Massive Core/Star Formation Triggered By Cloud-Cloud Collision: Effect Of Magnetic Field (Sakre et al. 2021, PASJ)

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Background

- Massive stars (> 8 $M_\odot$) are important in astrophysics.
- Their formation process is not well understood.
- Cloud-cloud collision (CCC) is strong candidate for massive star formation (Fukui et al. 2021).

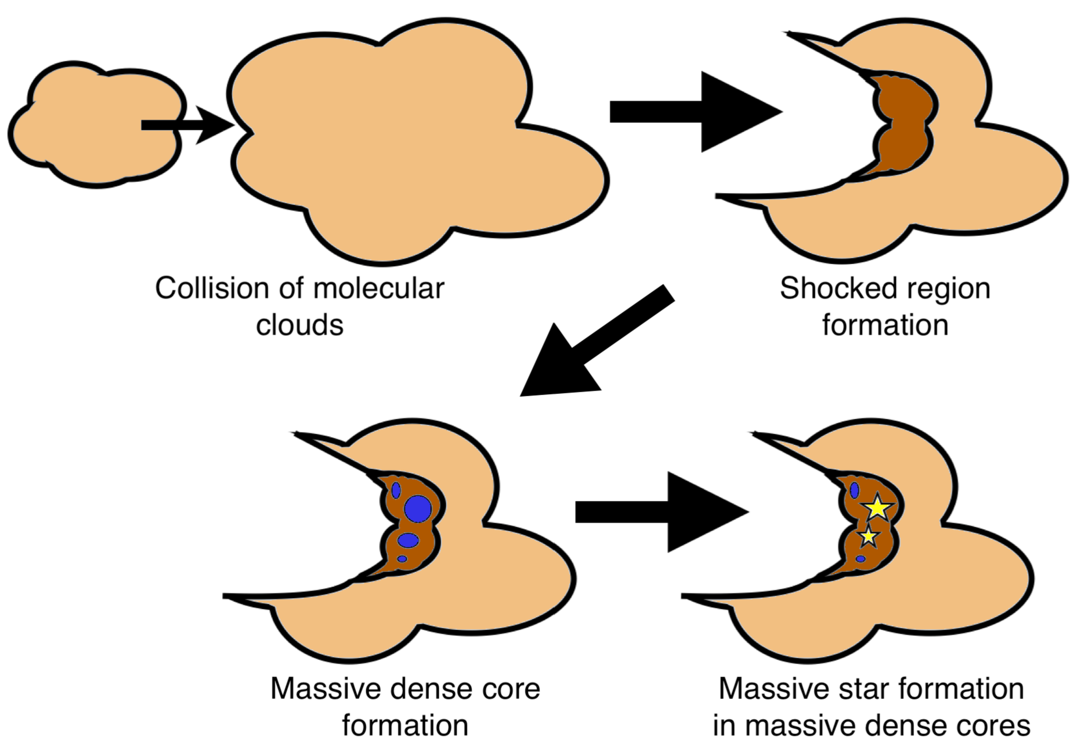

Figure 1: Schematic view of massive star formation triggered by CCC

Motivation & Aim

- Simulation study of magnetic fields and massive dense core formation by CCC.
- Previous studies:
- Wu et al. 2017: star formation rate is not affected in presence of magnetic field. However, their resolution is not enough to resolve dense cores.
- Inoue et al 2018: MHD shock leads to massive filament formation in collision of dense, turbulent clump with uniform region. However, they did not simulate collision of typical turbulent clouds
- This study: Effect of magnetic fields on massive core formation in CCCs with enough resolution.

Numerical Methods

- Code: *Enzo* (Bryan et al. 2014)
- 3D AMR, Ideal MHD, HLL solver, Divergence cleaning

Numerical Models

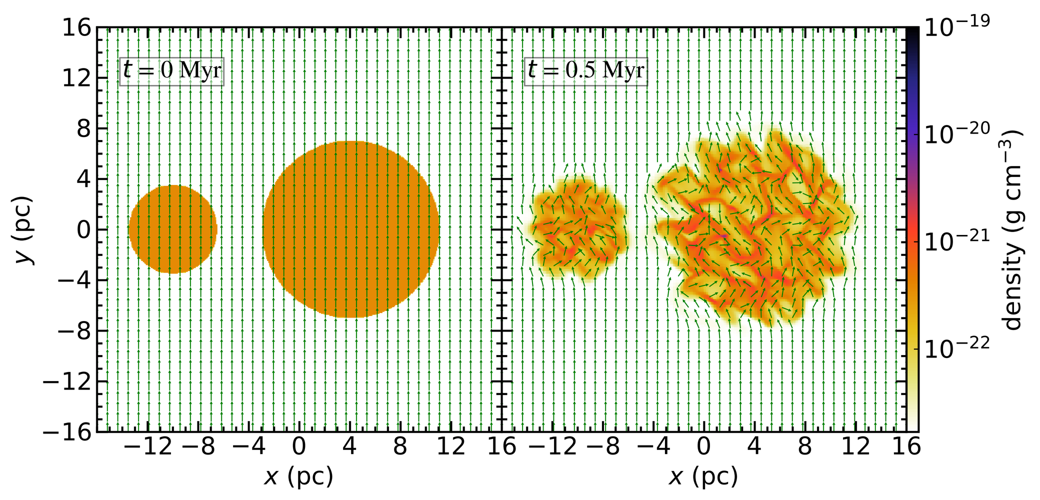

Figure 2: Slice plots of the gas density at t = 0 (left) and 0.5 Myr (right) for the strong B_0 perpendicular to collision axis model. Arrows show normalized magnetic field vectors.

- Clouds: Small (radius 3.5 pc) and Large (7 pc) clouds with typical density of molecular clouds.
- Uniform initial magnetic field ($\boldsymbol{B}_0$):
  (1) Strength: 0.1 (weak) and 4μG (strong). Strong model is consistent with observed relation by Crutcher et al. 2010.
  (2) Direction: parallel, perpendicular, and oblique to collision axis.
- Turbulence: Generated at t = 0 Myr, consistent with Larson relation (Larson 1981).
- Collision speed: 10 km s^{-1} given to Small cloud at t = 0.5 Myr.
- Resolution: 0.015 pc, small enough to resolve dense cores.

Numerical Results

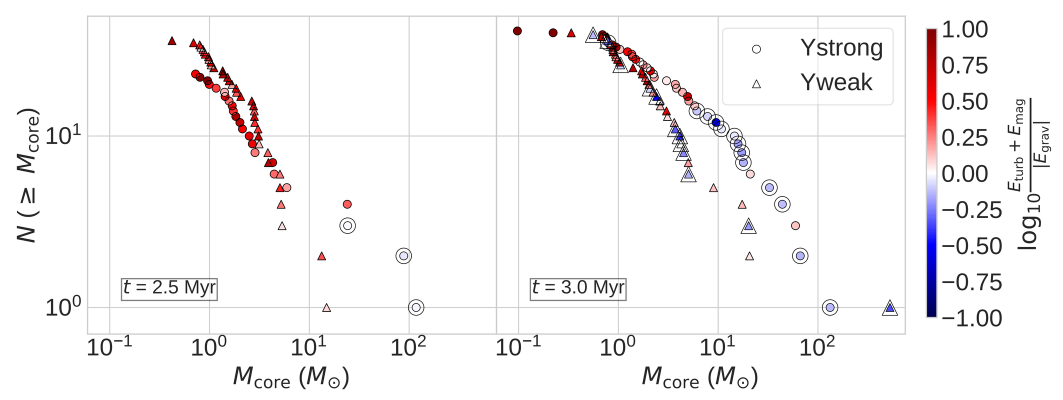

Figure 3: Cumulative core mass distributions (CMDs) at t = 2.5 (left) and 3.0 Myr (right) for the strong (circle) and weak (triangle), $\boldsymbol{B}_0$ perpendicular to collision-axis. Color shows gravitational boundness, and bound cores are shown by large open markers.

- Greater number of massive, gravitationally bound cores formed in strong B_0 (4 μG) than weak B_0 (0.1 μG) models (figure 3).
- Reason for this:
- Weak B_0 models: Spatial displacement of the shocked region (see right panel of figure 4). This is caused by the nonlinear thin shell instability (NTSI) (Vishniac 1994). This leads to formation of small mass, dense clumps at extrema of spatial displacement of the shocked layer.
- Strong B_0 models: No such spatial displacement (see left panel of figure 4). NTSI is suppressed by the strong magnetic fields. They support low-mass dense cores against gravitational collapse.

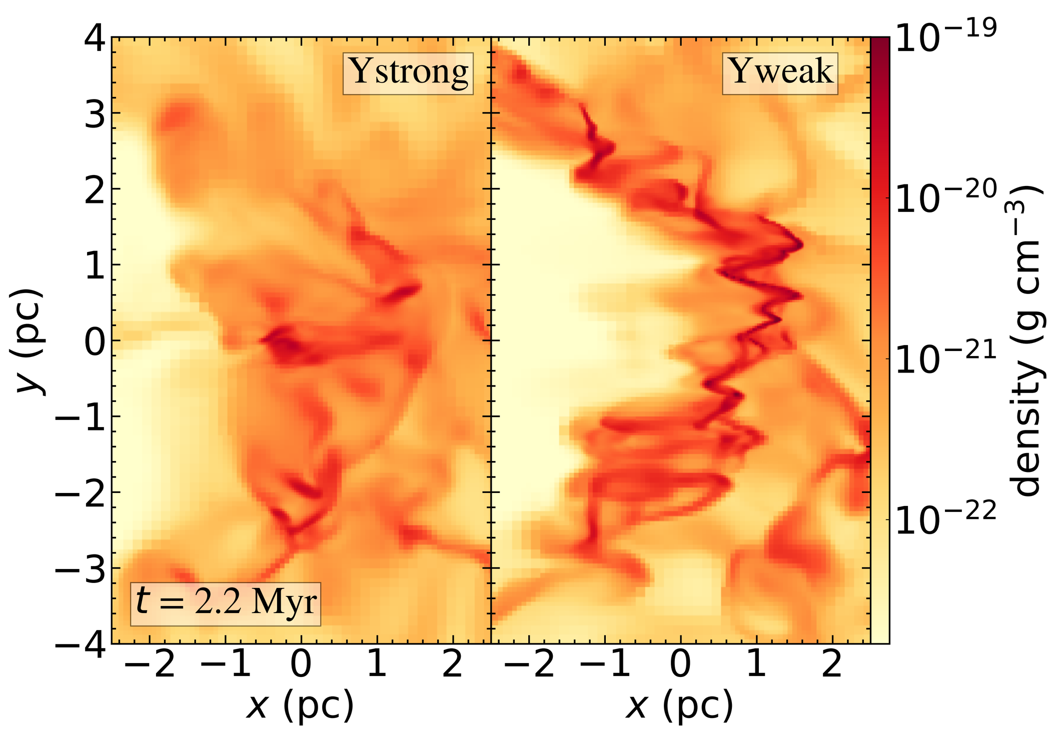

Figure 4: Shocked regions at t = 2.2 Myr for the strong (left) and weak (right), $\boldsymbol{B}_0$ perpendicular to collision axis models.

- No large difference in CMDs due to B_0 direction

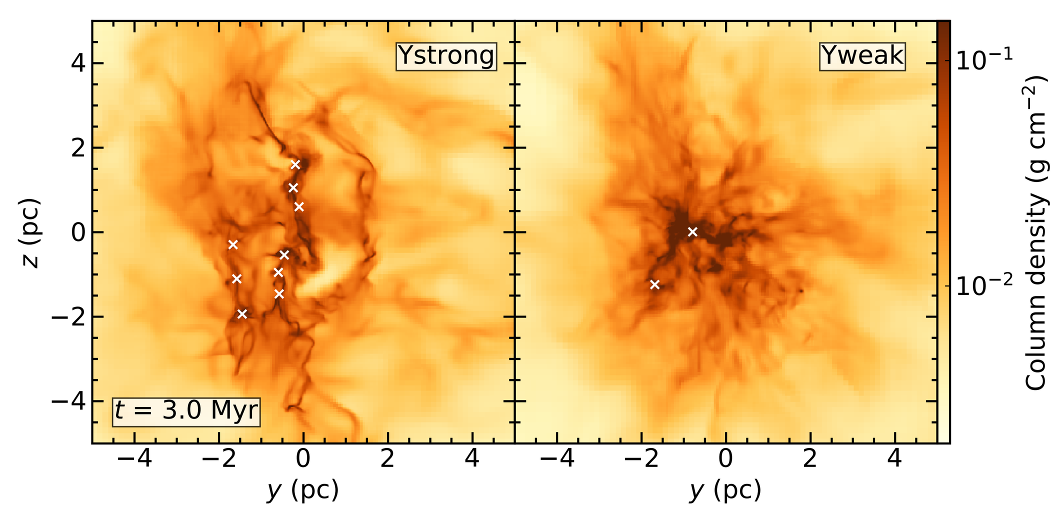

Figure 5: Massive bound cores shown by cross markers on column density map viewed along collision axis at t = 3.0 Myr for the strong (left) and weak (right), $\boldsymbol{B}_0$ perpendicular to collision axis models.

- Strong B_0 (perpendicular & oblique) models: Massive bound cores are formed in filaments, which are normal to $\boldsymbol{B}_0$ (figure 5)
- Weak B_0 models: Very massive bound core is formed near the center (figure 5)
- For comparison, we simulate isolated cloud models. Less number of massive bound cores are formed in them than colliding models with same B_0 at the same evolution time.

Discussion

- We estimate the magnetic field strength which can suppress NTSI. Our estimation indicates that this strength increases with collision speed.
- Collision speed and cloud size would play an important role in massive core formation in magnetized, colliding clouds.
- To investigate this, higher speed collisions of larger-sized, magnetized clouds are carried out, which will be published in Sakre et. al (in prep.).

Summary

- We simulated CCC with turbulent magnetic fields to investigate massive bound core formation.
- We show that a greater number of massive, gravitationally bound cores are formed in the strong B_0 (4.0 μG) models than the weak B_0 (0.1 μG) models.
- This is partly because the strong magnetic field suppresses the spatial shifts of the shocked layer that are caused by the nonlinear thin shell instability in a weak magnetic field case.
- The spatial shifts promote the formation of low-mass dense cores in the weak magnetic field models.
- The strong magnetic fields also support low-mass dense cores against gravitational collapse.
- In the strong B_0 (perpendicular & oblique) models, massive bound cores are formed in filaments, which are roughly normal to $\boldsymbol{B}_0$.
- We show that less number of massive bound cores in isolated, non-colliding cloud models than colliding models with same $\boldsymbol{B}_0$ at the same time evolution.
- We give a simple analytic model for the magnetic field strength required to suppress the instability of the shocked layer formed by colliding clouds.

References

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