Simulation and Observational Data Analysis for Understanding the Structural Evolution of Molucular Cloud

Kotora Sasaki[1], Nario Kuno[1], Hajime Fukushima[1], Shinji Fujita[2], Shingo Nozaki[3]

1: University of Tsukuba, Japan 2: The Institute of Statistical Mathematics, Japan
3: Kyushu University, Japan

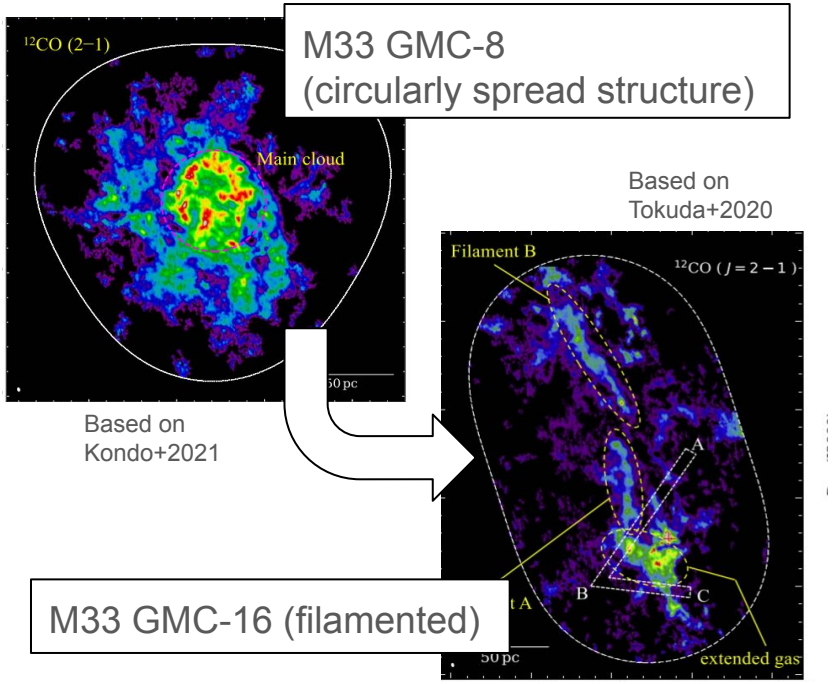
INTRODUCTION

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.

- 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**

METHOD

Simulation data:

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

Observation data:

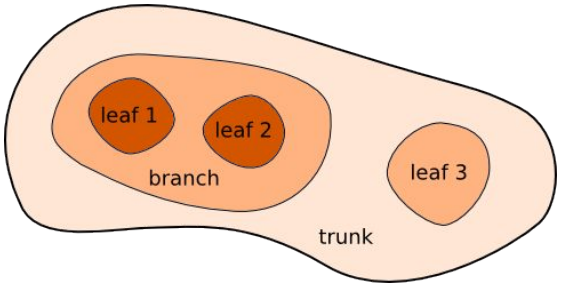
	Distances [kpc]	Class II / I Ratio	Class II III / 0 I Ratio
W43 Main	5.5	4.58 (Saral+2017)	
W49A	11	2.1(Saral+2015)	
W51A, B	5.4	2.50 (Saral+2017)	
M16	1.7		1.7 (Povich+2013)
M17	2.0		1.4 (Povich+2013)

We used Dendrogram for our analysis.

Apply structural analysis methods used in observations to simulations

⇒ **It is easy to compare simulation data with observation data**

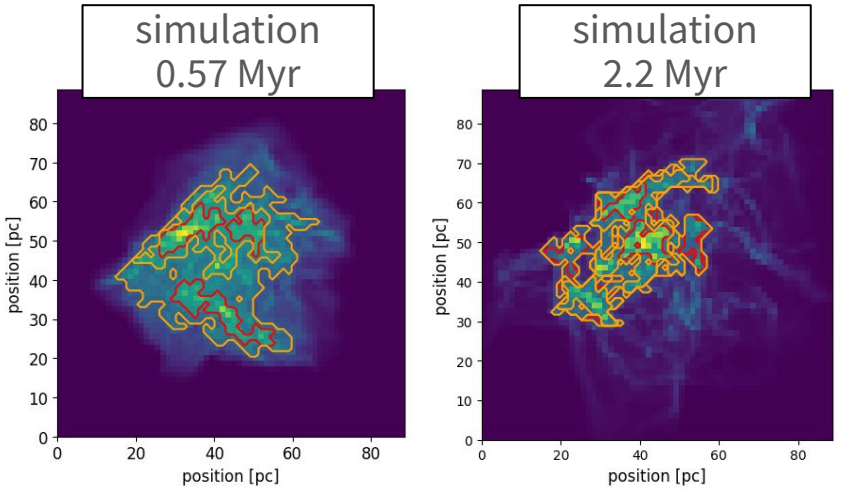
Find and discuss the size, mass, etc. of the structure.

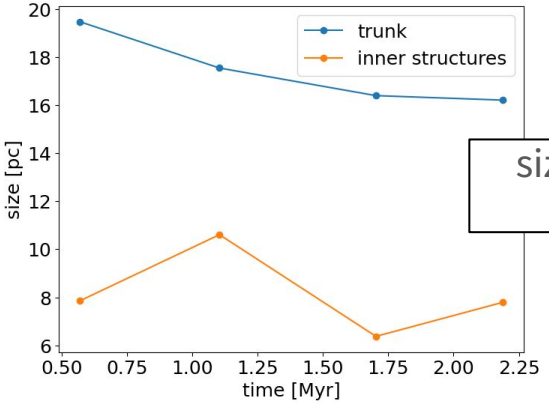


RESULT (SIMULATION DATA)

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.
(Same for all 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.





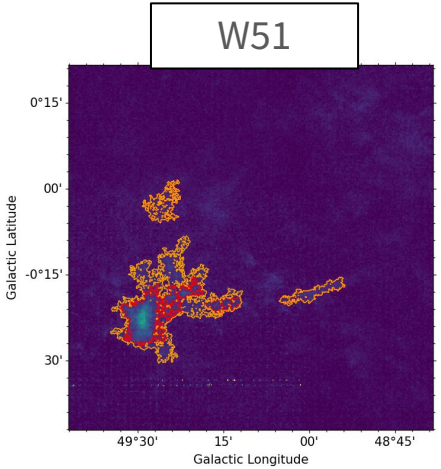
size in simulation
2D data

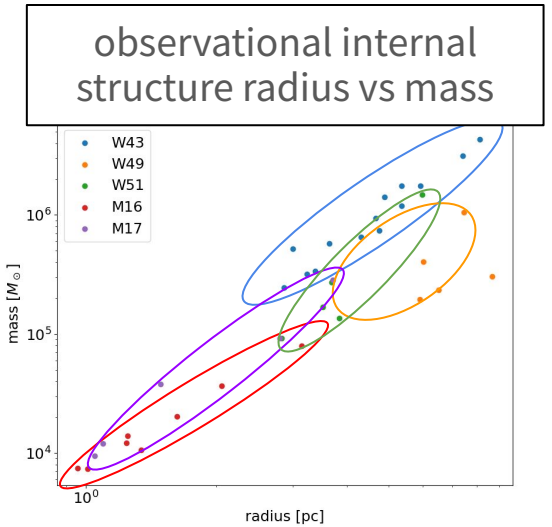
RESULT (OBSERVATION DATA)

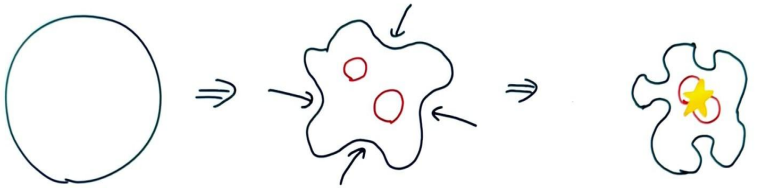
Following the graph in order of estimated age of molecular clouds (M17 < M16 < W49A < W51A, B < W43 Main), size and mass of the structure are increasing or decreasing on a positive correlation. (Note that it is necessary to take into account the difference in the original mass as well as the evolutionary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

It is possible that the increase or decrease in size and mass of such structures is also caused by collisions between them.

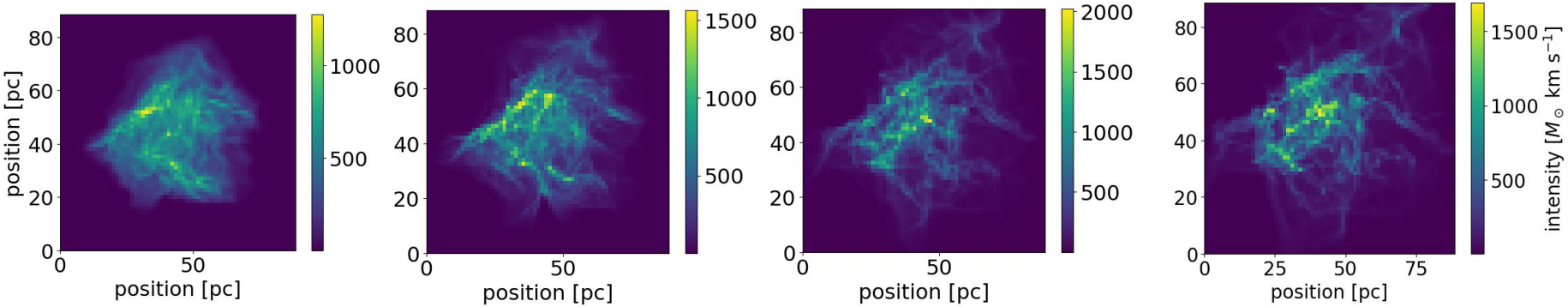
These results suggest that collision and growth of internal structures of Giant Molecular Clouds promote massive star formation.



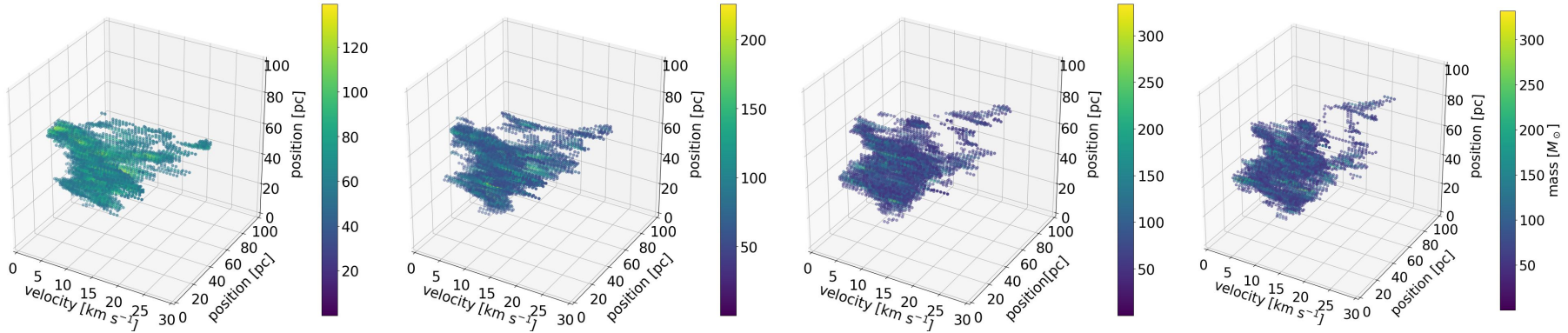




APPENDIX: SIMULATION DATA ($10^6\ M_\odot$)

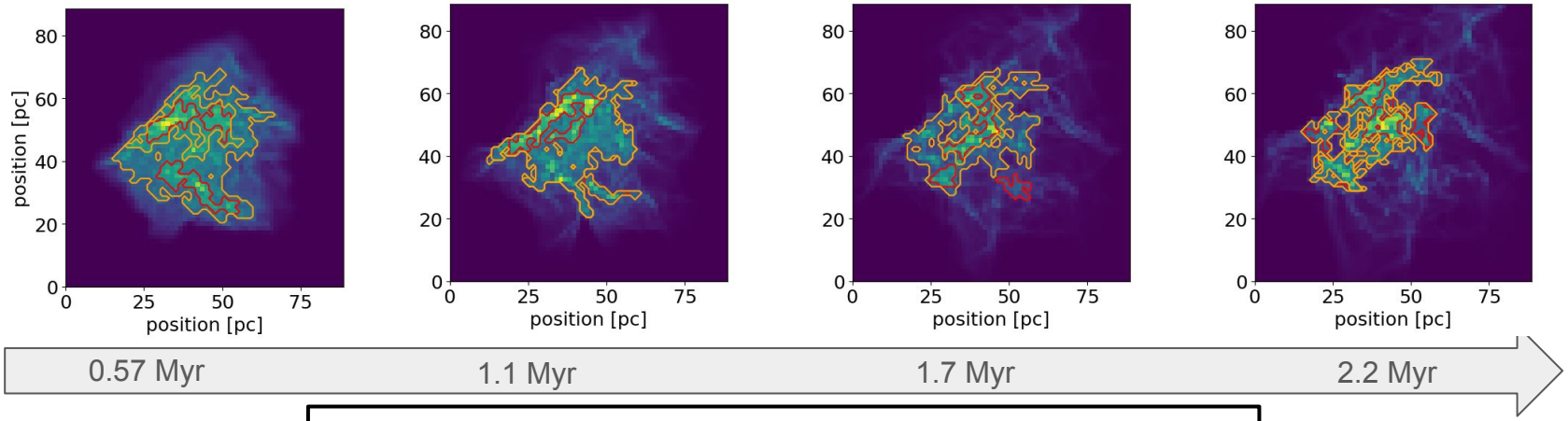


integral intensity map

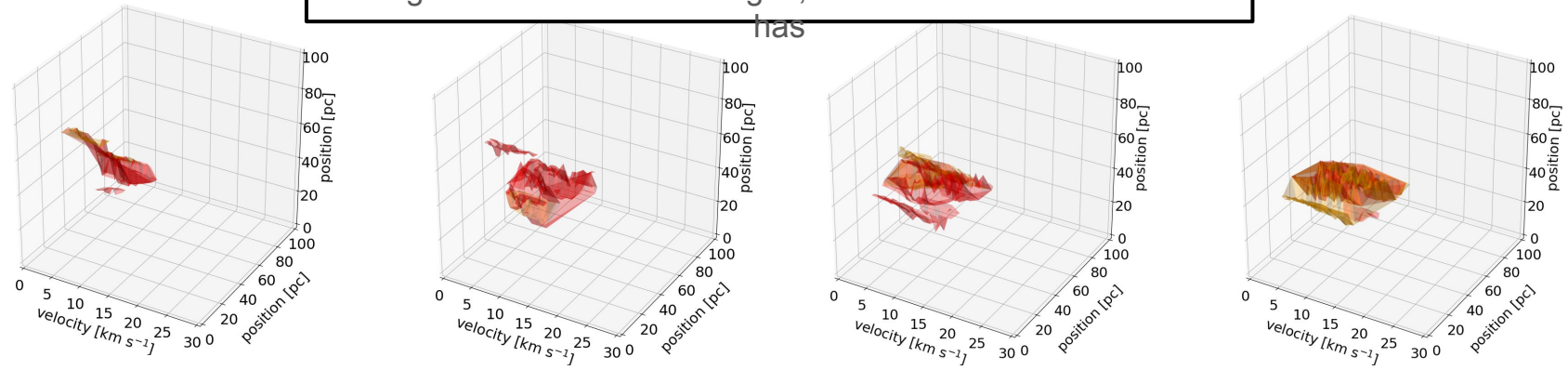


3D scatter plots

APPENDIX: SIMULATION DATA ANALYSIS ($10^6\ M_\odot$)

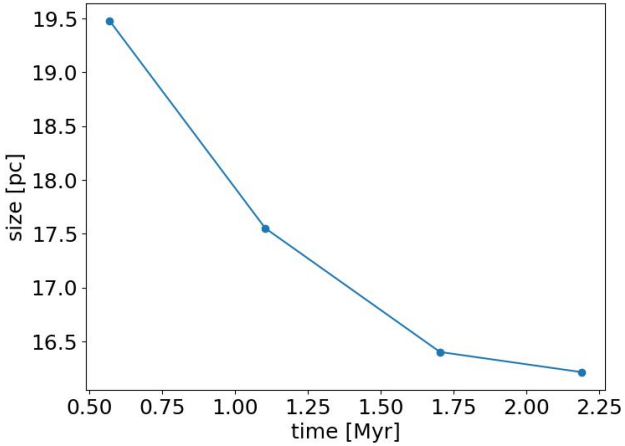


The greater the mass of the gas, the more internal structure it has

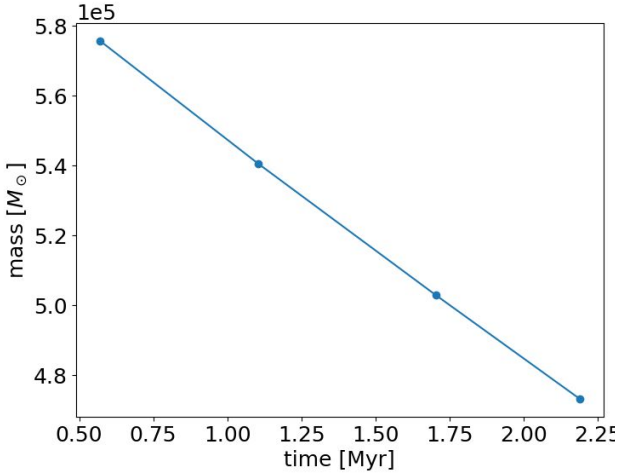


APPENDIX: TRUNK CHANGE ($10^6\ M_\odot$)

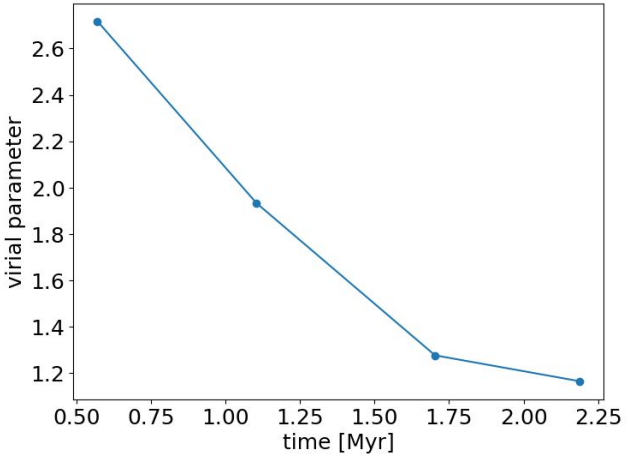
size

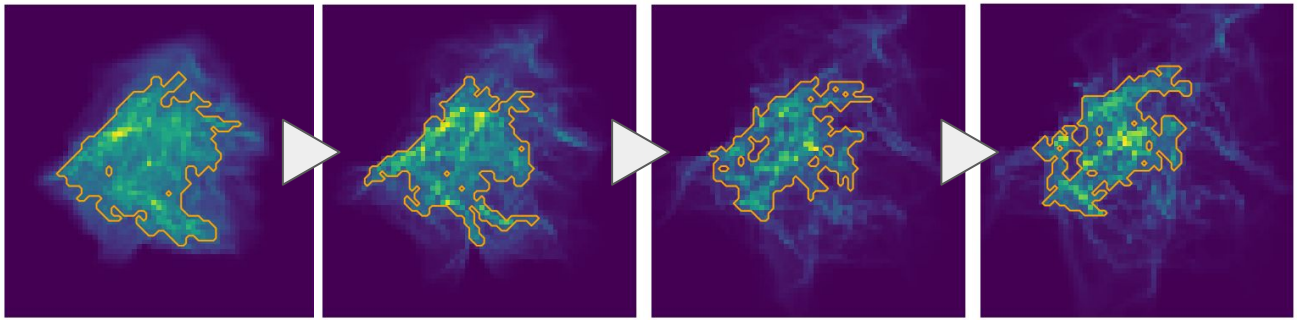


mass



virial parameter

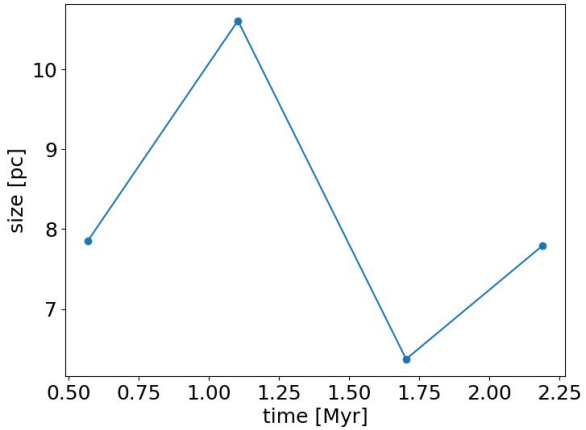




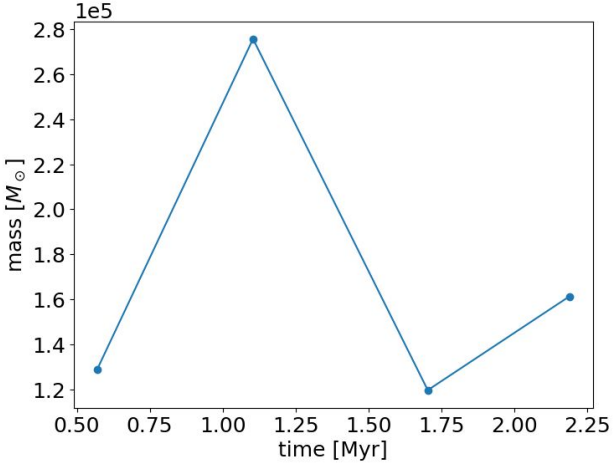
All are decreasing, corresponding to changes in the overall molecular cloud.

APPENDIX: INTERNAL STRUCTURE CHANGE (10^6 $M_\odot$)

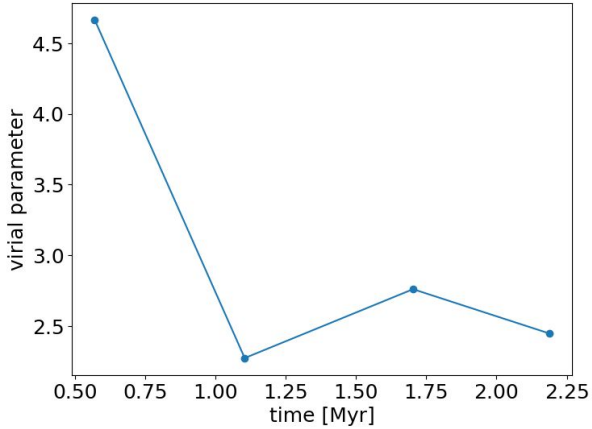
size average

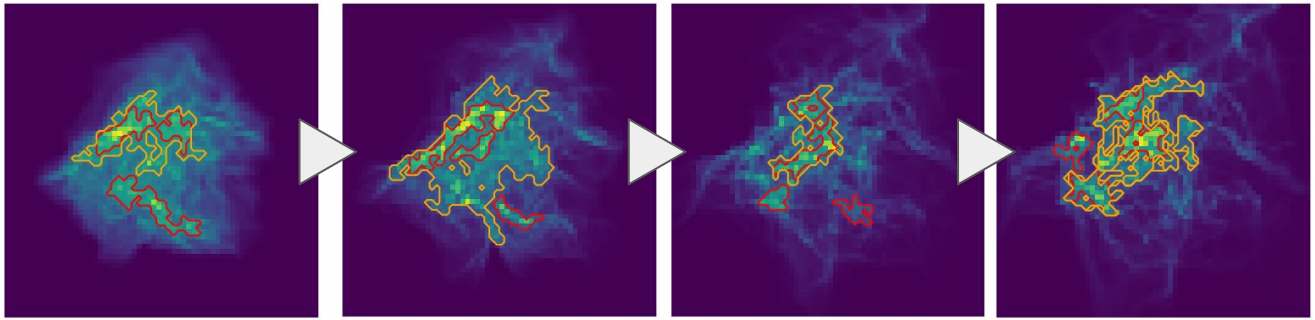


mass average



virial parameter average

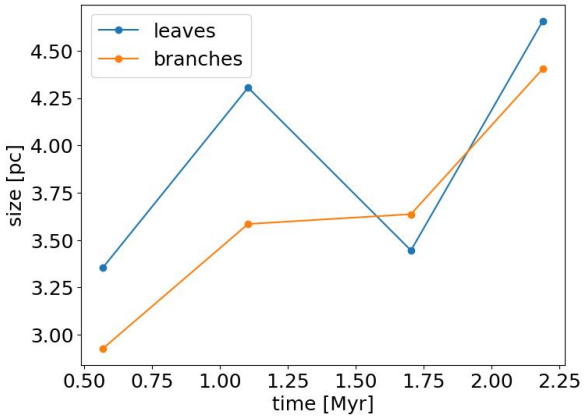




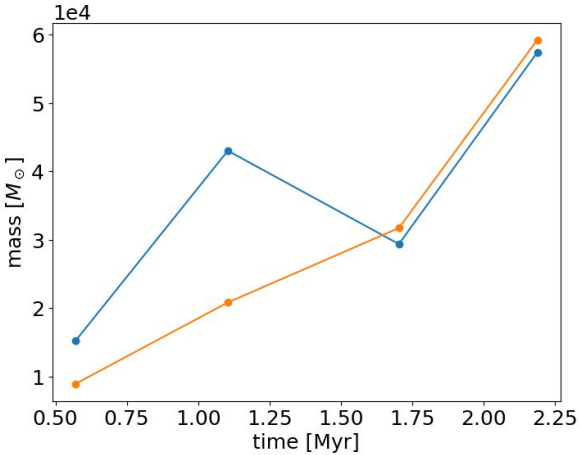
Corresponding to the internal structure of molecular clouds, all of which increase and decrease repeatedly.

APPENDIX: 3D DATA CHANGE (10^6 $M_\odot$)

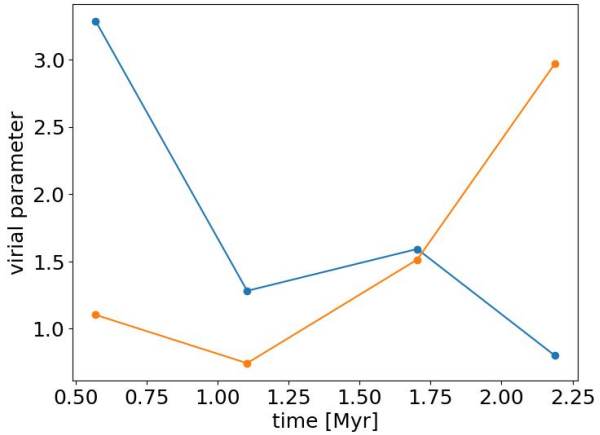
size average

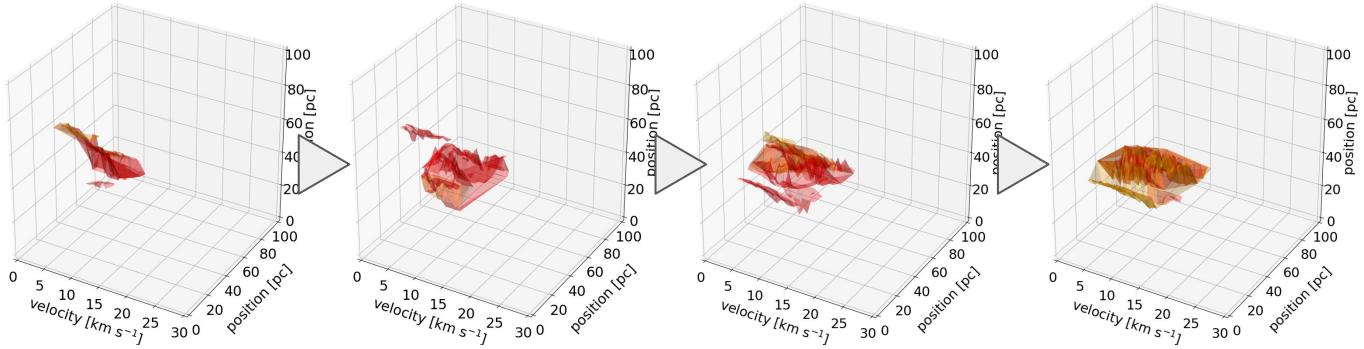


mass average



virial parameter average

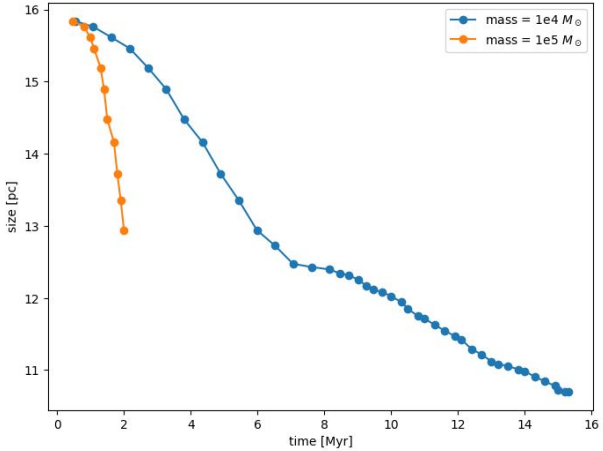




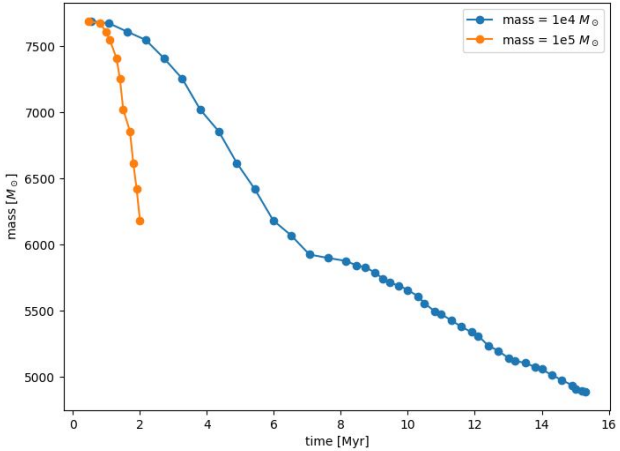
Internal structure is considered in more detail and grows with repeated increases and decreases

APPENDIX: TRUNK CHANGE (10^4, 10^5 $M_\odot$)

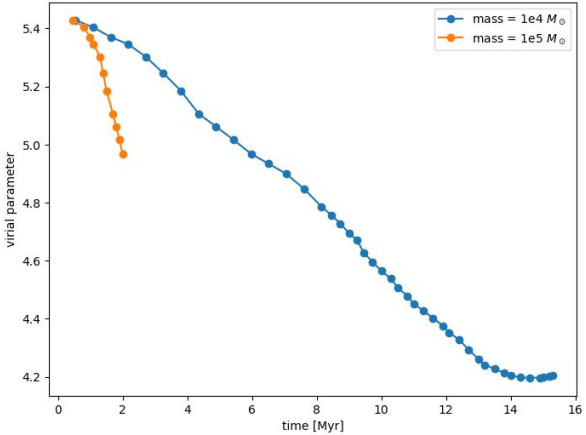
size



mass



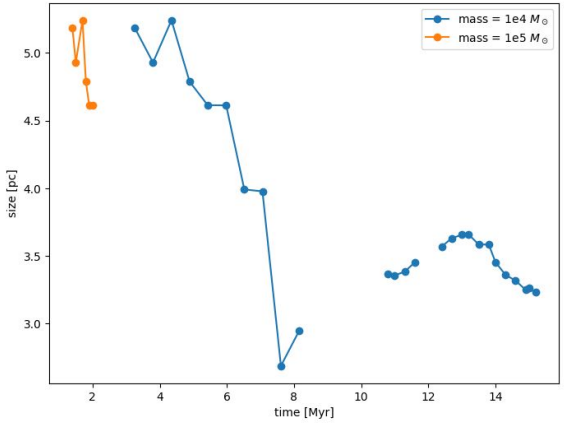
virial parameter



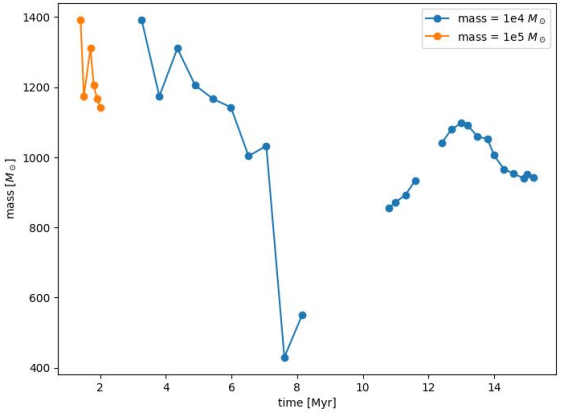
All are decreasing

APPENDIX: INTERNAL STRUCTURE CHANGE (10^4, 10^5 $M_\odot$)

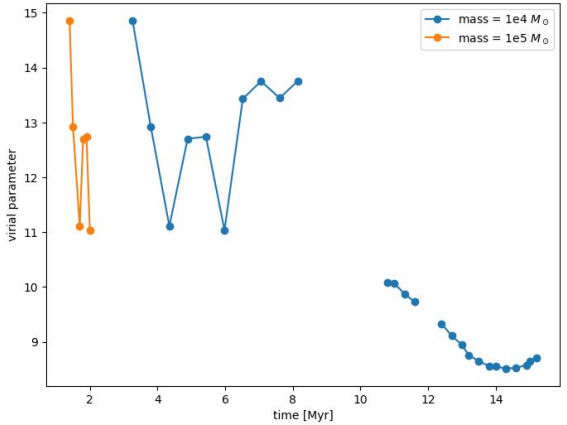
size average



mass average



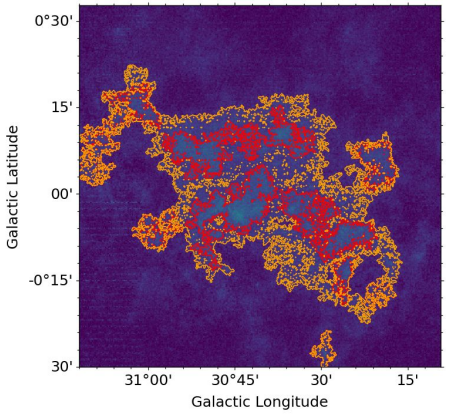
virial parameter average



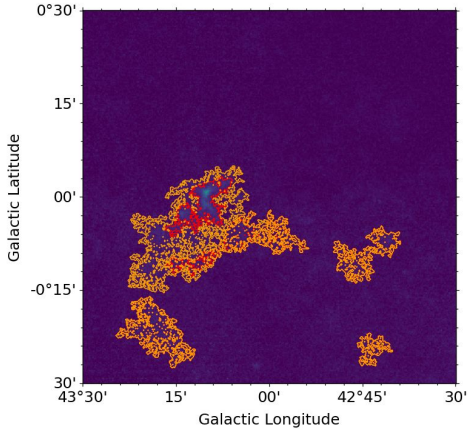
All are increasing or decreasing, but the larger masses are more frequent for shorter periods of time.

APPENDIX: OBSERVATION DATA ANALYSIS

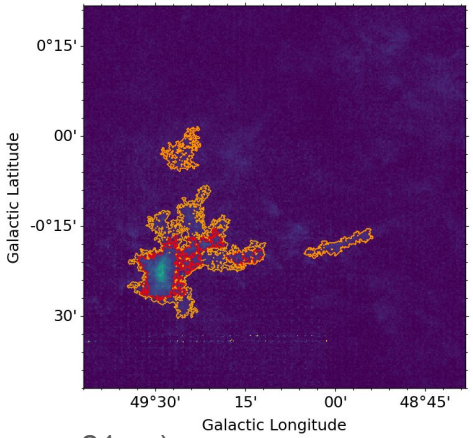
W43 (100 pc × 100 pc)



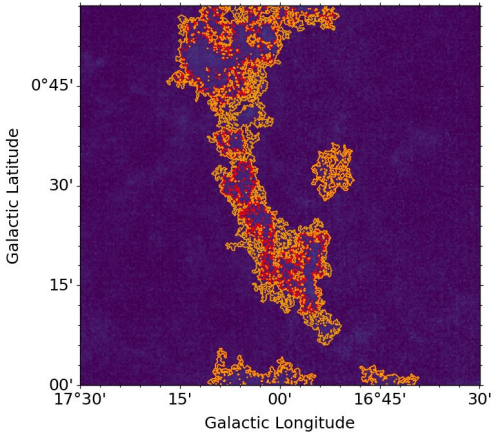
W49 (100 pc × 100 pc)



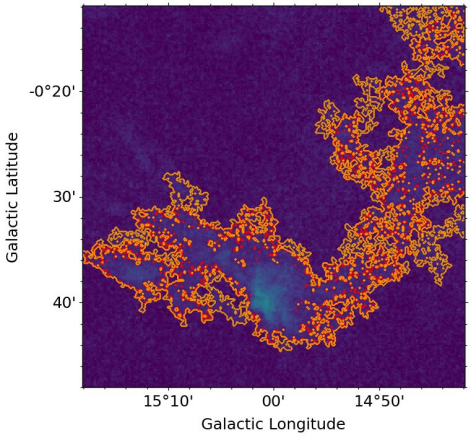
W51 (100 pc × 100 pc)



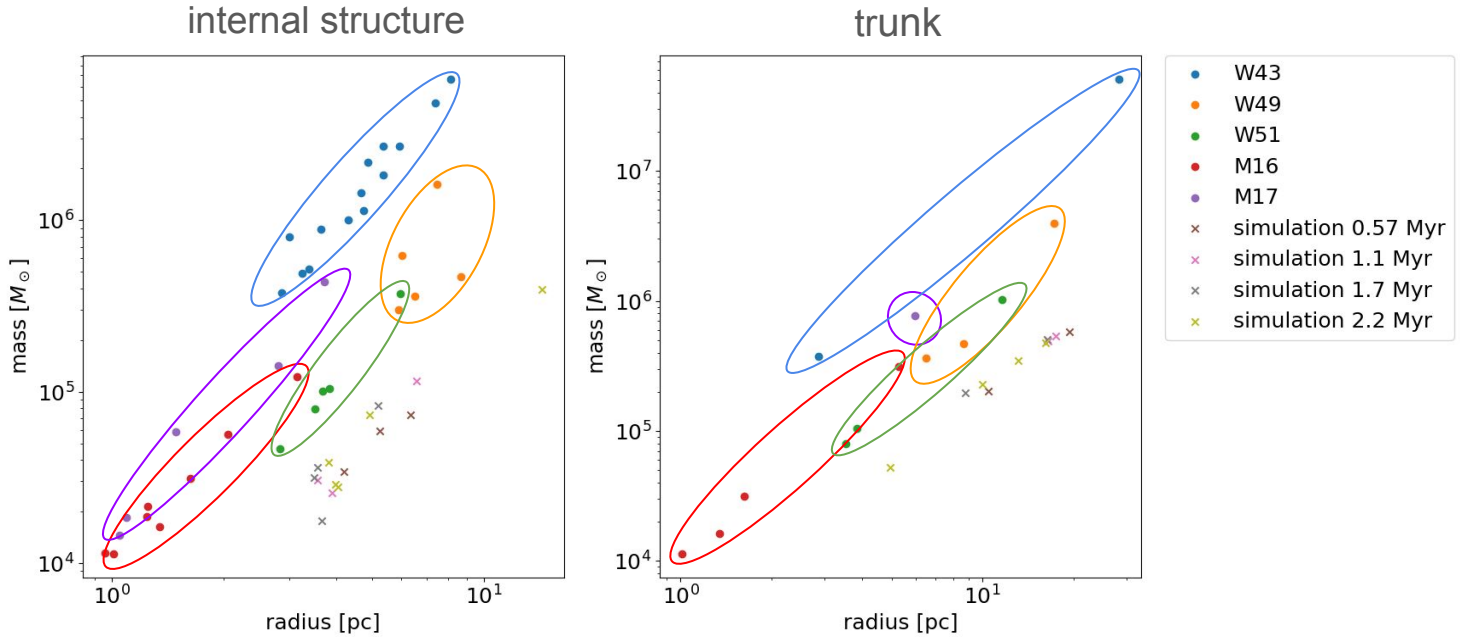
M16 (30 pc × 30 pc)



M17 (21 pc × 21 pc)



APPENDIX: OBSERVATION DATA SIZE VS MASS



APPENDIX: OBSERVATION DATA SIZE VS VIRIAL