

1. INTRODUCTION

Star formation occurs in molecular clouds of dense interstellar gas, but evolutionary process of the structure of molecular clouds leading to star formation is unknown.

Star Formation Research Methods

- Observations: Comparison of multiple molecular cloud structures to assess relative evolutionary stages, but it is difficult to understand time evolution of structure from single molecular cloud data
- Simulation: Various fluid models can be used to study star formation mechanisms to reproduce observational data

⇒ **By analyzing the time evolution of self-gravity fluid in simulations that reproduce observations, it is easy to study the time evolution of structure of molecular clouds.**

Aims

Analyze self-gravity hydrodynamic simulations and compare with observations for a detailed understanding of molecular cloud evolution

2. METHOD

Simulation Data

Three types of fluid spheres were time evolved.

Integral intensity maps (2D data) and 3D scatter plots (3D data) were created and analyzed from 3D mass data of line-of-sight velocity, position, and position.

⇒ **Similar data format to observed data, making comparisons with observations easy**

To investigate the mass dependence of the analytical results, simulations were performed and analyzed with three different initial masses.

	Radii [pc]	Masses [M_{\odot}]	Surface Densities [M_{\odot}/pc^2]	α_{vir}
Sim1	30	10^6	350	1
Sim2	20	10^5	80	1
Sim3	20	10^4	8	1

Observation Data

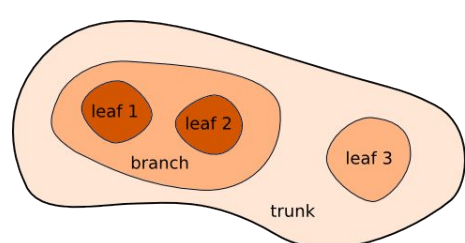
An integrated intensity maps were created and analyzed from ^{13}CO emission line data obtained by the FUGIN project (Umemoto et al. 2017).

In pre-main-sequence stars in the HII region around molecular clouds, their evolutionary stages can be classified into Class 0-III based on the spectral slopes at infrared wavelengths of 2.2 μm and 25 μm . If the number ratio of each Class object is considered as the age of the molecular cloud, the age of the molecular cloud is M17 < M16 < W49A < W51A, B < W43 Main.

	Distances [kpc]	Class II / I Ratio	Class II III / 0 I Ratio
W43 Main	5.5	4.58 (Saral+2017)	
W49A	11	2.1(Saral+2015)	
W51A, B	5.4	2.50 (Saral+2017)	
M16	1.7		1.7 (Povich+2013)
M17	2.0		1.4 (Povich+2013)

Analysis Method: Dendrogram

- Minimal structure without internal structure: leaf
- Structure containing internal structure: branch
- Outermost structure: trunk



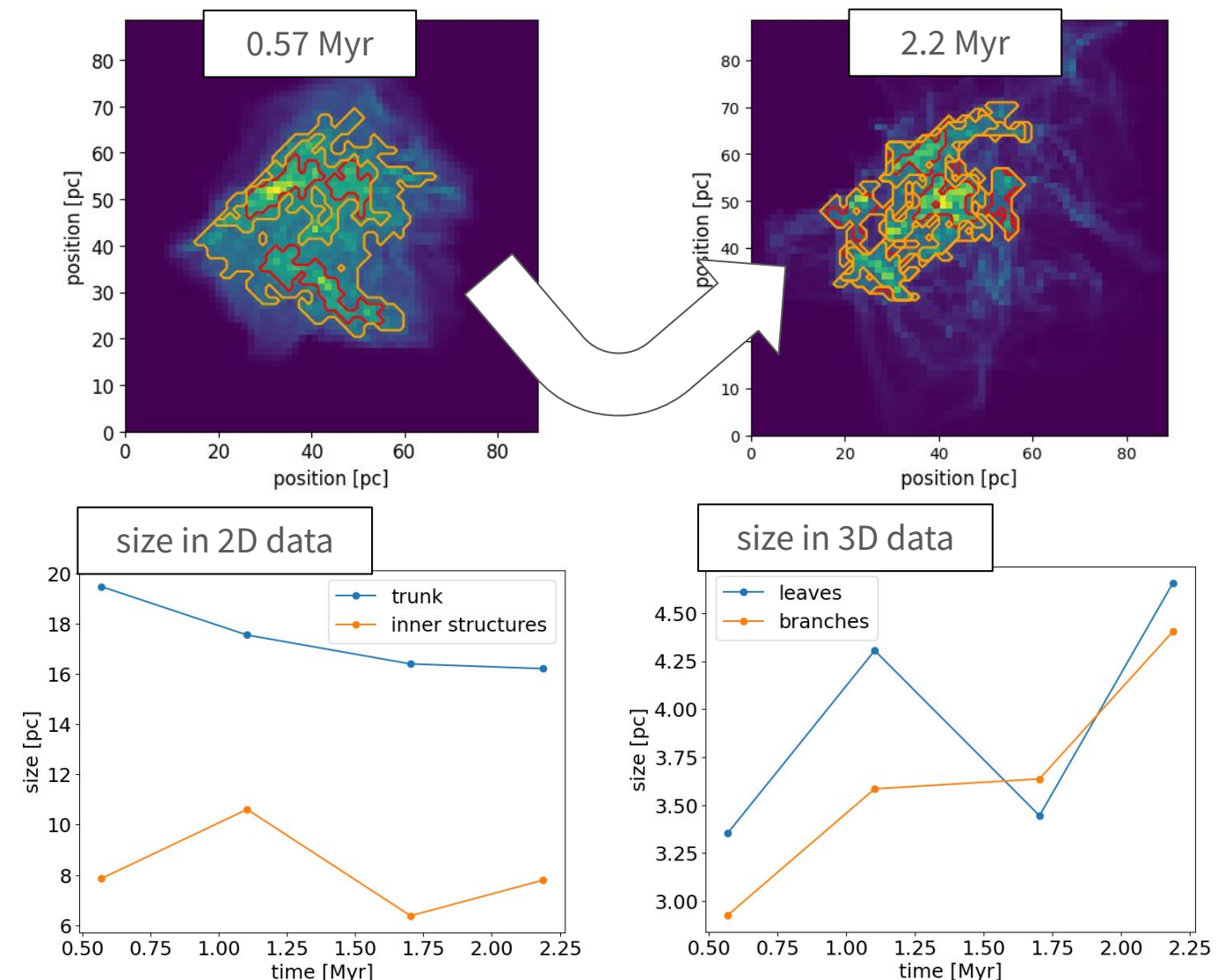
Hierarchical structure with dendrograms <https://dendrograms.readthedocs.io/en/stable/>

Apply structural analysis methods used in observations to simulations
⇒ **It is easy to compare simulation data with observation data**

Find and discuss the size, mass, etc. of the structure.

3. RESULT

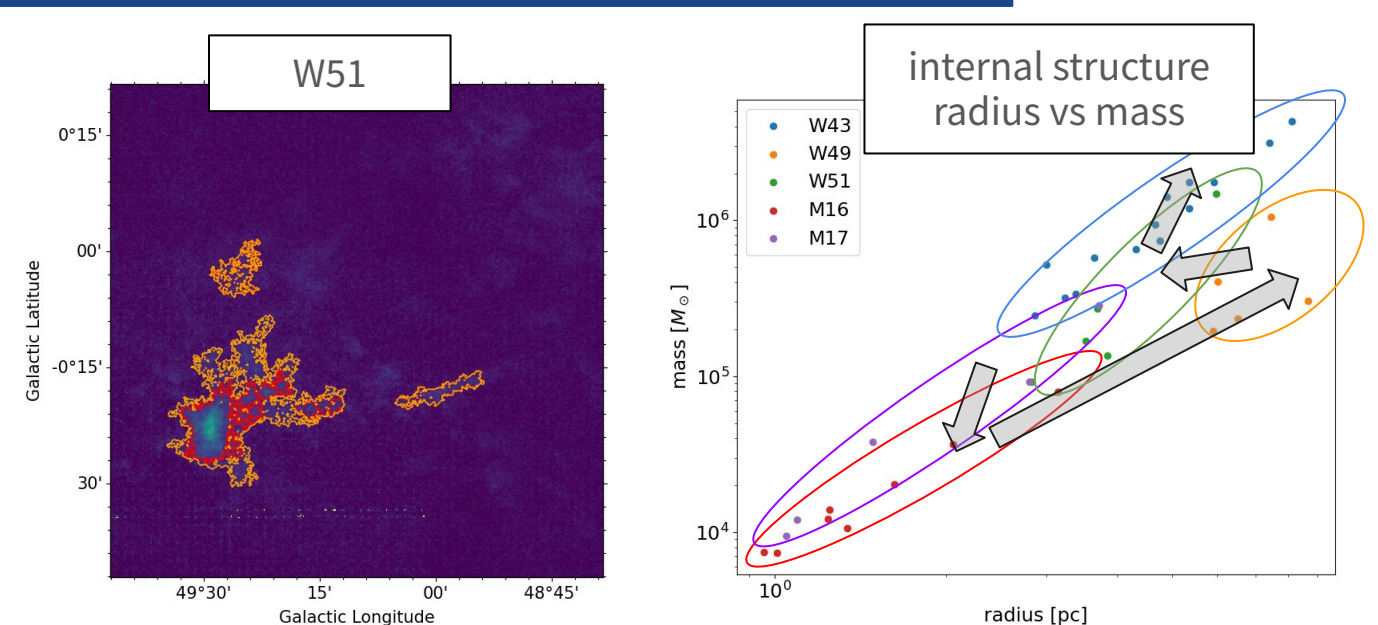
Simulation Analysis (initial mass = $10^6 M_{\odot}$)



2D data: The fluid as a whole (trunk) is contracting while the size and mass of the smaller (internal) structures inside are increase or decrease monotonically. (Same for other initial masses)

3D data: The size and mass of smaller structures (leaf) increase and decrease while the size and mass of larger structures (branch) increase monotonically.

Observation Data Analysis



Following the graph in order of estimated age of molecular clouds (M17 < M16 < W49A < W51A, B < W43 Main), size and mass of the structure are increasing or decreasing on a positive correlation. (Note that it is necessary to take into account the difference in the original mass as well as the evolutionary stage.)

4. DISCUSSION

From the simulation analysis results,

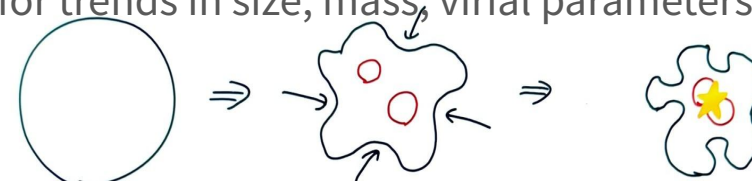
- The entire molecular cloud (trunk) contracts due to self-gravity.
- Internal structures grow into larger structures by repeatedly colliding and merging with each other.

The results of the observational data analysis showed an increase or decrease in size and mass, similar to the internal structure in the simulation.

Molecular cloud collisions on the scale of a few pc to a dozen pc, as in Nishimura+2018, Nishimura+2021, Kohno+2021, and Kondo+2021, are favored as triggers of massive star formation. The internal structures in this study are consistent with these structures in size scale, and it is possible that the increase or decrease in size and mass of such structures is also caused by collisions between them.

These results suggest that collision and growth of internal structures of Giant Molecular Clouds promote massive star formation.

In the future, we would like to analyze and compare simulations with the addition of a magnetic field and further analyze observational data to look for trends in size, mass, virial parameters, etc.



Molecular cloud evolution. It is thought that small-scale structures arise in the interior while contracting as a whole, and that they collide and merge to form efficient star formation.