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Cluster Formation Triggered by Cloud-Cloud Collision: The Case of Serpens South

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Gutermuth et al. (2008)

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Outline of My Talk

- Introduction
  - -Importance of Cluster Formation Study
  - -Initial conditions of cluster formation
- Serpens South (d~415pc)
  - filamentary infrared dark cloud
  - youngest embedded cluster among d < 500pc
- 3D MHD simulations of Cloud-Cloud Collision
- Cloud-cloud collision in Serpens South
- Summary

Why is cluster formation so important?

- Clustered SF vs. Distributed SF

  - Most stars form in clustered environment (Lada & Lada 2003).

  - Massive stars form in clusters.

    They influence the formation and evolution of galaxies significantly.

    Dominant mode of star formation

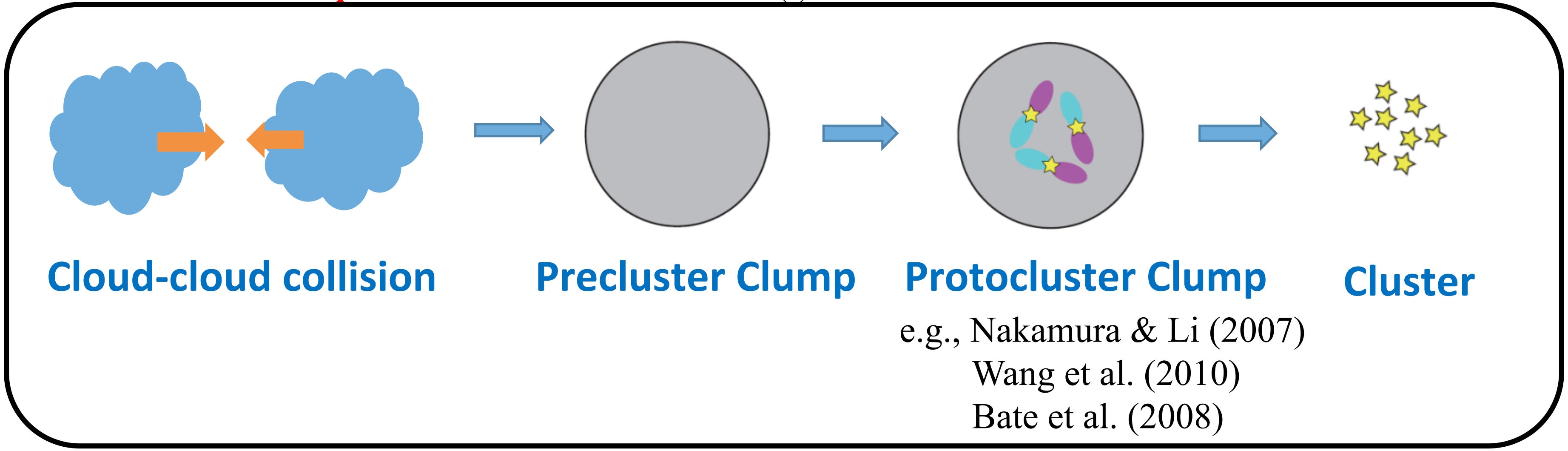
- Unfortunately, our knowledge of cluster formation is still limited…. No standard scenario for cluster formation

  - Previous studies have focused on isolated SF like Taurus.

  - Formation sites of massive stars and clusters are far from us.

How do clusters form?

- Recent observations have revealed that clusters form in pc-scale dense clumps with 100-1000 $M_\odot$.



- Cloud-cloud collision is a promising mechanism to form such dense clumps (Tasker & Tan 2013).
- Observations of cloud-cloud collision

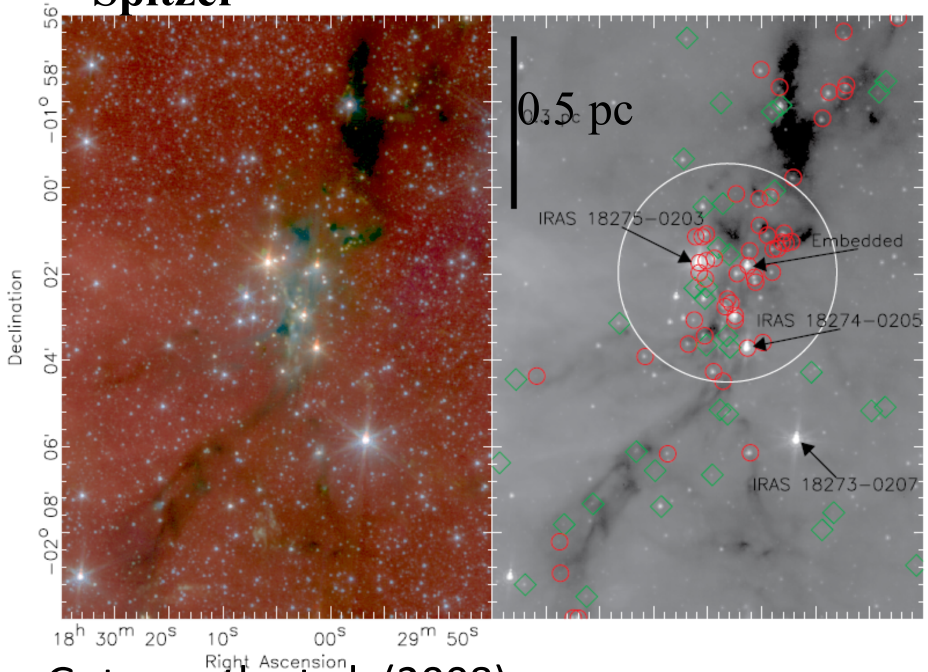
  Velocity difference

(e.g., Fukui et al. 2014; Duarte-Cabral et al. 2011; Higuchi et al. 2010)

Why Serpens South?

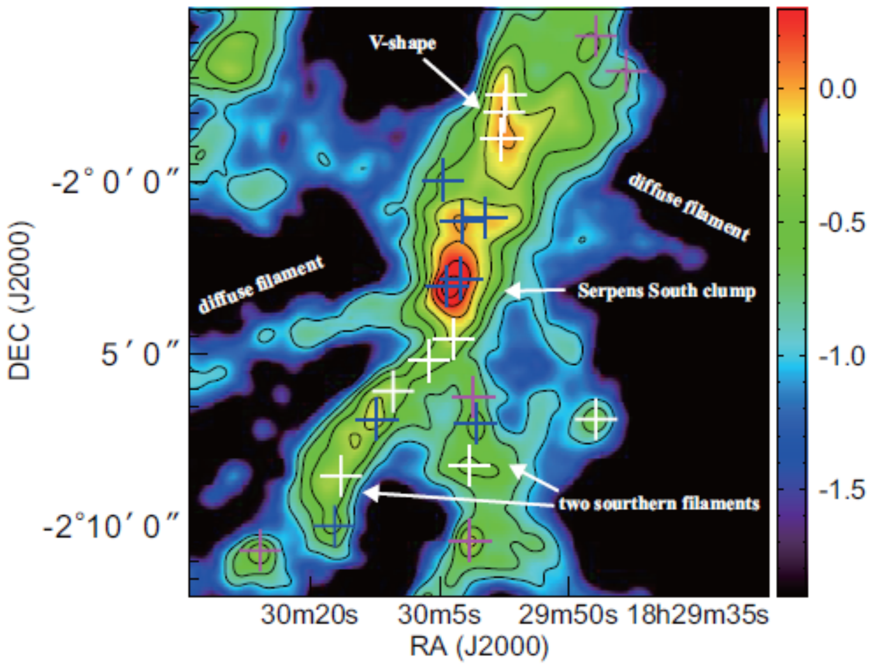
- nearby cluster-forming region in Aquila Rift at a distance of 415pc
- Discovered by Spitzer Gould Belt Survey (Gutermuth et al. 2008)
- Nearest cluster-forming filamentary infrared dark cloud Class I ~ 0.4Myr (Evans et al. 2009)
- Fraction of Class 0/I protostars is extremely high ~ 80 %
- Cluster formation was presumably initiated in the last 0.5 Myr.

Spitzer



Gutermuth et al. (2008)

1.1mm AzTEC/ASTE image Log(Jy/beam)



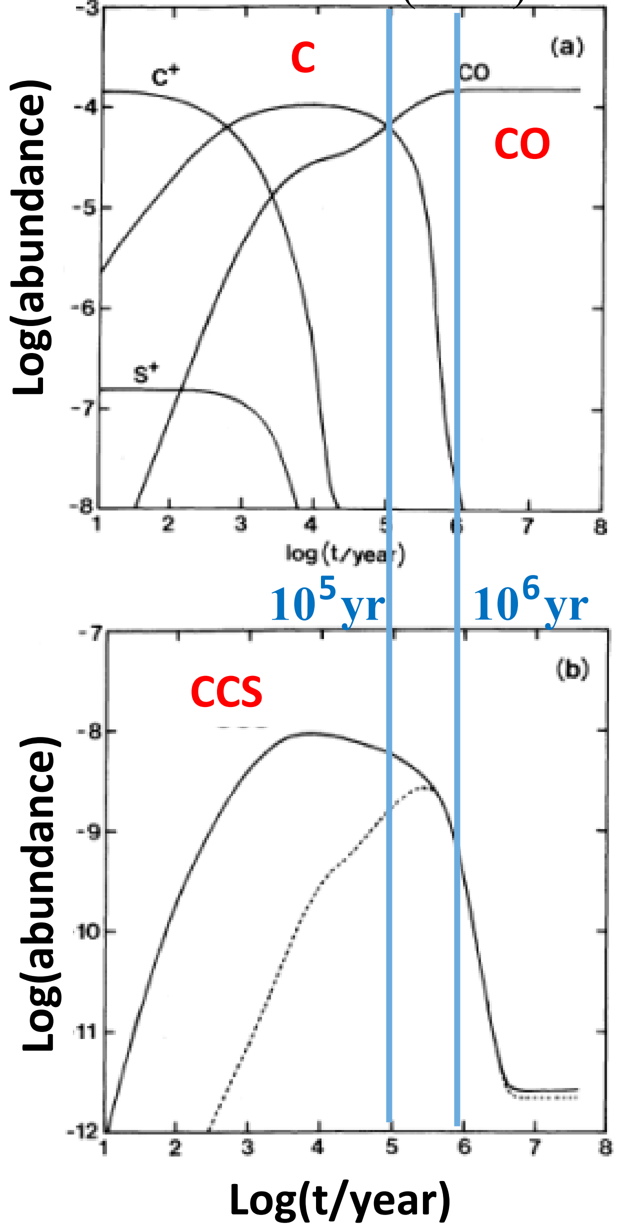
Tanaka, FN, et al. (2013)

CCS Molecule: Age Indicator of Prestellar Phase

- CCS is a carbin-chain molecule and abundant only in the first 0.5Myr.
- It is an age indicator of prestellar phase

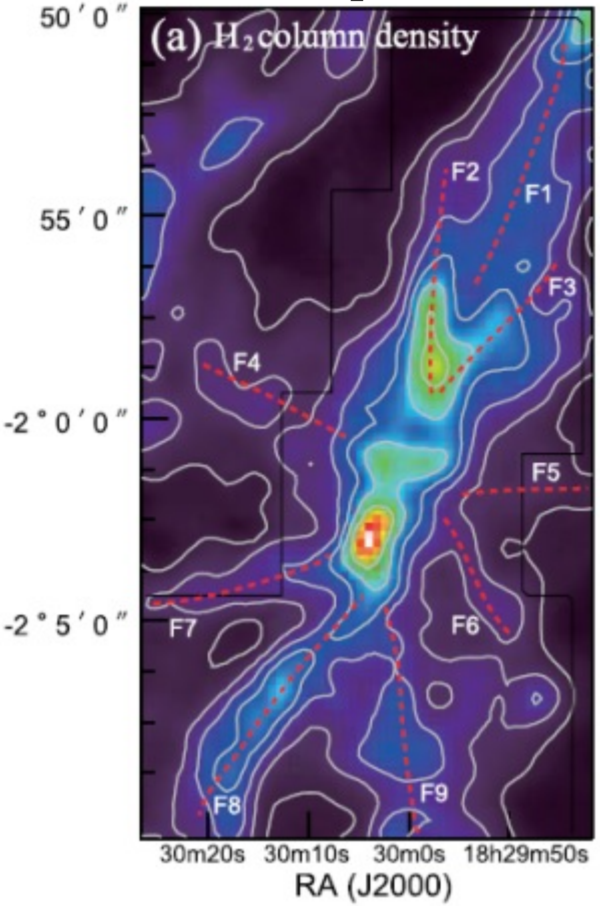
  Suzuki et al. (1992); Marka et al. (2012)
- Observations of CCS (J_N=4_3-3_2) with the Z45 new receiver (Nakamura et al. 2015) installed in the Nobeyama 45-m telescope.

Suzuki et al. (1992)



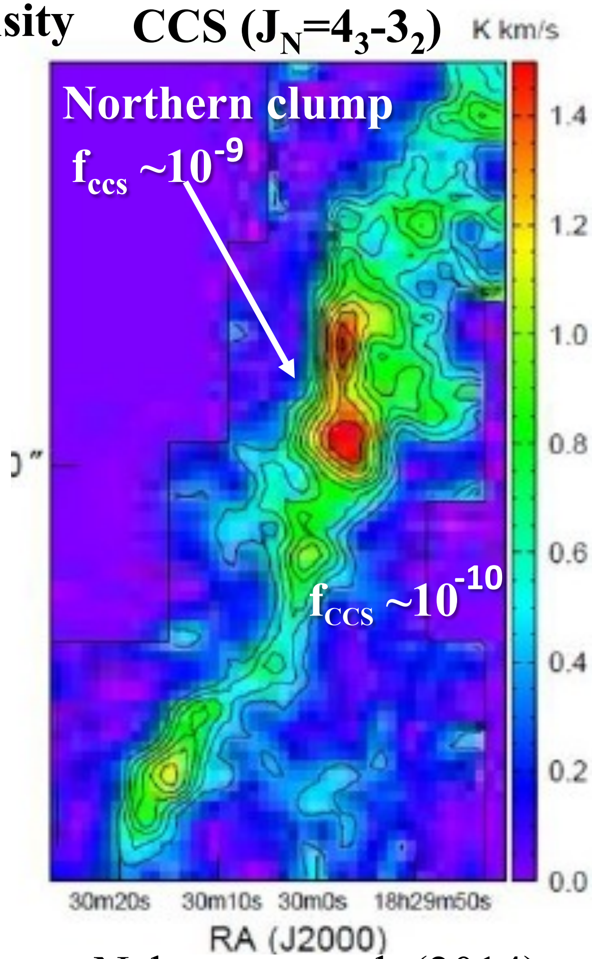
CCS in Serpens South

Herschel H_2 column density

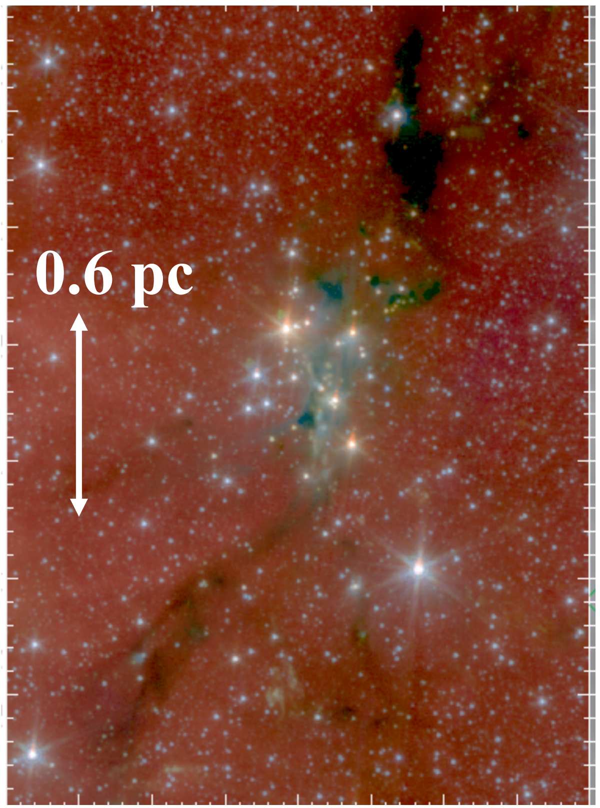


See also Andre et al. (2010)

CCS ($J_N=4_3-3_2$)



Nakamura et al. (2014)



Gutermuth et al. (2008)

CCS emission is extremely strong along the filament, particularly, in the northern precluster clump → this region is very young (< 0.5Myr)

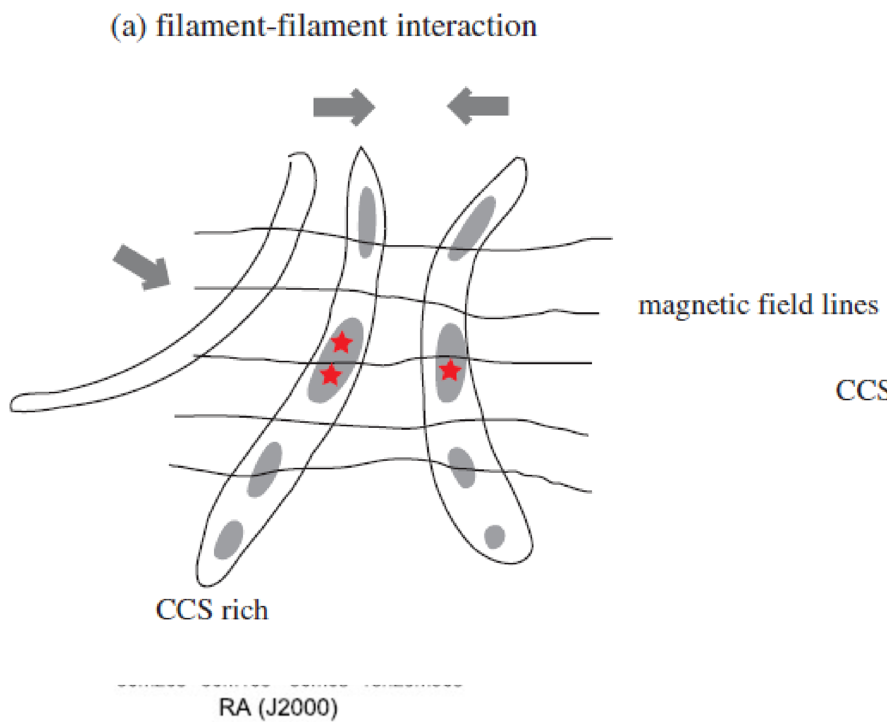
First cluster-forming region having strong CCS

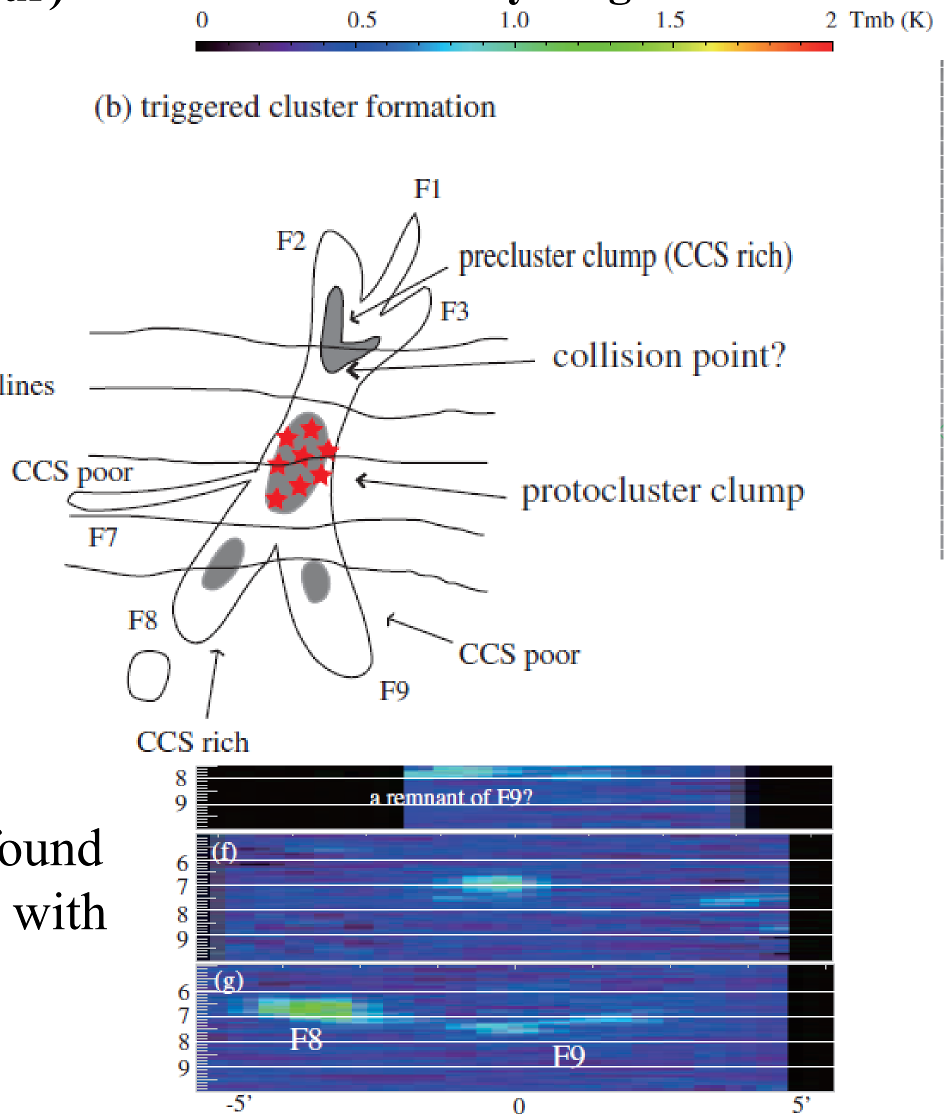
(see also Friesen et al. (2013) for HC_7N)

Multi-Filaments in Serpens South

Herschel H2(image)+CCS (J_N=4_3-3_2 contour)

Position-velocity diagrams of CCS





From CCS position-velocity maps, we found filaments consist of several components with different line-of-sight velocities.

→ cluster formation may have been triggered by filament-filament collision.

See also Fernández-López et al. (2014)

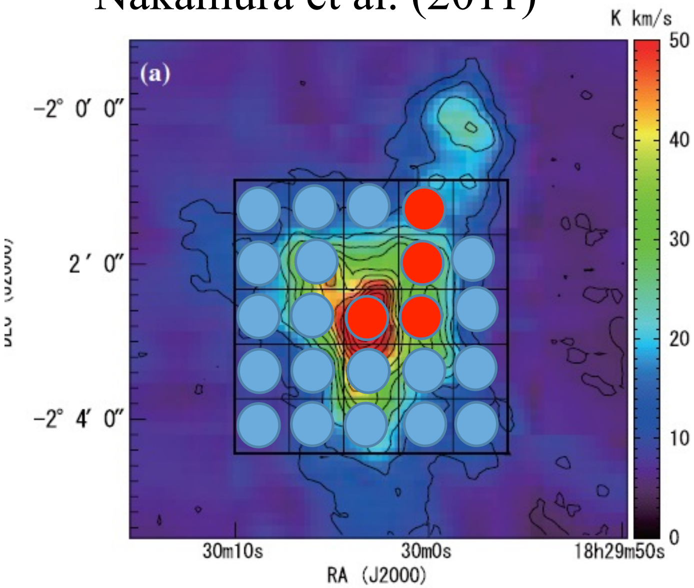
Nakamura et al. (2014)

Inflow toward Central Cluster

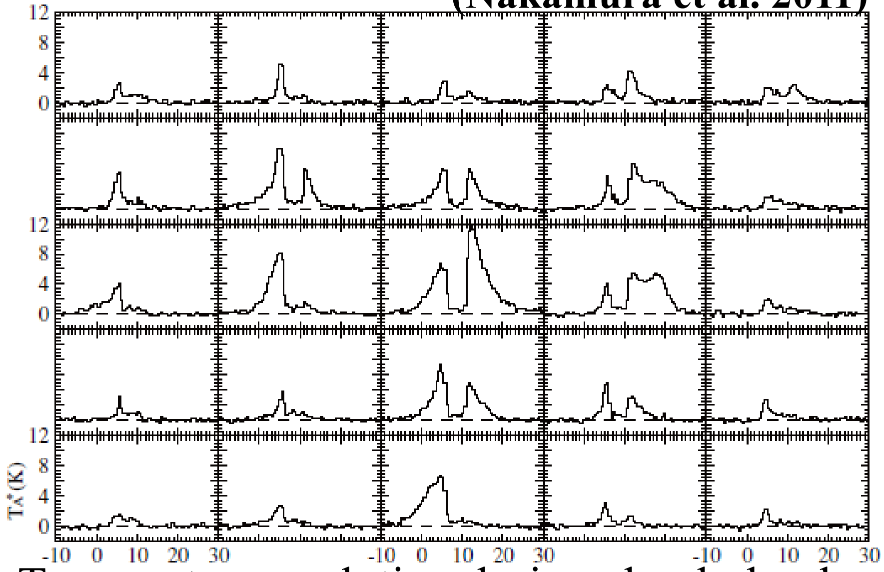
In many parts of this region, optically-thick lines show strong **self-absorption** and **blue-skewed** profiles with wide line widths.

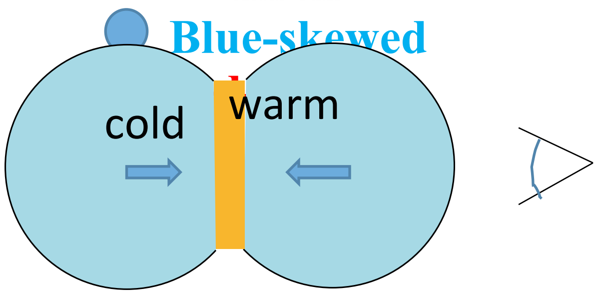
→ Existence of large-scale infall motions

Nakamura et al. (2011)

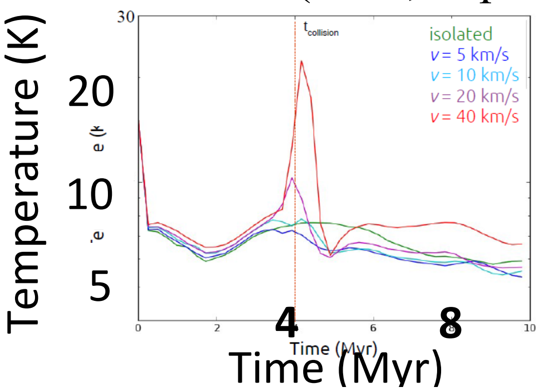


CO (3-2) profile map (Nakamura et al. 2011)





Temperature evolution during cloud-cloud collision
Wu et al. (2014, in prep)

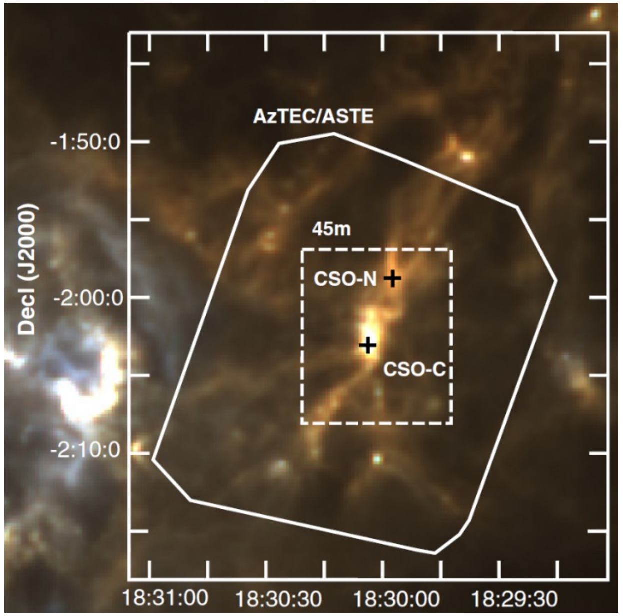


T increases in the first 0.5 Myr, and declines steeply due to raditative cooling.

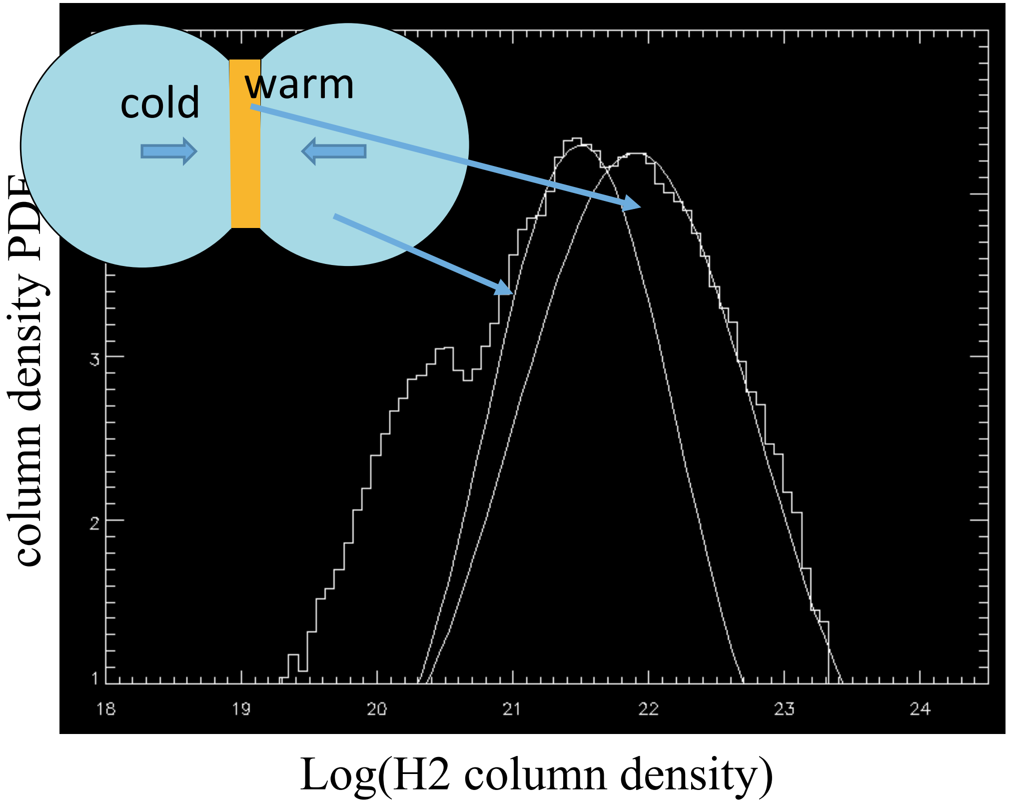
Evidence of Cloud-Cloud Collision

We derived H_2 column density map by SED fitting of Herschel data.

The column density PDF has three peaks: Post-shock, pre-shock clouds and Low-density gas influenced by the nearby W40 HII region or another cloud?

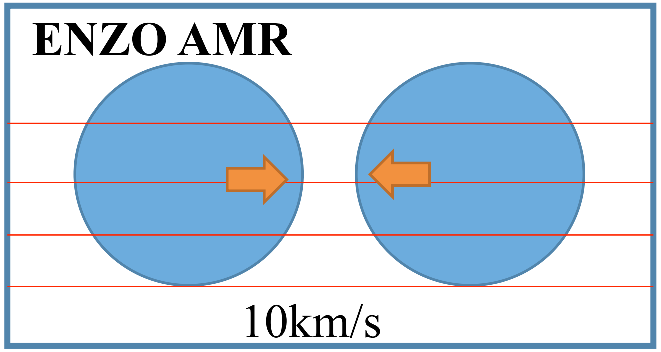


Column density PDF constructed with H2 column density cacluated by SED fit

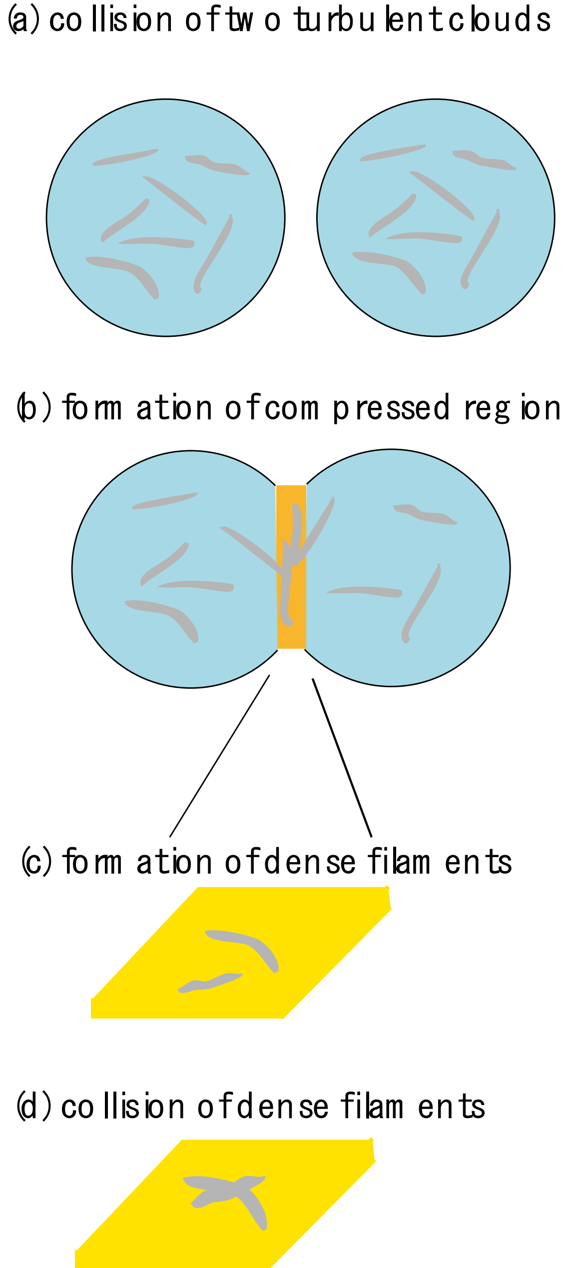


Numerical Simulations of Cloud-Cloud Collision

3D MHD Simulations of head-on collision of two turbulent, magnetized clouds, including cooling and heating (Wu, FN, et al. 2015, in prep)



Two identical clouds with uniform density of $10^2 cm^{-3}$ and mass of $\sim 10^4 M_\odot$. At t=0, the turbulent velocity field is injected only in the clouds



Summary

- Serpens South is a very young cluster-forming infrared dark cloud (~0.5 Myr). Evidence: high fraction of Class I population, abundant CCS
- Cluster formation in Serpens South was triggered by cloud-cloud collision. Evidence: multi peaks in PDF, extended blue-skewed profiles

These features are consistent with the cloud-cloud collision simulations.

- Dense filaments were formed mainly by merging of small filaments created by local turbulence (a bundle of filaments is a natural outcome). Merging of small filaments may be more dominant than mass accretion along the filaments in terms of mass loading to cluster-forming regions.

Hacar et al.(2013)