The Role of Cloud Cloud Collisions in High mass Star Formation

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outline

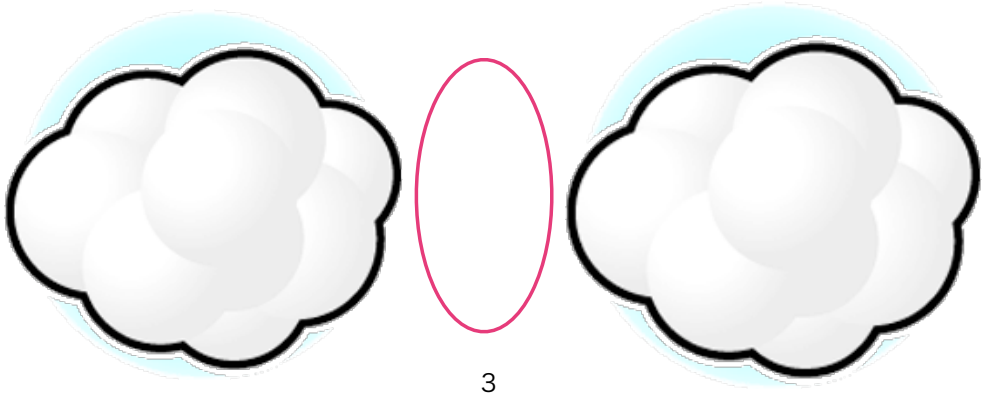
- motivation
- recent observational evidence of cloud cloud collision
- collision time scale estimation
- our numerical simulation

what is a trigger of high mass star formation ?

- Cloud-Cloud Collisions -

- High Density Region

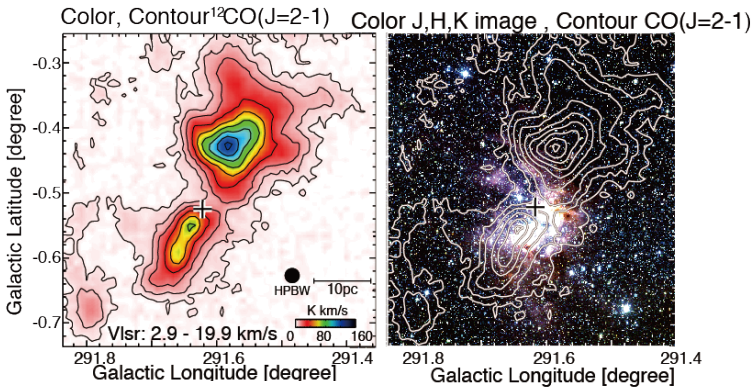
High Mass Cores ?

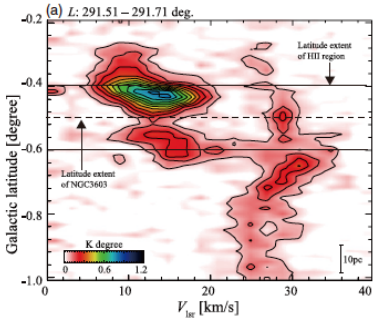


Recent Cloud Collision Observation Papers

- Furukawa+ 2009
- Kang + 2010
- Ohama+ 2010
- Torii + 2011
- Nakamura + 2012
- Fukui + 2014,
- Higuchi +2014
- Torii + 2015,
- Tsuboi+2015

CO(J=2-1) and infrared images of NGC3603





position - velocity

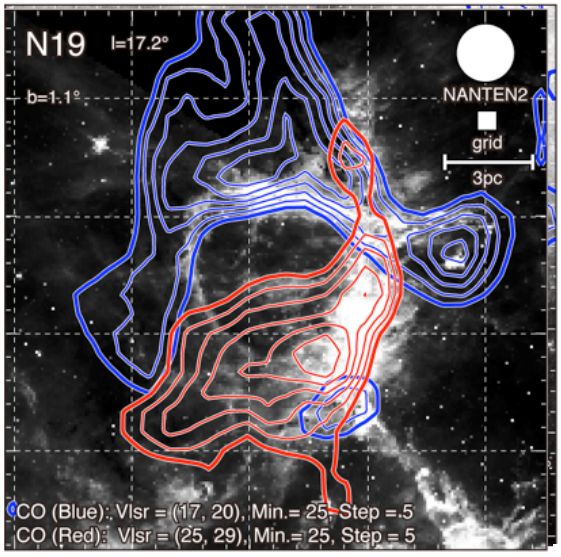
Δv ~ 15km/s

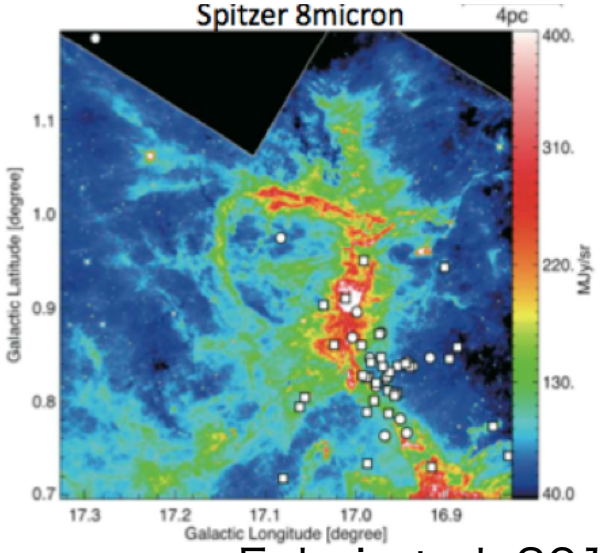
Fukui et al. 2014

Cloud Cloud Collision evidence in Spitzer bubbles

partial arc-like structures of 8 micron
and off-center star formation regions

two velocity components of CO with Δv ~ 20 km/s



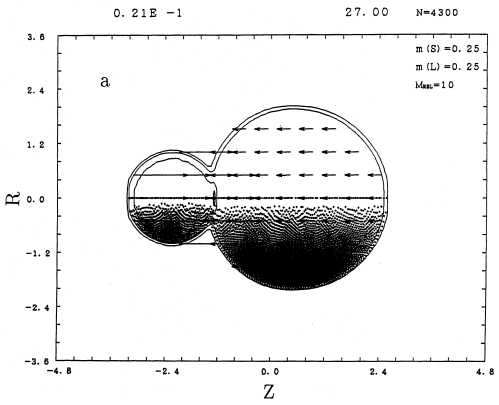


Fukui et al. 2014

CCCs Simulation

Habe & Ohta(1992), Anathpindika(2010)

1



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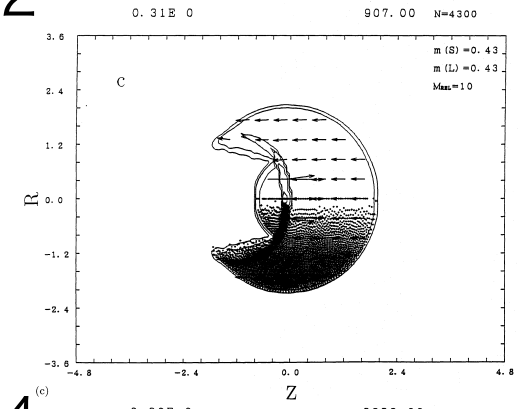

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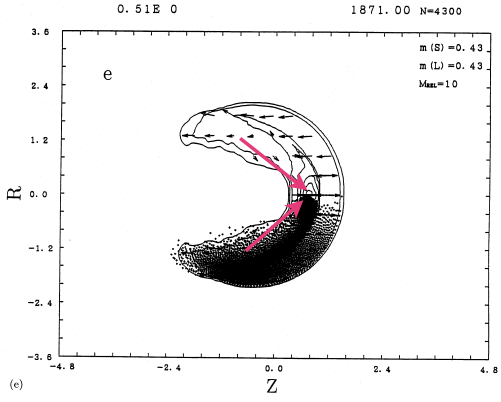

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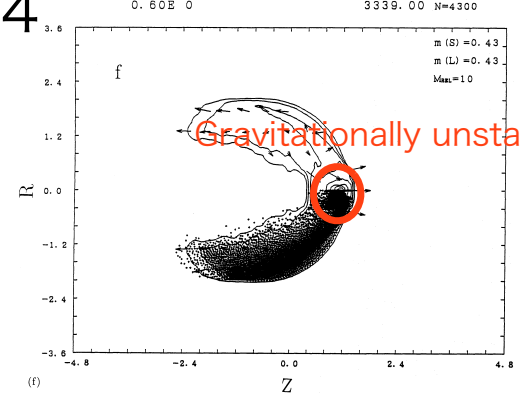


Gravitationally unstable

cloud cloud collision rate ?

- two estimations of collision time scale of GMCs

a) $\tau_{col} \sim 240 Myr$

for random clouds with $\sigma_{cloud} \sim 10 km/s$

e.g. McLeod 2012

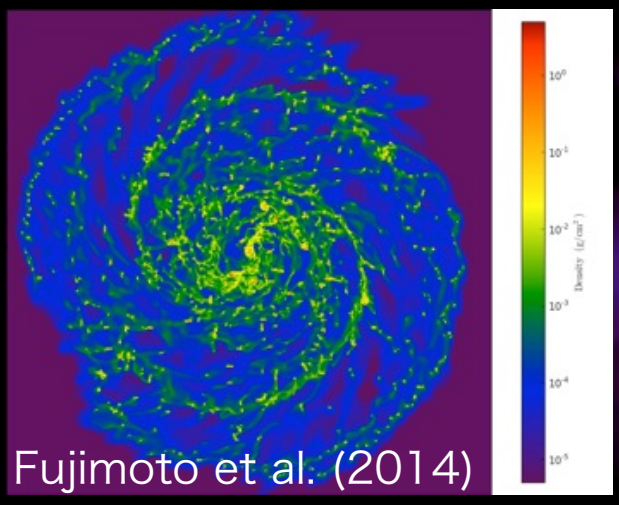
b) $\tau_{col} \sim 10 - 30 Myr$

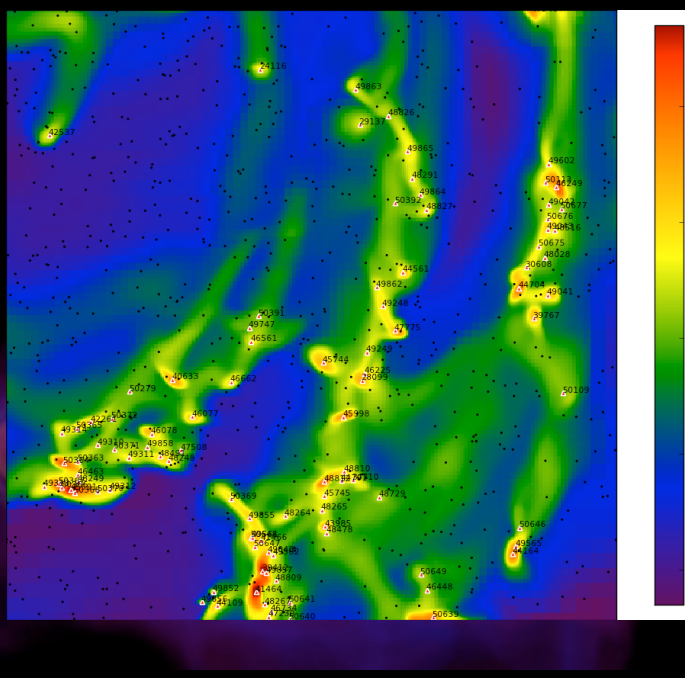
from GMCs simulations of galaxy scale

Tasker and Tan 09, Tasker 11

Fujimoto et al. 14ab, Dobbs et al. 15

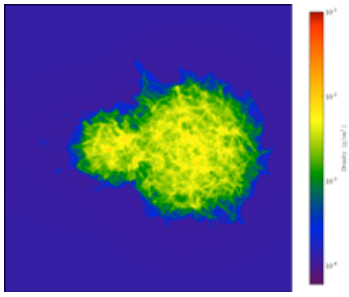
CCCs in galaxies



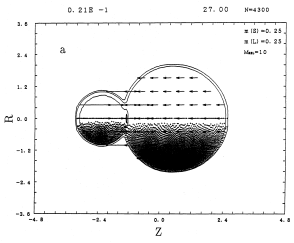


CCCs in molecular cloud simulations of whole galaxy

→ frequent enough for massive star formation in our Galaxy (Tan 2000)



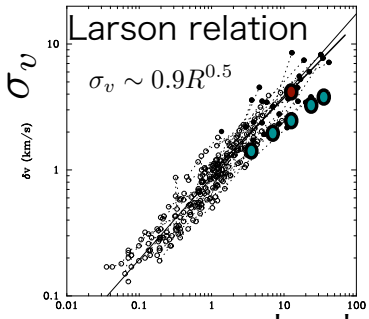
Our Simulation



Takahira et al. (14, 15)

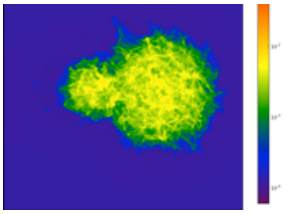
Habe & Ohta (92)

- Turbulent clouds (Larson) collisions
- 3D Hydrodynamic AMR code (ENZO)
- High resolution: $\Delta l \geq 0.014pc$
- Radiative cooling
- Self-gravity



cloud size

Cloud Model



$Small = 7613M_\odot$

$Medium = 14935M_\odot$

$Large = 26722M_\odot$

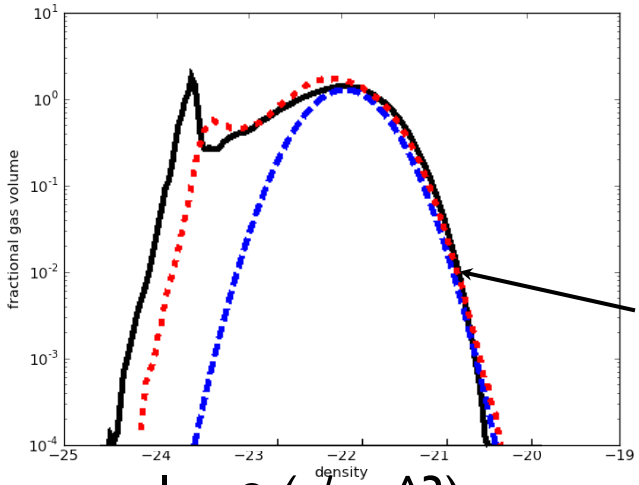
	Small	Medium	Large
$M_c\,[M_\odot]$	7613	14935	26722
r_c [pc]	14.4	20.9	28.0
$\bar{n}\,[\mathrm{cm}^{-3}]$	24.47	15.94	11.86
t_{ff} [Myr]	10.4	13.0	15.0
σ_v [km/s]	2.62	3.17	3.57
T_{BE} [K]	480	720	960
k_{min}, k_{max}	5-12	10-19	10-25

collision velocity

$v_{col} = 5, 10, 20, 30km/s$

Probability Density Function (PDF)

turbulent clouds (before collision)



black line : t = 0.2 t_ff

red dotted line : t = t_ff

blue line : log normal form
(supersonic turbulence PDF)

$$f(\rho) = \frac{A}{\sqrt{2\pi\sigma^2}} \exp\left(-\frac{(\ln(\rho/\bar{\rho}) - \mu)^2}{2\sigma^2}\right)$$

Padoan + 1997, Federrath + 2008

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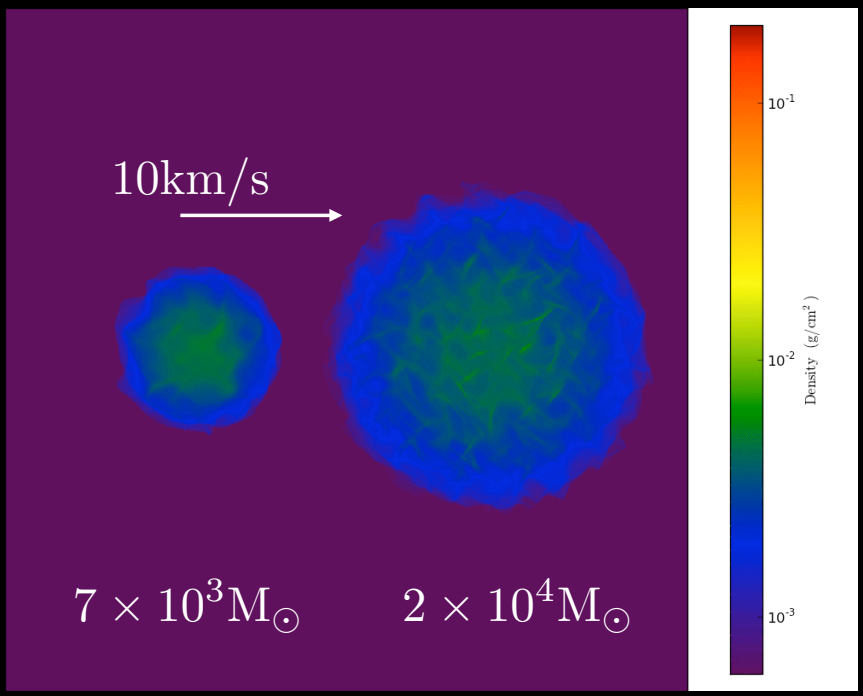
Small-Large clouds

ENZO code



White : cores

Red : bound cores

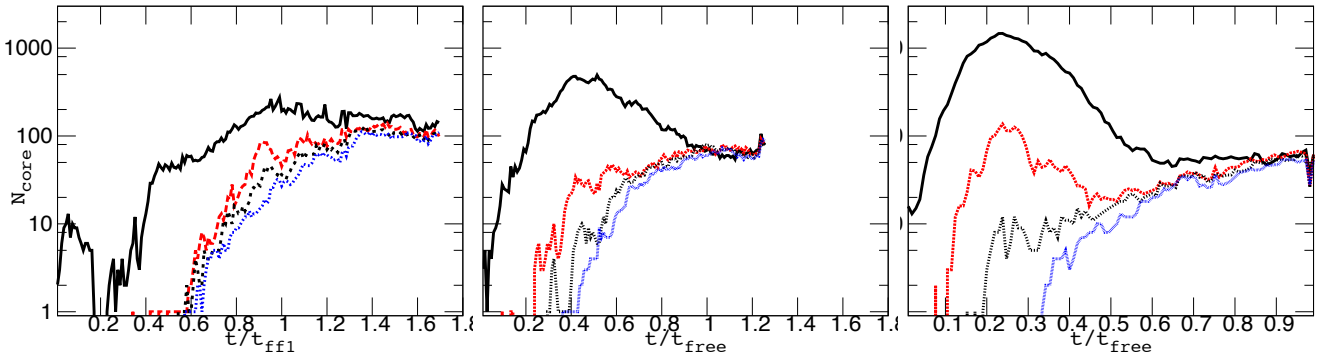
$\rho > 10^{-19}$ [g/cc]

(Gravitatinal E. + Internal E. < 0)

12

Core Number Evolution

5km/s 10km/s 20km/s



density threshold for core definition:

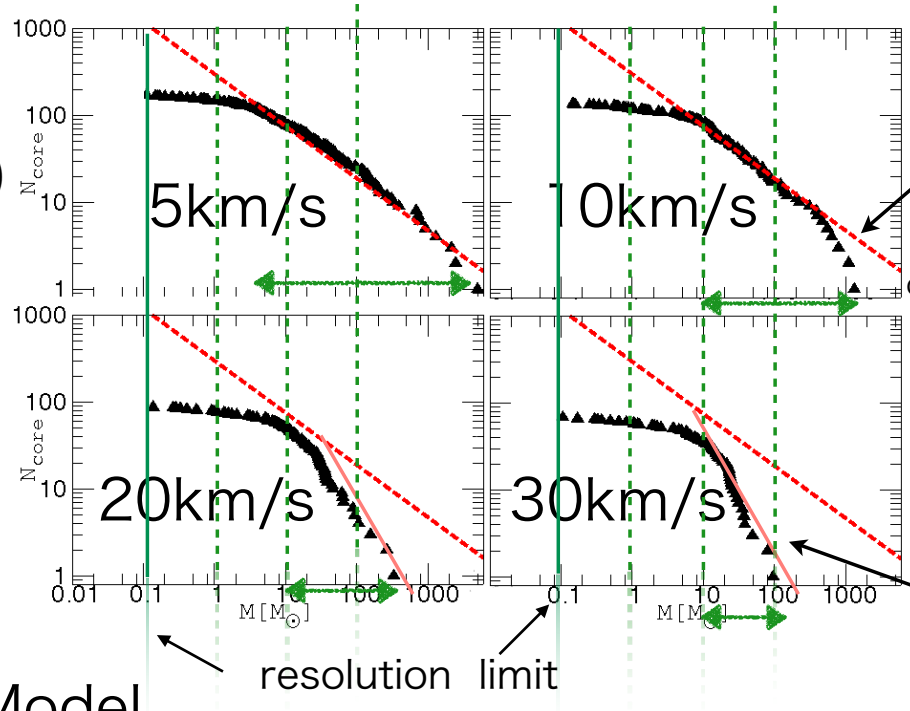
$1 \times 10^{-20} gcm^{-3}$ shock compression

$5 \times 10^{-20} gcm^{-3}$

$1 \times 10^{-19} gcm^{-3}$

$5 \times 10^{-19} gcm^{-3}$ M-L model

cumulative Core Mass Function $\rho_{th} = 10^{-19} g/cm^3$



$\alpha = 1.6$

(Orion molecular cores, Tatematsu 93)

$\frac{dN}{dM} \propto M^{-\alpha}$

$\alpha = 2.3$

Salpeter (1955)

resolution limit

M-L Model

Core mass range is M > 10 M_sun for high velocity collision

summary

- turbulent clouds collisions with $v = 5 - 30km/s$
- partial arc-like structure (Spitzer bubbles)
- core mass function limited to $M > 10M_{\odot}$ with power index $\alpha = 1.6 \sim 2.3$ for $v > 10km/s$
- massive cores with accretion rate $\dot{M} > 10^{-4}M_{\odot}/yr$ (McKee & Tan 2004)
- our results support CCCs have the important role in high mass star formation