

An evolutionary trend of the Giant Molecular Clouds in the Antennae Galaxies

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Giant molecular clouds (GMCs) are the main star formation sites, and their evolutions are important to understanding galaxy evolution. This poster focuses on the nearest starburst galaxies, Antennae galaxies, to how galactic interaction accelerates GMC evolution. We identified GMCs and HII regions and classified GMCs into three types: Type I: without HII regions, Type II: with HII regions of $L_{\text{H}\alpha} < 10^{37.5}$ erg/s, Type III: with HII regions of $L_{\text{H}\alpha} > 10^{37.5}$ erg/s. These three types are interpreted as evolutionary sequences. We obtained three results: (1) the fraction of Type III is larger than Type II, (2) the fraction of Type I is 70%, and velocity differences between GMCs and HII regions are larger than 100 km/s in arm region, (3) 1-4 Myr clusters concentrated on GMCs in the overlap regions, on the other hands, there is no difference in the distributions of clusters at different ages in the arm region. In addition, the high-resolution simulation showed the latest galactic collision was 6 Myr ago. For these results, galactic collision at 6 Myr ago caused star formation and accelerated GMC evolution into Type III, representing sequential evolution from the arm to the overlap regions.

1. Introduction

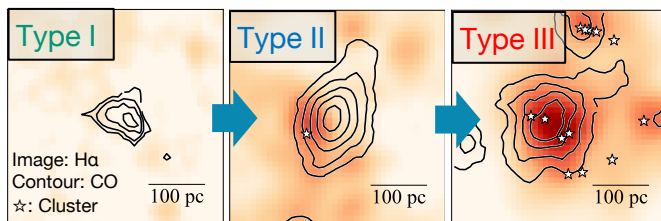
Giant molecular cloud (GMC) evolution/star formation is essential in galaxy evolution, which drives the evolution of the Universe.

➔ Focus on star formation in GMCs

Type classification

(Fukui+1999, Kawamura+2009, Demachi+2024, Konishi+2024)

Classified GMCs into 3 Types and interpreted them as an **evolutionary sequence**. GMCs evolve in 10-20 Myr estimated by cluster age.

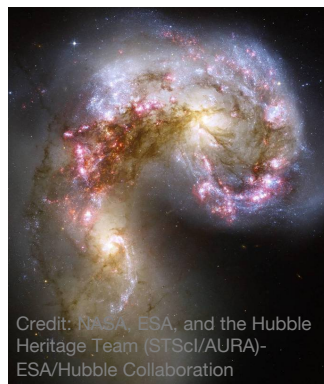


This scheme is confirmed in ~10 galaxies, including dwarf and grand-design galaxies.

2. This study

Antennae galaxies (NGC 4038/ NGC 4039)

- Nearest Star-burst galaxy (distance~22 Mpc) (Schweizer +2008)
- ~1000 clusters, including super star clusters (SSCs; $\sim 10^6 M_{\odot}$) (Whitmore +2010)
- ~100 km/s cloud-cloud collision cause SSCs formation (Tsuge+2021)



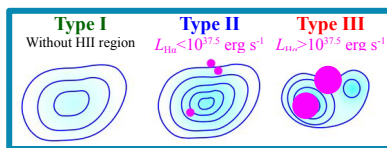
Best suited to reveal the relationship between cluster formation and GMC evolution due to galaxy collisions. Unveil time evolution of GMCs and star-formations observationally by applying Type classification

	Telescope	Spatial Resolution	Velocity resolution	Reference
$^{12}\text{CO}(1-0)$	ALMA	0.71" (76 pc)	5 km/s	2018.1.00272.S; Pl. Wilson, C.
H α	VLT (MUSE)	0.56" (60 pc)	57 km/s	Weilbacher+2018

3. Analysis

*1: Rosolowsky+2021,
*2: Rosolowsky+2008

1. Identify GMC by PYCPROPS^{*1} and HII region by AstroDendro^{*2}.
2. Determine the association between GMC and HII region if their boundaries are overlapped and the difference between peak velocity $< \pm 100$ km/s.
3. Classify GMCs based on $L_{\text{H}\alpha}$ of associated HII regions.



4. Results

Two characteristic regions of the arm region and the overlap region are defined.

[The arm region]



[The overlap region]

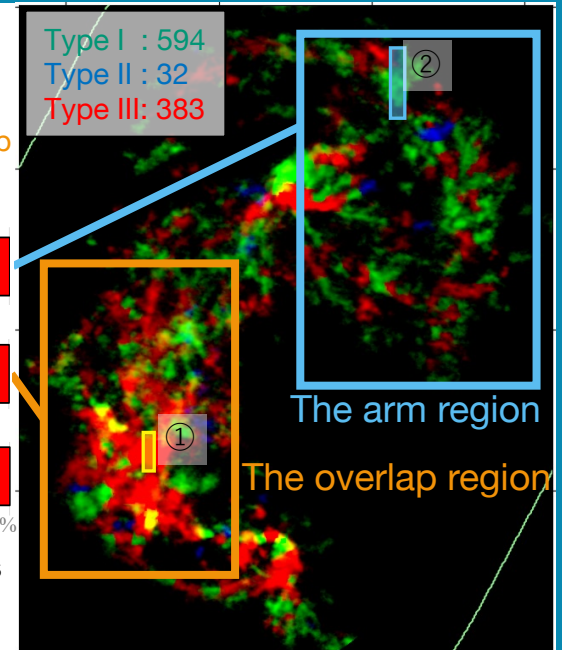


[All]

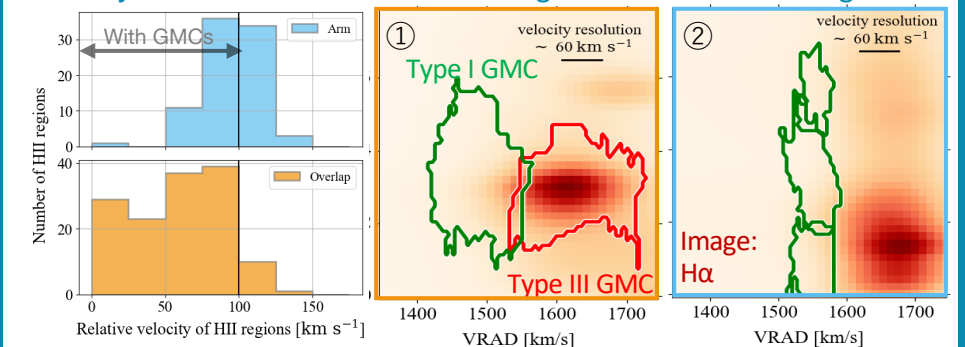


0% 20% 40% 60% 80% 100%

- There are many HII regions not associated with GMCs in the arm region.

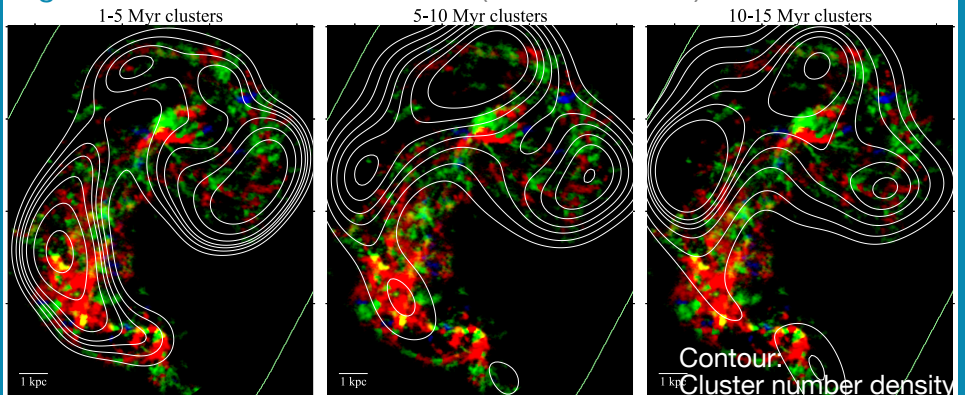


Velocity difference of GMCs & HII regions on the line of sight



- In the overlap region, GMCs and HII regions are well associated
- In the arm region, velocity differences between GMCs and HII regions are large. There may be small undetected GMCs ($\sim 10^6 M_{\odot}$) associated with HII regions.

Age distribution of HST clusters (Whitmore +2010)

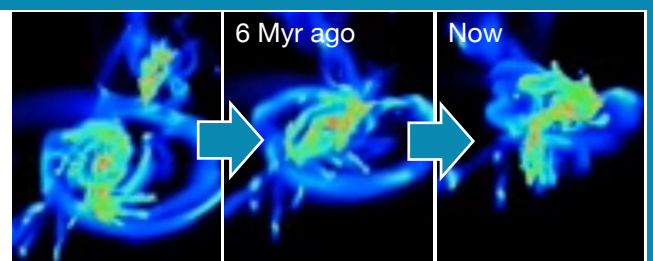


- In the overlap region, 1-4 Myr clusters concentrate on GMCs
- In the arm region, no difference in the distribution of clusters at different ages

5. GMC evolution and galactic collision

- 1.5 pc resolution simulation showed that it is 6 Myr after the galactic collision. (Renaud+2015)
- The arm region collides first, then the overlap region collides.
- Consistent with 1-4 Myr cluster distribution.

→The simulation of the time evolution of the density map of gas



6. Conclusions

We propose an evolution model as below:

6 Myr ago, the galactic collision caused star formation and accelerated GMC evolution sequentially from the arm to the overlap region. There may be dispersed clouds associated with HII regions in the arm region. In the overlap region, GMCs are now colliding and forming young clusters.