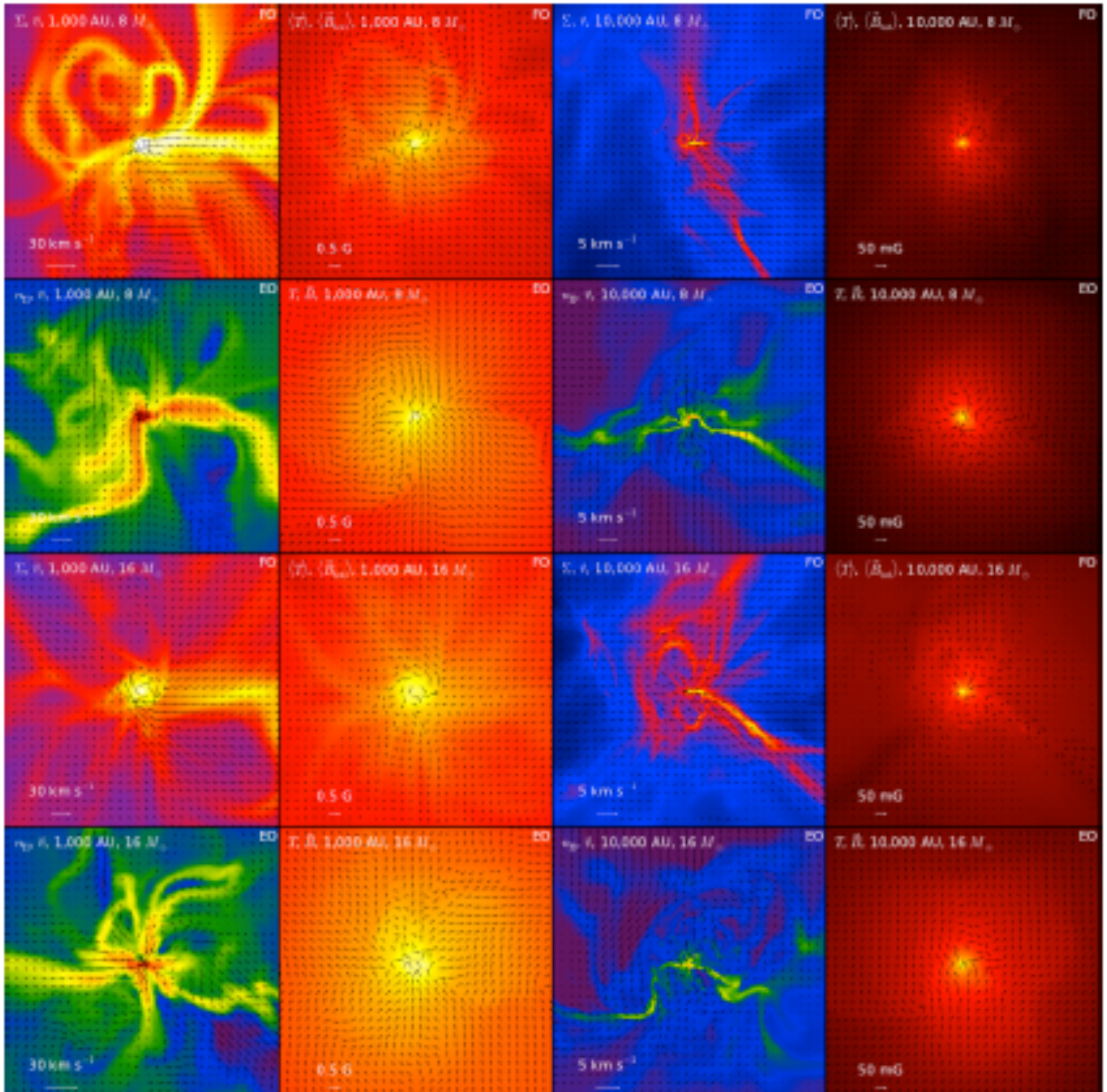
ESTIMATED 12M TIME:	**8.0 h**	**ESTIMATED ACA TIME:**	**0.0 h**	**ESTIMATED NON-STANDARD MODE TIME (12-M):**	**0.0 h**

Searching for MASSIVE STARLESS CORES with ALMA



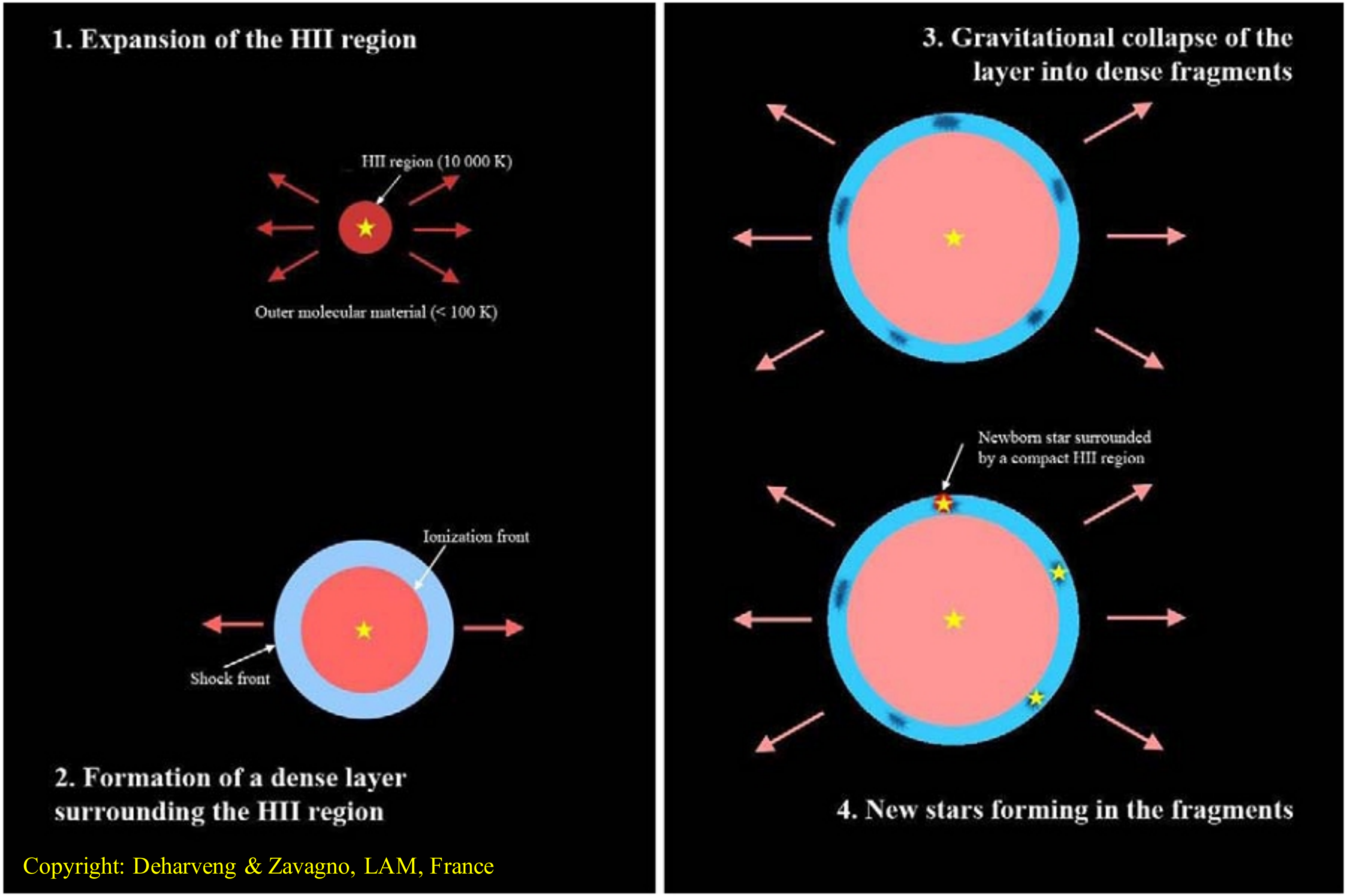


C1-S (Tan+2013):
M~60 Msun
R~0.08 pc



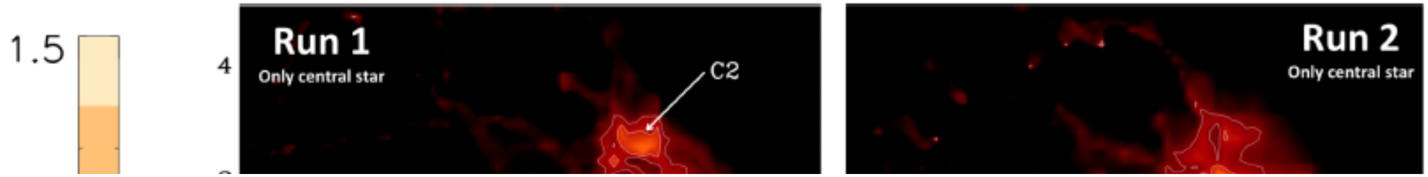
(Myers 2013)

combined magnetic fields and radiation to show that the two together suppress fragmentation much more effectively than either one alone.

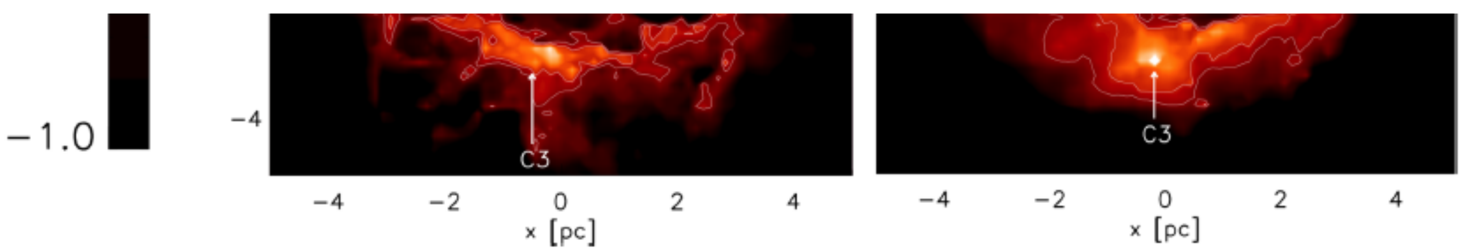


Collect and Collapse model（Elmegreen & Lada, C. J. 1977; Whitworth 1994a,b）

14%-30% high-mass star formation in the Galaxy were triggered (Thompson et al. 2012)?



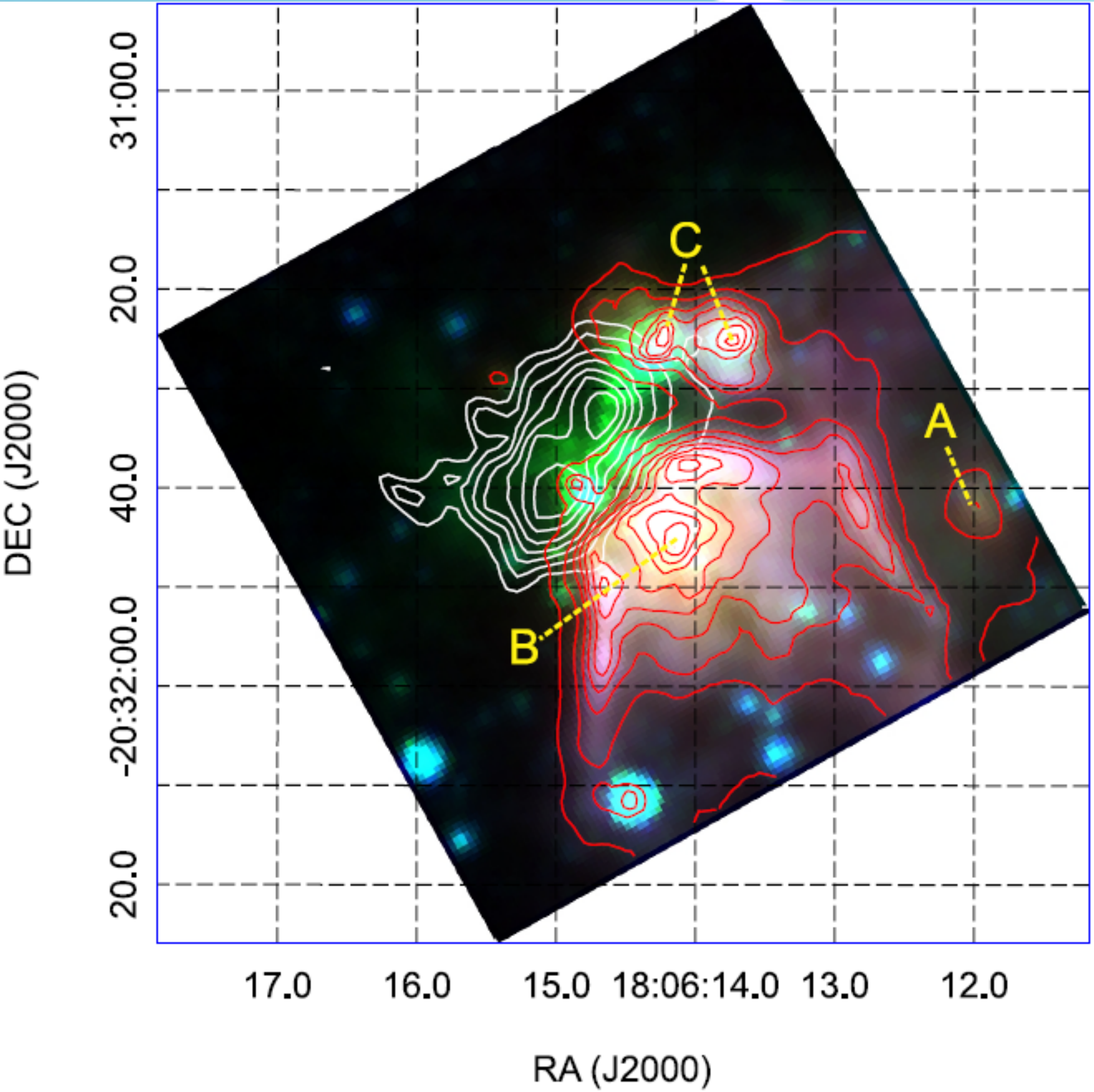
The distribution of clumps similar to the one seen in RCW 120 can readily be explained by a non-uniform initial molecular cloud structure. Hence, a shell-like configuration of massive clumps does not imply that the Collect and Collapse (C&C) mechanism is at work. Rather, a hybrid form of triggering, which combines elements of C&C and radiation driven implosion (RDI). (Walch+2015)



Open Questions for high-mass star formation studies (see also Hirato-san's talk)

- 1. Simultaneous low-mass and high-mass star formation in proto-clusters
- 2. Do massive disks exist?
- 3. Is global collapse dominate the dynamical evolution of proto-clusters?
- 4. Do high-mass starless cores exist?
- 5. What are the roles of stellar feedback and magnetic fields in high-mass star formation?
- 6. Is triggered high-mass star formation possible?

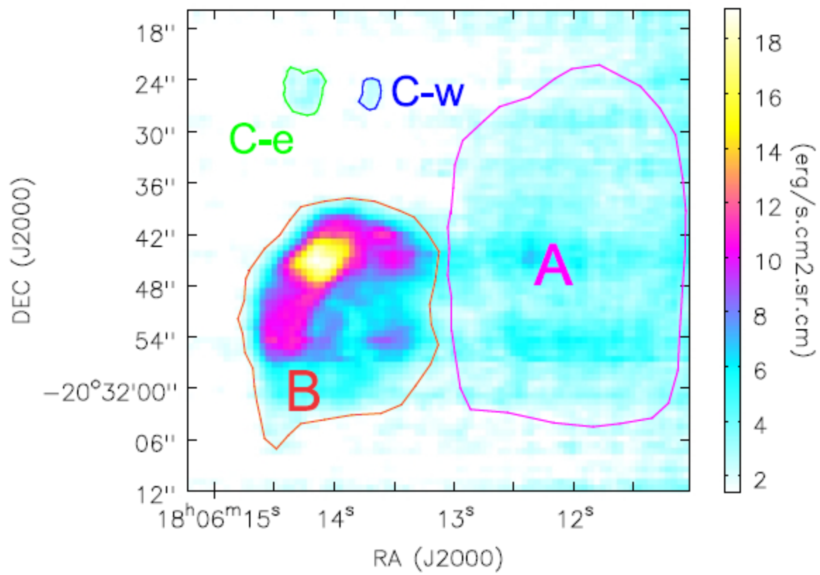
2. ALMA Reveals Sequential High-Mass Star Formation in the G9.62+0.19 Complex



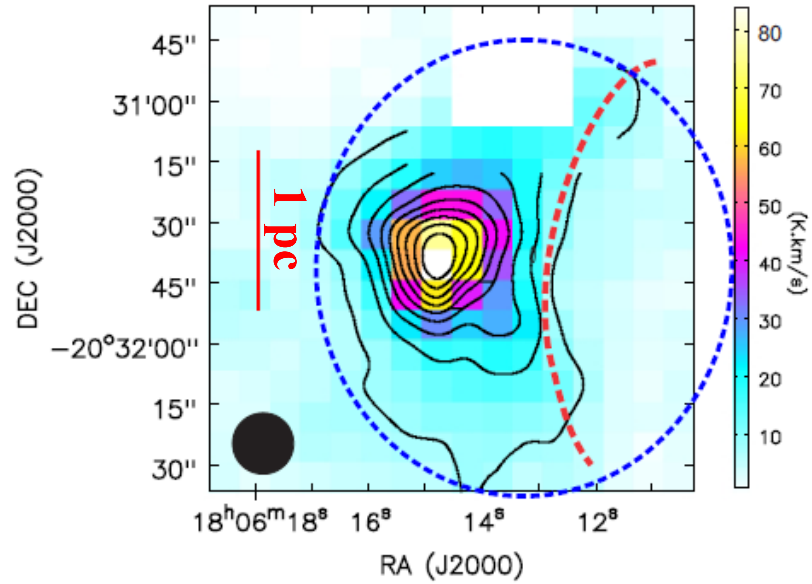
White: 450 micron
Red: 8 micron PAH
Green: 4.5 micron
Blue: 3.6 micron

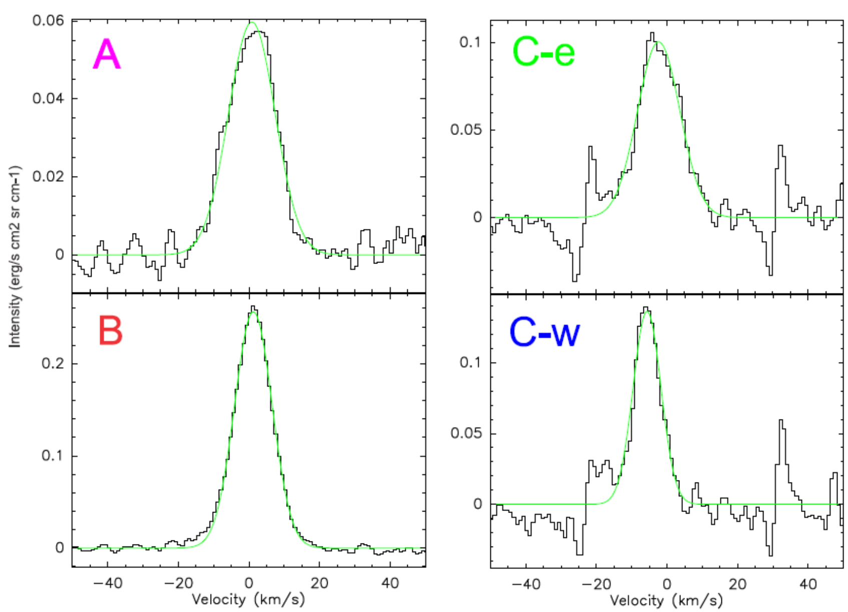
d=5.2 kpc
Mclump~2800 Msun
n~1E5 cm-3
Mvir~1200 Msun
Pmol/k~6E7 K cm-3
Pi/k~4E7 K cm-3

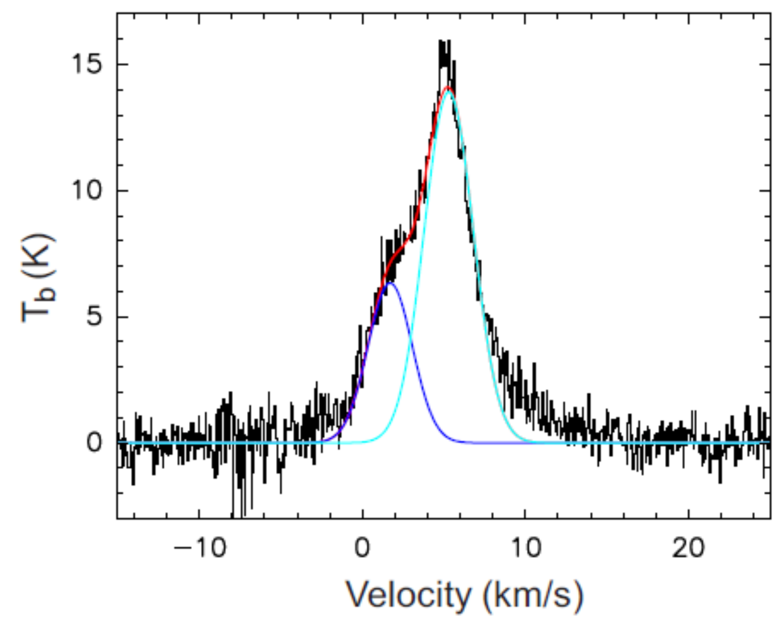
[Ne II] 12.8 micron



C18O (3-2)

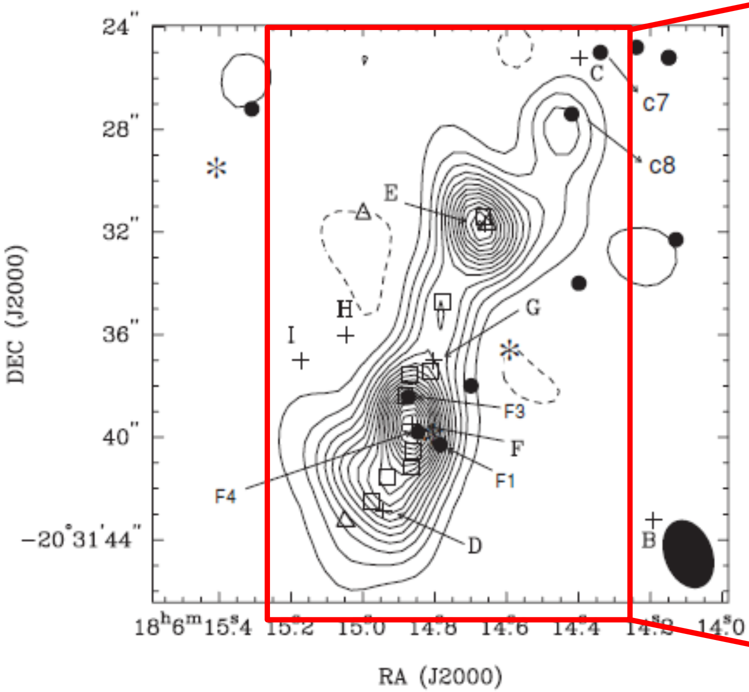






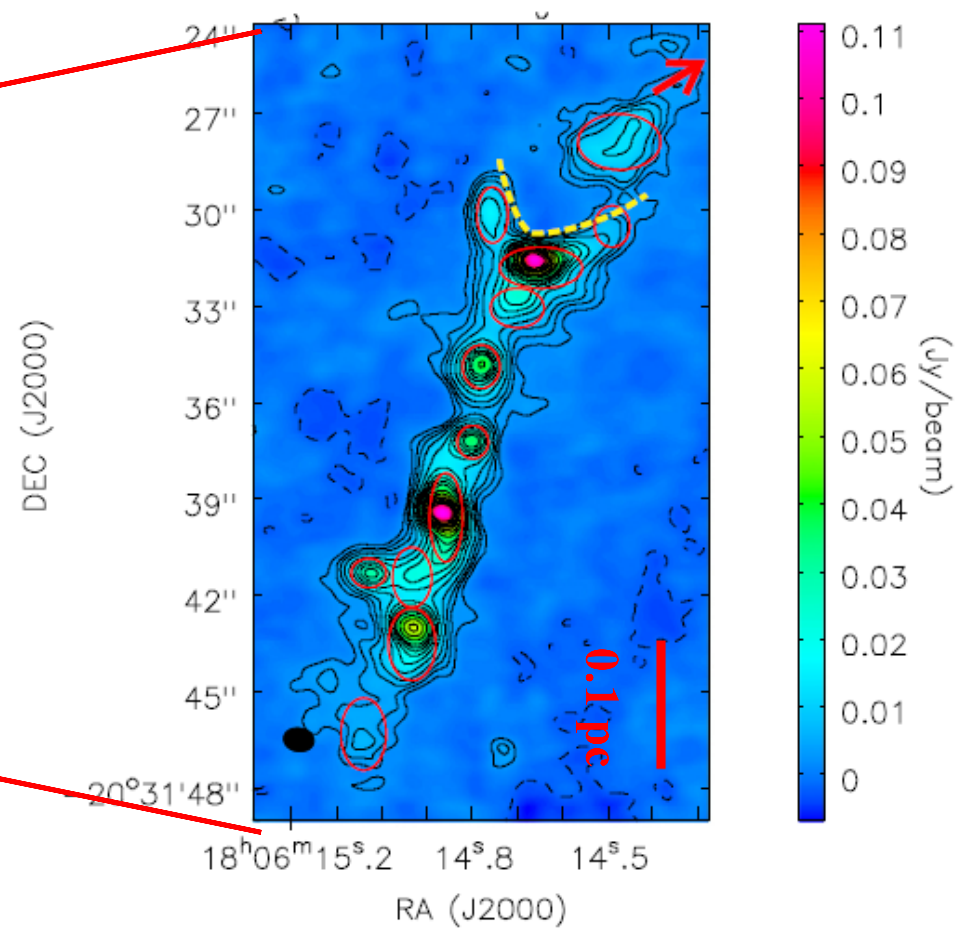
shop

SMA 860 micron



Liu et al. (2011)

ALMA 1.1 mm



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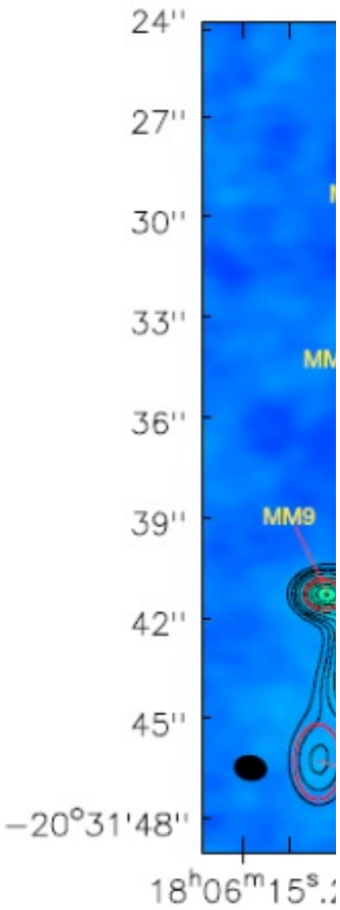


M_{core} (M_{sun})	λ_{core} (pc)
Observed values	
~20	~0.08
Thermal Jeans fragmentation[a]	
6.0±0.1	0.13±0.01
Turbulent fragmentation[b]	
504±20	0.56±0.02
Thermal Cylindrical fragmentation[c]	
6.6±0.5	0.10±0.01
Turbulent Cylindrical fragmentation[d]	
430±30	0.40±0.03

formation:

ions, no outflows

m radio emission

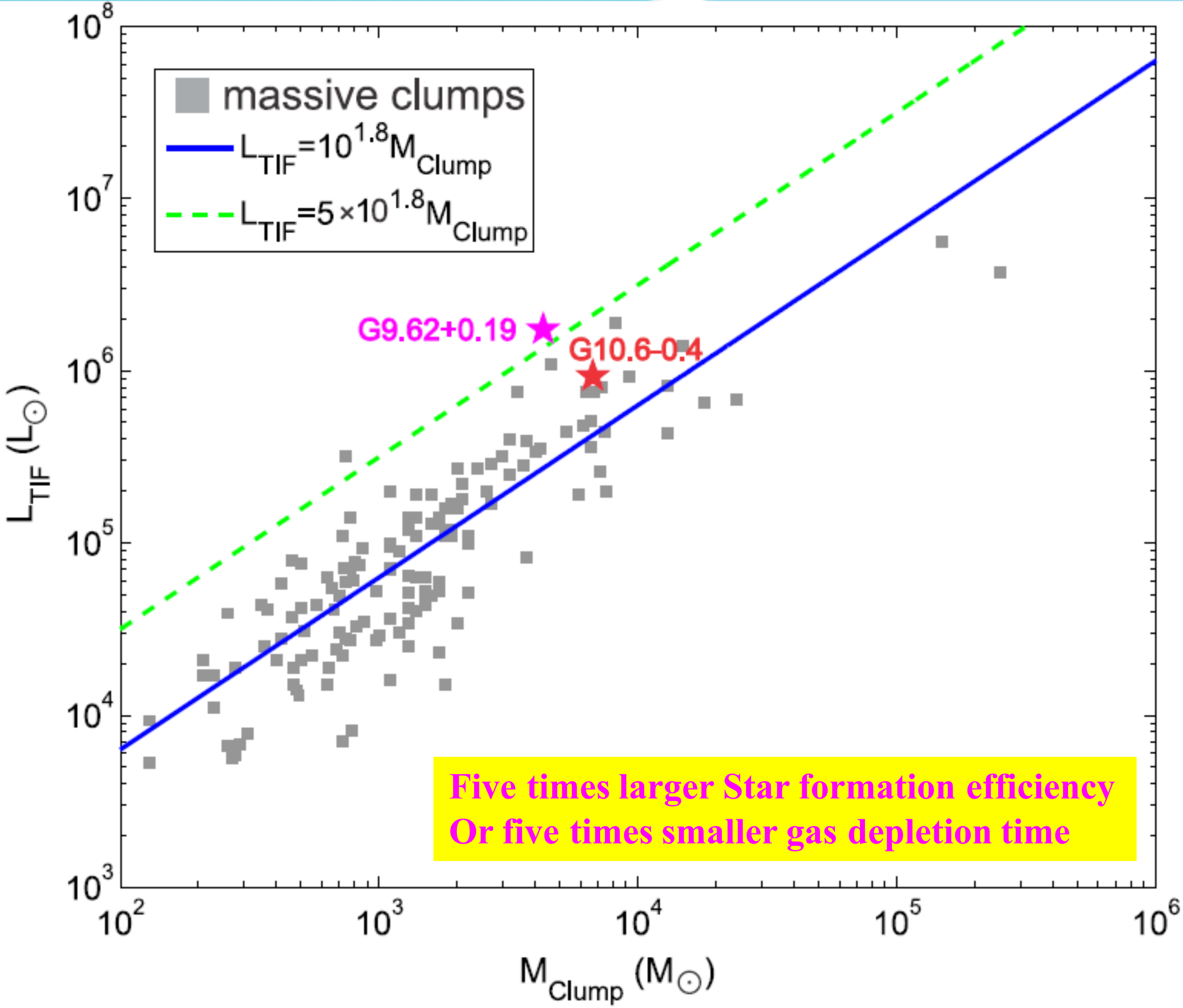
utflows

starless cores
Isun for Td=35 K
Isun for Td=20 K)

Spatia ... **.02 Msun**
Suppr ... **ack?**

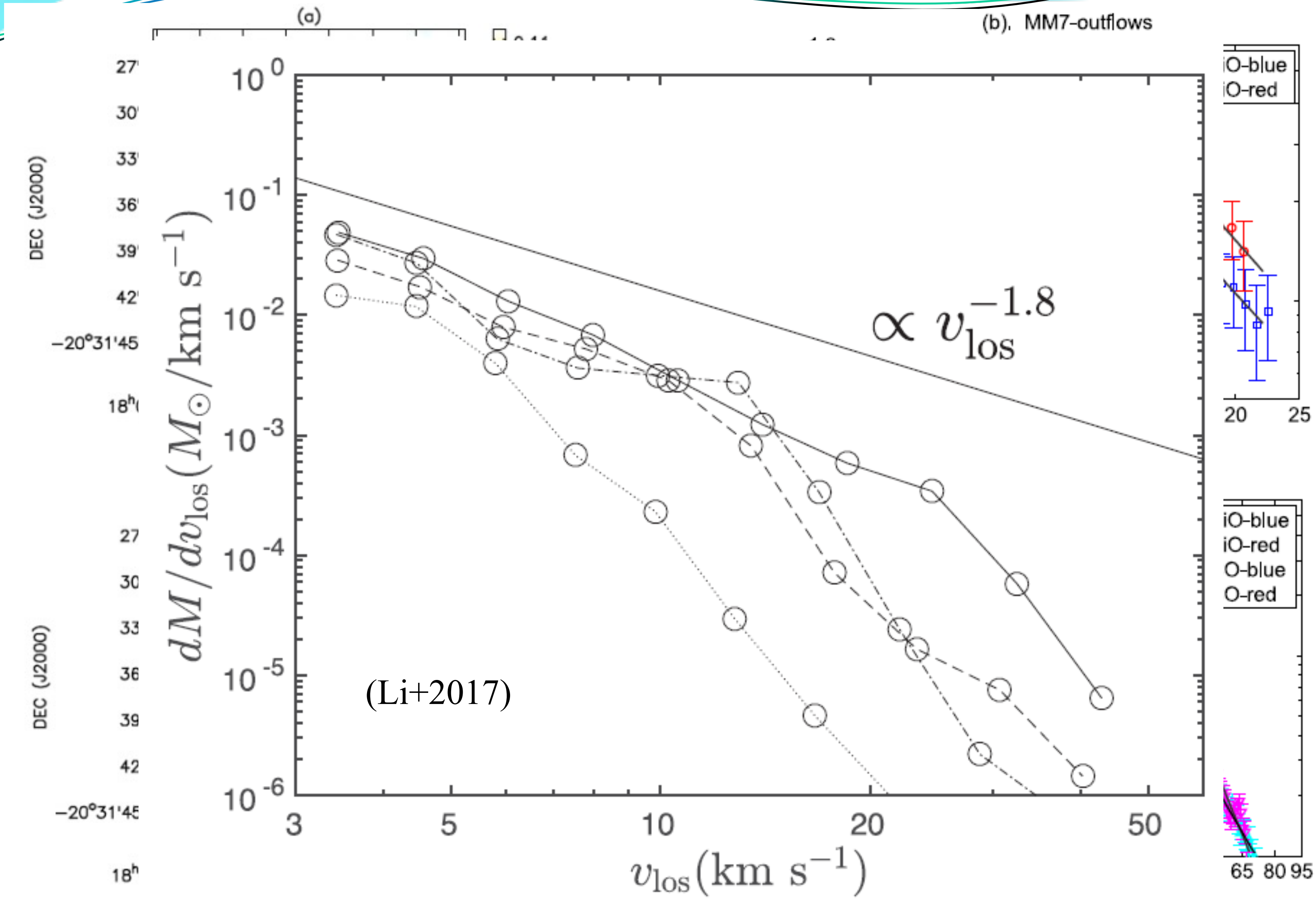
Collect and Collapse process not works (Whitworth+1994a,b)

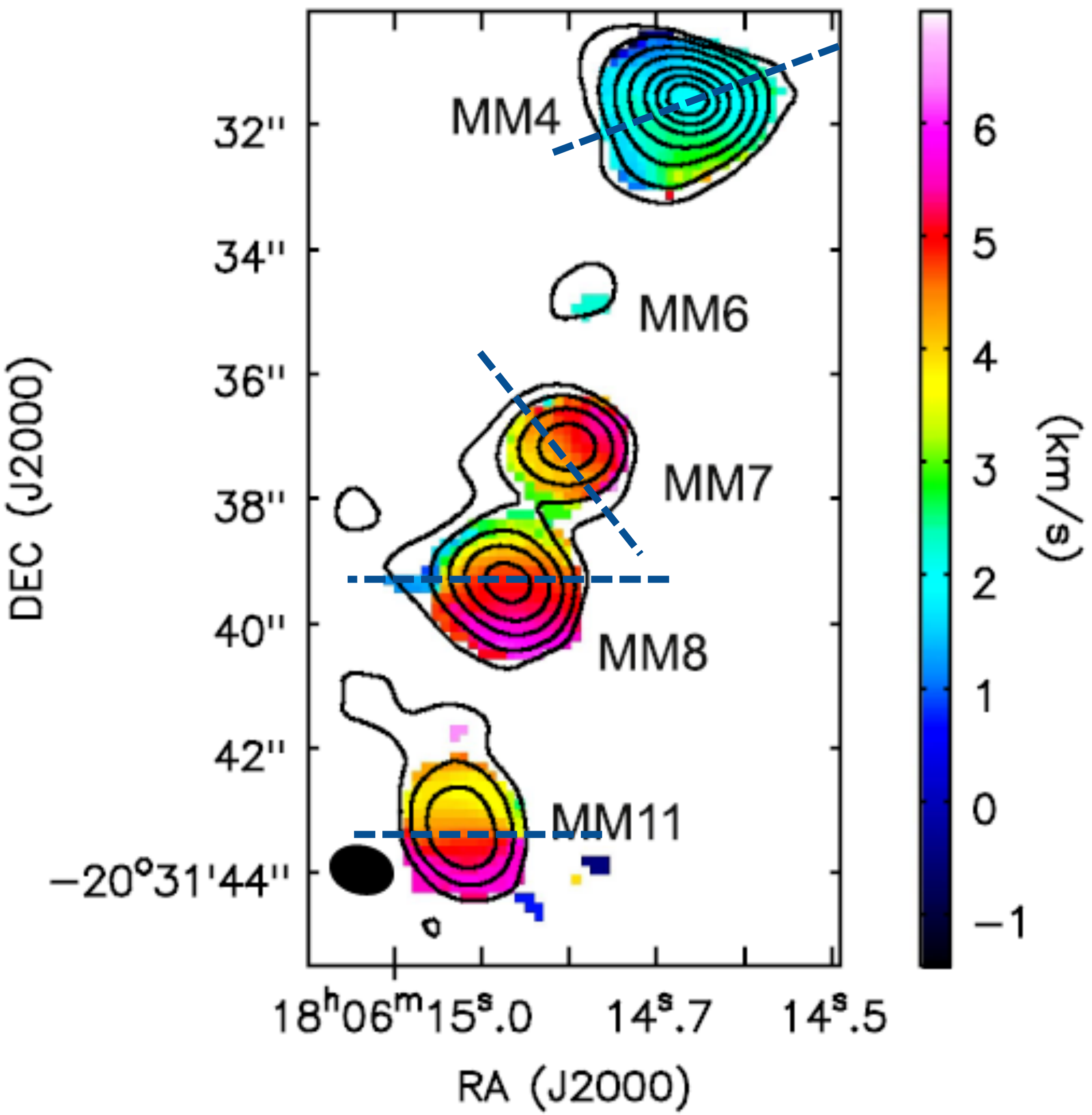
- Time (tfrag): 0.75 Myr (tdyn~3.7E4 yr)
- radius (Rfrag): 1.55 pc (0.1 pc)
- column density through the shell (Nfrag): 1.6E22 cm-2
- mean mass (Mfrag): 25 Msun
- initial separation of the resulting fragments (2rfrag): 0.52 pc (0.1 pc)



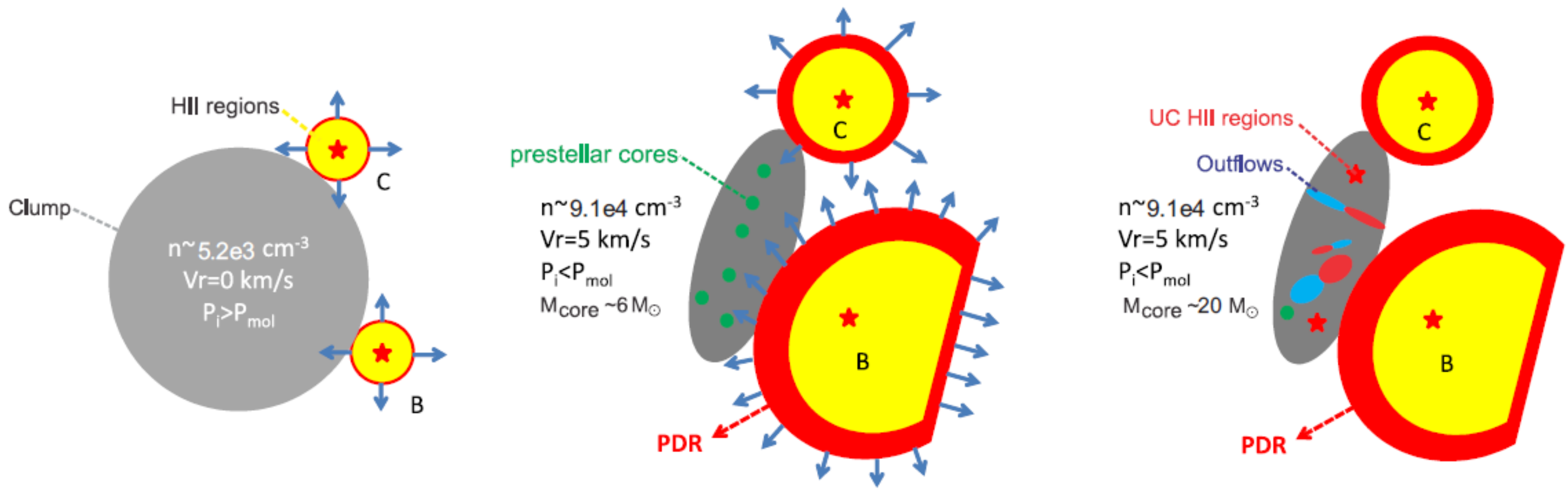
Five times larger Star formation efficiency
Or five times smaller gas depletion time

Molecular Outflows




MM4
MM6
MM7
MM8
MM11
32''
34''
36''
38''
40''
42''
−20°31'44''
DEC (J2000)
18h06m15s.0
14s.7
14s.5
RA (J2000)
6
5
4
3
2
1
0
−1
(km/s)

What we have learned from G9.62+0.19?



(a). Compression phase (b). Fragmentation phase (c). Accretion phase

Our findings suggest that stellar feedback from HII regions and forming massive YSOs may enhance the star formation efficiency and suppress the low-mass star formation in adjacent pre-existing massive clumps.

Summary

- 1. ALMA reveals sequential high-mass star formation in taking place in G9.62+0.19 complex
- 2. Several massive starless core candidates (M~30 Msun with Td=20K) were identified.
- 3. The fragmentation of the massive clump near HII regions is dominated by thermal instability
- 4. SiO and CO outflows were identified toward hot cores or HMPOs; massive disks can be studies only with higher spatial resolution.
- 4. Ideal collect and collapse model does not work. But the massive clump might be compressed by the HII regions.
- 5. stellar feedback from HII regions and forming massive YSOs may enhance the star formation efficiency and suppress the low-mass star formation

Thanks!