A study of the physical relation between embedded clusters and their natal clumps by using the Nobeyama 45m telescope with the 25Beam Array Receiver System (BEARS)

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○ ○ Abstract ○ ○

We have carried out a survey of the dense clumps associated with 11 embedded clusters in the $C^{18}O$(J=1-0) line emission with the Nobeyama 45m telescope in the period from 2005 December to 2006 May. The target sources were selected which is still embedded and well-studied in near infrared observation. In this survey we made typically 6′× 6′ maps around the center of the 11 regions. We have found M_{MAX}-ΔV_{clump} correlation and interpreted as follows: The most massive stars form within individual cores through the dynamical accretion in a similar way to the case of the low-mass star formation.

○ ○ Introduction ○ ○

- Near Infrared Observations (Lada & Lada 2003)
  - Size (0.1-3.8pc)
  - Contained stellar number (36-1740)
  - Mass (20-1100M☉)
  - Highest stellar mass (3-40M☉)

- Radio Observations (Lada 1992)
  - Natal clumps(0.5-1pc) associated with the embedded clusters
    - massive(100-1000M☉)
    - dense($10^{4-5}cm^{-3}$)

What is the relation between clumps and clusters properties??

○ ○ Target selection ○ ○

- Catalogs of the near infrared clusters (Lada and Lada 2003)
  - Well-studied and near-by (< 2kpc) clusters
    → 76 objects objects
- Young phase (1-3Myr) associated with gas
  - From the survey of NH_3, H_2O maser with the 45m telescope (Sunada et al. 2007)
    → Detected NH_3 molecular emission 32/76 objects

Finally, we select the targets with the variety of their properties

11 objects !!

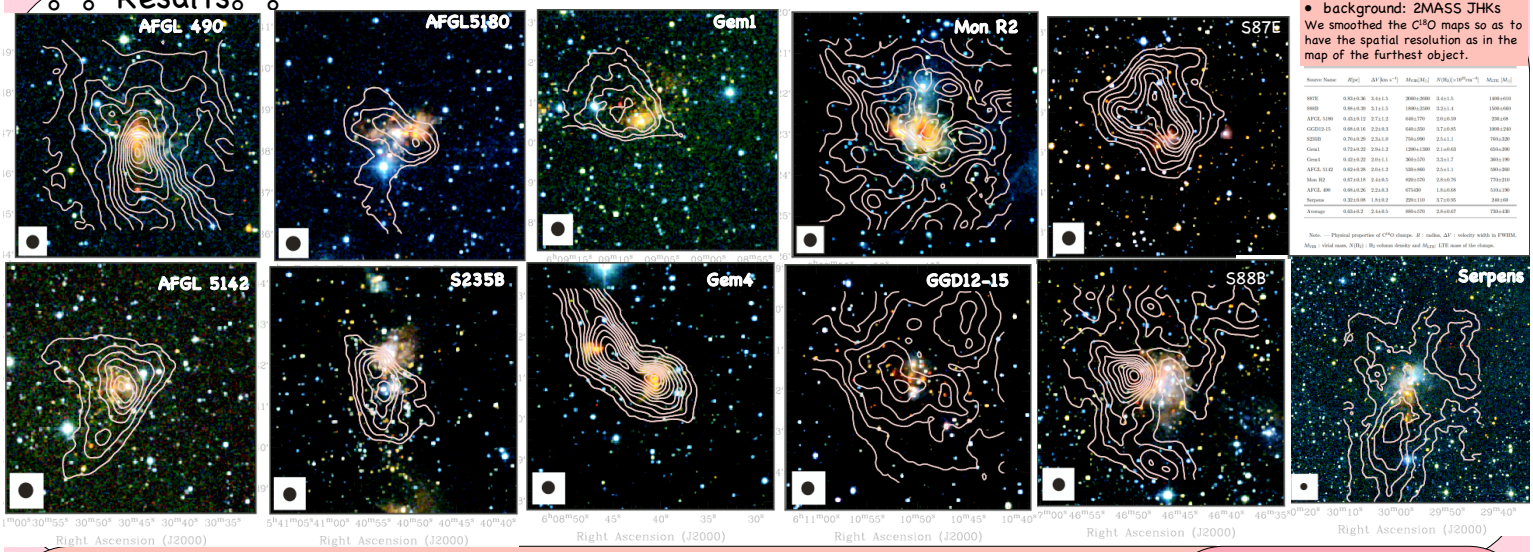
We did systematic surveys of the natal clumps associated with the clusters

○ ○ Observation ○ ○

- Nobeyama 45m telescope
  - OTF mapping using BEARS
    - 2005.12-2006.5
- Line
  - $C^{18}O$(1-0)(109.782182GHz)
  - Critical density 10^4cm^{-3}
  - Beam size 15″
  - Velocity resolution 0.1km/s

← BEARS
Sunada et al. 2000
Yamaguchi et al. 2000

○ ○ Results ○ ○



- pink-contour: $C^{18}O$ clumps
- background: 2MASS JHKs

We smoothed the $C^{18}O$ maps so as to have the spatial resolution as in the map of the furthest object.

Source Name	$R_{[pc]}$	ΔV [km s^{-1}]	M_{vir}[$M_\odot$]	N([$R_\odot$]×10^{20}cm^{-2})	M_{LTE} [$M_\odot$]
SFE	0.83±0.36	3.4±1.5	2000±2000	3.4±1.5	1400±610
S88B	0.98±0.39	3.1±1.1	1900±2500	2.2±1.4	1100±600
AFGL 5180	0.43±0.12	2.7±1.2	640±770	2.0±0.59	230±68
GGD12-15	0.98±0.16	2.2±0.3	640±350	3.7±0.85	1800±240
S235B	0.70±0.29	2.3±1.0	750±990	2.5±1.1	750±320
Gem1	0.72±0.22	2.0±1.2	1100±1300	2.1±0.63	650±200
Gem4	0.42±0.22	2.0±1.1	360±570	3.3±1.7	300±190
AFGL 5142	0.62±0.28	2.0±1.2	530±860	2.5±1.1	500±260
Mon R2	0.87±0.18	2.4±0.5	820±570	2.8±0.76	770±210
AFGL 490	0.46±0.26	2.2±0.3	470±430	1.8±0.68	510±130
Serpens	0.32±0.08	1.8±0.2	220±110	3.7±0.95	240±60
Average	0.63±0.2	2.4±0.5	980±570	2.8±0.67	730±430

Note. — Physical properties of $C^{18}O$ clumps. R : radius, ΔV : velocity width in FWHM, M_{vir} : virial mass, N(H_2) : H_2 column density and M_{LTE} LTE mass of the clumps.

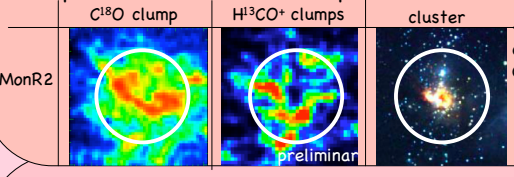
Discussion1 : What does the role of $C^{18}O$ clumps?

1. Initial size , initial mass

- $SFE=M_{clusters}/M_{clump}+M_{clusters}$
- SFE_{C18O}～ 15%

Compare SFE_{H13CO+}=30% (from our $H^{13}CO^+$ data : preliminar results) with this ,the $C^{18}O$ clumps can retain 85% of the natal molecular gas.

- Compare the distribution clumps with clusters

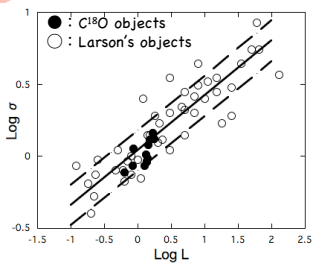


2. Initial velocity width

- Size-line width relation

Larson 1981 $\sigma \propto L^{0.38}$
(turbulent similarity-law)
The $C^{18}O$ clumps seem to well obey the Larson-Law, unlike the cores (Caselli & Myers et al. 1995)

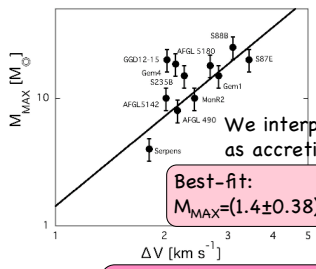
←The $H^{13}CO^+$ gas seems to be converted into stars. In contrast, $C^{18}O$ gas seems retain.



Conclusion.1 : $C^{18}O$ clumps retain the initial clump size, mass and turbulent ! !

Discussion2 : High-mass stars can form through dynamical accretion !?

The relation between M_{MAX}&ΔV_{clump}



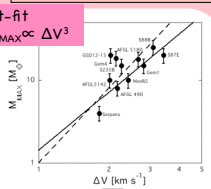
We interpret this relation as accretion scenario.

Best-fit:
$M_{MAX}=(1.4\pm0.38)\Delta V_{clump}^{2.3\pm0.29}$ c.c.=0.79

The evidence of accretion scenario !!

Solid: Best-fit
Dashed : $M_{MAX} \propto \Delta V^3$

→ Compare the best-fit line with dashed line, there isn't so much of a difference between them.



$M_{star}=(1.4\pm0.38)\Delta V^{2.3\pm0.29}$

$$M_{star} = \dot{M} \times \tau_{ff}$$

$$\dot{M} = (0.98 \sim 47)\frac{\sigma^3}{G}$$

Considering Shu～Larson Penston

$$\tau_{ff}$$

Using the usual accretion model, M_{star}-dv relation is derived.

M_{star}= 1.8～ 85ΔV^3

Conclusion.2 : High Mass star also form by the accretion scenario ! !

In fact, accretion rate of massive core is $10^{-4}M_\odot$/yr (Ikeda et al.2007) then 20M☉ star (=our targets) can form in 0.5Myr
→ consistent with the cluster age (1-3Myr)

○ ○ Summary ○ ○

- The average star formation efficiency for our $C^{18}O$ clumps is estimated to be 15% and the clumps are located toward the clusters. In addition, the $C^{18}O$ clumps seem to well obey the Larson's law. Consequently, we consider that the $C^{18}O$ clumps keep the mass, size, and velocity width just before the cluster formation.
- The good correlation between M_{MAX} and ΔV_{clump} ($M_{MAX}/M_\odot$) = $1.4\pm0.38)(\Delta V_{clump}/km/s)^{2.3\pm0.29}$ for the $C^{18}O$ clumps can be well interpreted as the formation of the most massive stars are likely to be born within the individual cores through the dynamical accretion in a similar way to the case of the low-mass star formation.

Reference
Lada & Lada 2003, ARA&A 41, 57 ; Lada 1992, ApJ;393, 25; Larson 1981, MNRAS, 194, 809; Sunada et al. 2000, Proc, SPIE, 4015, 237; Yamaguchi et al. 2000, Proc. SPIE, 4015, 614; Sunada et al. 2007 PASJ in press; Ikeda et al. 2007, ApJ, 665, 1194
Caselli & Myers et al. 1995, ApJ, 446, 665