

# Progress Report

Kotora Sasaki

# About me

Name: Kotori Sasaki

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Hobbies: listening and playing music!



# Introduction: star formation from molecular clouds

Among the various types of interstellar matter in the universe, molecular clouds are responsible for star formation. However, the process of star formation by molecular clouds remains a mystery.

To understand star formation, it is necessary to construct a consistent scenario.

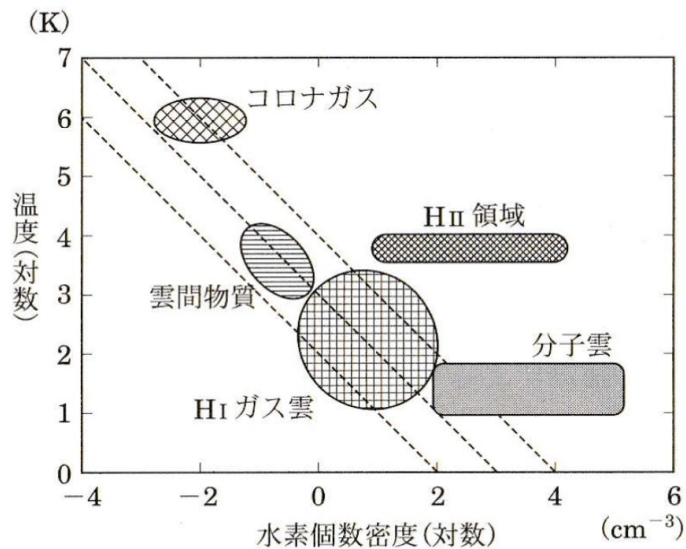


Molecular clouds and ionized regions of M42  
(NASA, ESA, M. Robberto (Space Telescope Science Institute/ESA) and the Hubble Space Telescope Orion Treasury Project Team)

# Introduction: importance of considering simulation

It is difficult to understand the star formation process from only observational data:

- In the 10 million years of time it takes to form a star, the observational data only looks at that one moment in time.
  - Direct observation of star formation is difficult due to the thick optical gas at the site.
- Especially in the field of star formation, studies using not only observations but also simulated data are very important.

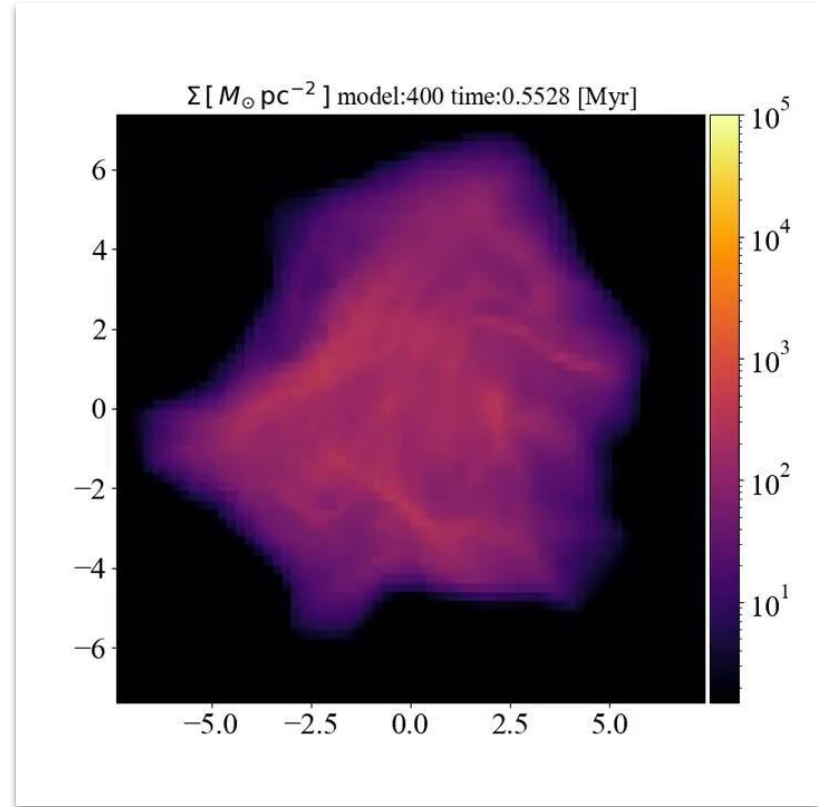


天文学辞典(日本天文学会)

# Introduction: previous work

In the simulations, no structural indicators for gravity contraction have been identified.

If such indicators were known, it would make comparisons with observed data easier.



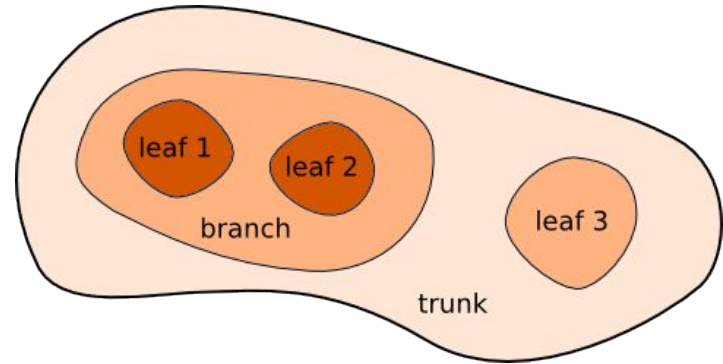
A density-uniform fluid corresponding to a giant molecular cloud being compressed by self-gravity. (Fukushima-san)

# Method: use dendrogram for analysis

The dendrogram in the `astrodendro` package is used for the analysis.

The dendrogram classifies data into leaves, which are the smallest structures, and branches, which have internal structures.

In the data, the more gas is gathered, the more complex the internal structure.

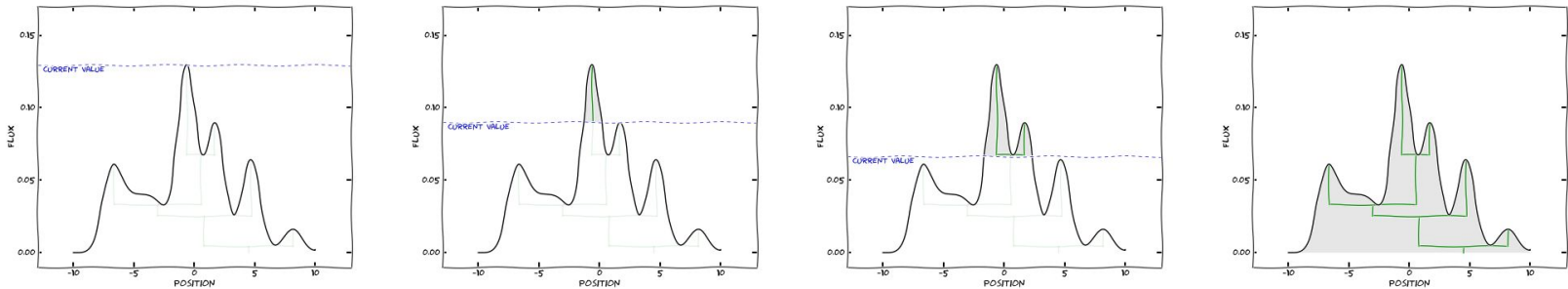


<https://dendrograms.readthedocs.io/en/stable/>

# Method: how the dendrogram algorithm works

In the dendrogram algorithm, the tree is built from the pixel/voxel with the highest value in the dataset and gradually other pixels/voxels are added.

In the figure, the current value descends from the maximum value, and the first leaf is generated with that value as the peak. When the current value reaches the second peak, the second leaf is generated independently. In the third figure, the two leaves are merged into a branch. Eventually, we end up with a single tree in this example.



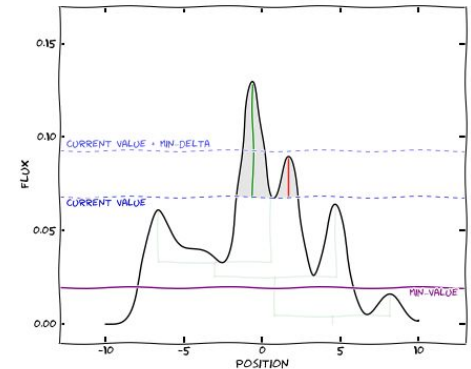
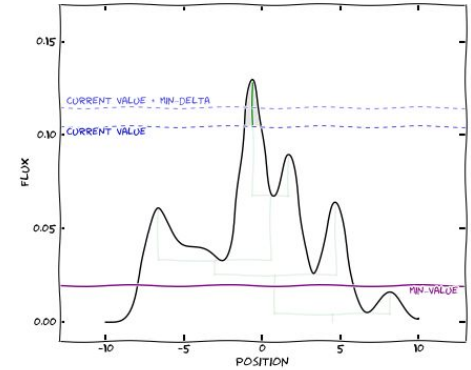
# Method: three parameters of the dendrogram

When running the dendrogram, the following three parameters are required:

`min_value`: any value lower than this will not be considered in the dendrogram.

`min_delta`: how significant a leaf has to be in order to be considered an independent entity. The significance is measured from the difference between its peak flux and the value at which it is being merged into the tree.

`min_npix`: the minimum number of pixels/voxels needed for a leaf to be considered an independent entity.



# Method: simulation data

The simulation data are divided into four stages according to time evolution.

Real time:

- m400: 0.5702 Myr
- m1000: 1.104 Myr
- m2200: 1.703 Myr
- m2800: 2.188 Myr

These are three-dimensional numpy arrays with the gas mass in the position-position-velocity coordinates.

size: (64, 64, 39)

About data:

- Self-gravitational AMR (M)HD + Sink particles
- No magnetic field

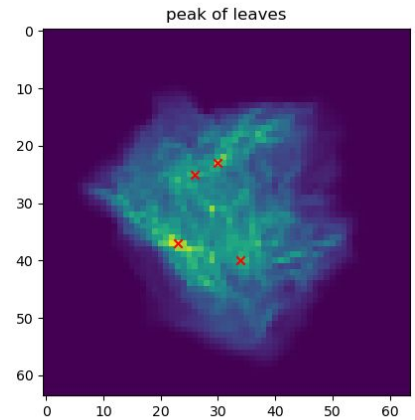
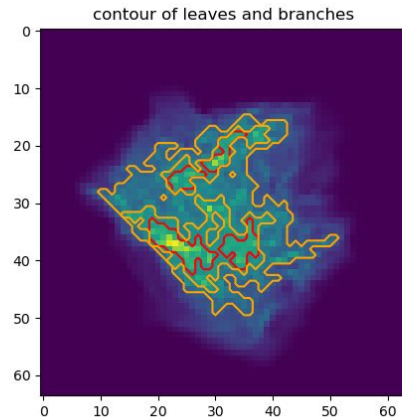
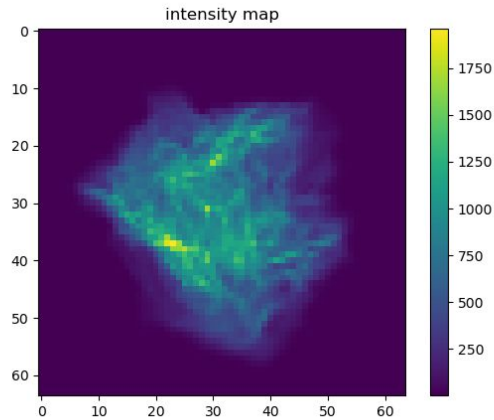


(Matsumoto 2007, 2015)

- Non-Equilibrium chemistry
  - H, H<sub>2</sub>, H<sup>+</sup>, H<sup>-</sup>, H<sub>2</sub><sup>+</sup>, e, CII, OI, OII, OIII, CO
- Heating and Cooling
  - Photoionization and photodissociation heating
  - Line cooling (CII, CO, OI, OII, OIII), dust cooling
  - Chemical heating and cooling
- Metal transfer  
(Sugimura et al. 2020, CO network:Nelson & Langer 1997)

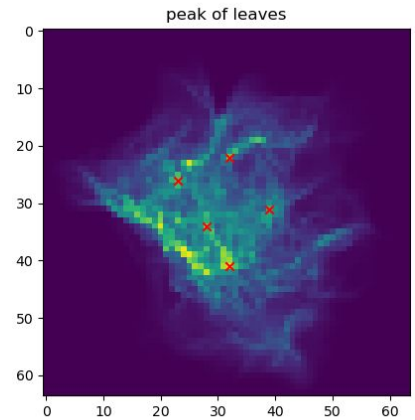
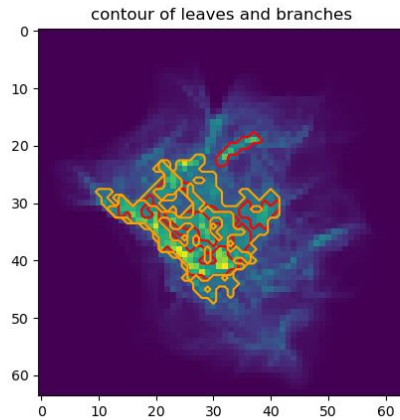
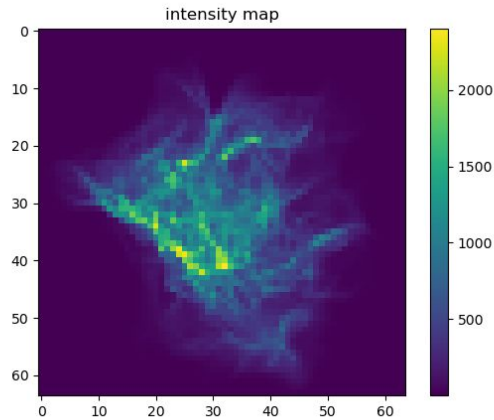
# Results: m400 (intensity map)

min\_value = 600, min\_delta = 200, min\_npix = 15



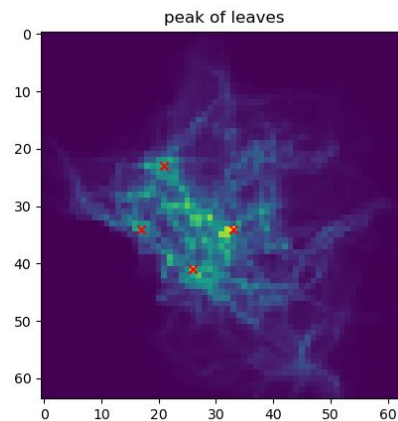
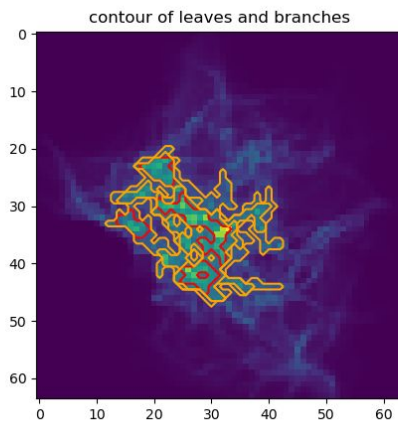
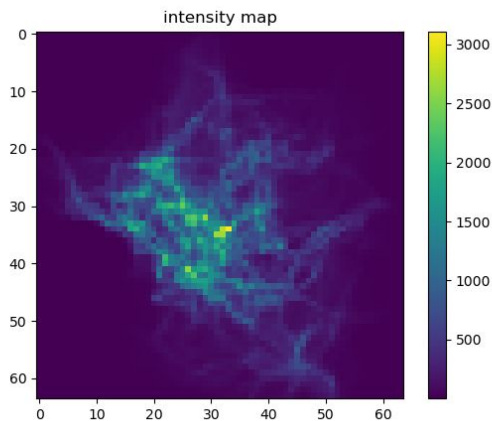
# Results: m1000 (intensity map)

min\_value = 800, min\_delta = 200, min\_npix = 15



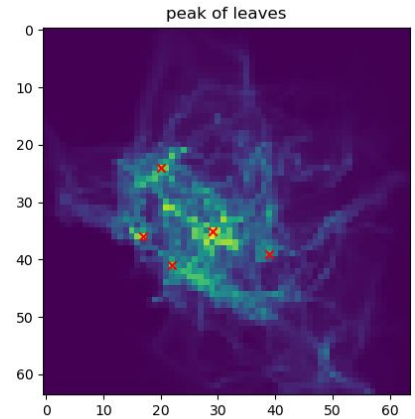
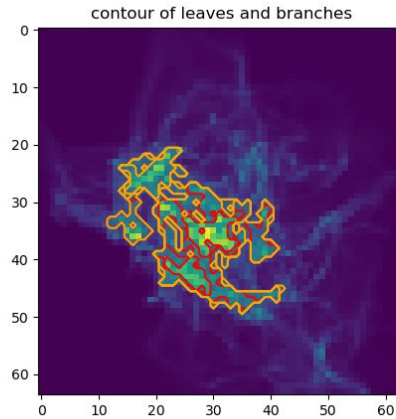
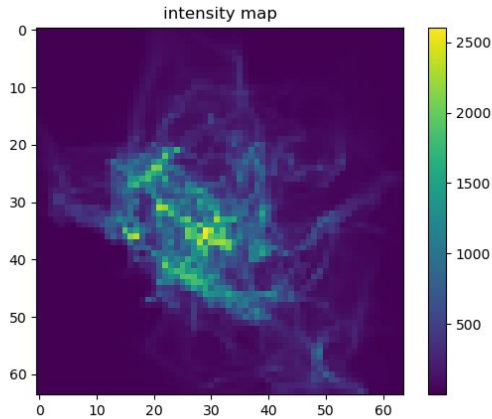
# Results: m2200 (intensity map)

min\_value = 700, min\_delta = 200, min\_npix = 15



# Results: m2800 (intensity map)

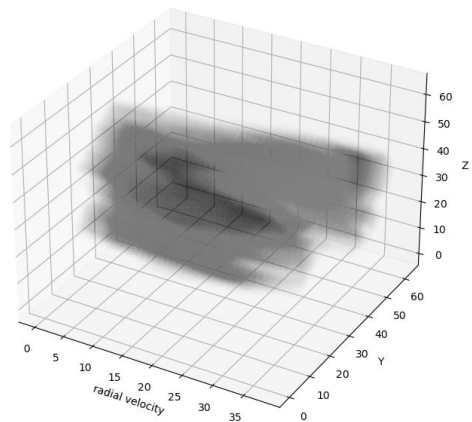
min\_value = 700, min\_delta = 200, min\_npix = 15



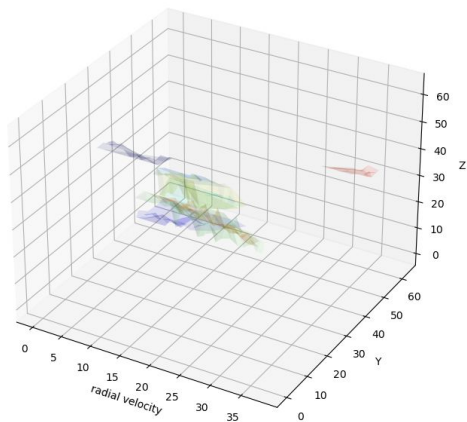
# Result: m400 (3D)

min\_value = 50, min\_delta = 20, min\_npix = 50

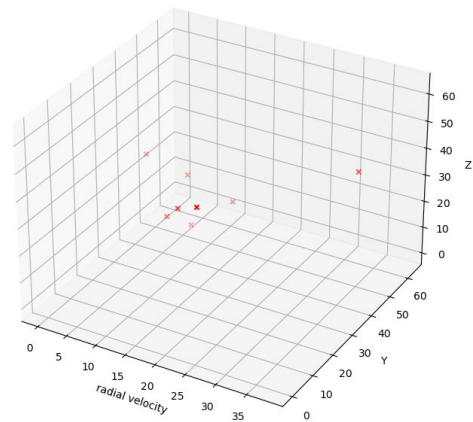
3D map



contour of leaves



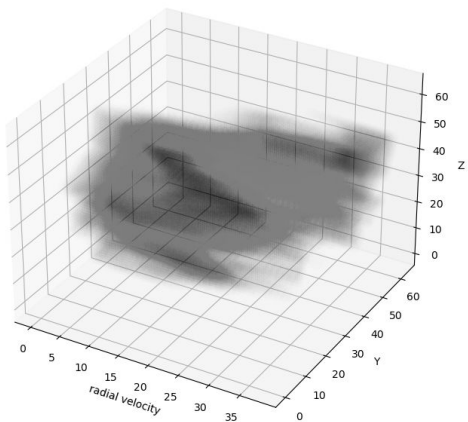
peak of leaves



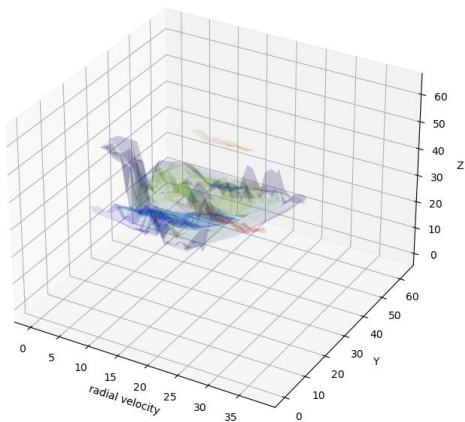
# Results: m1000 (3D map)

min\_value = 50, min\_delta = 20, min\_npix = 50

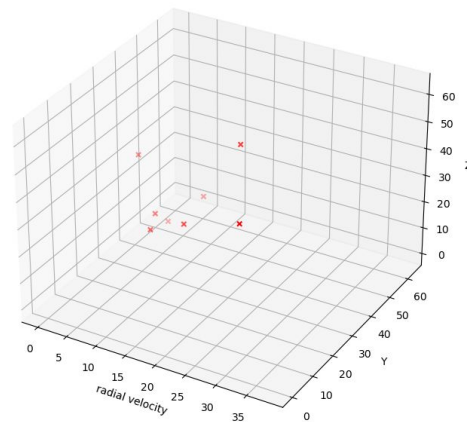
3D map



contour of leaves



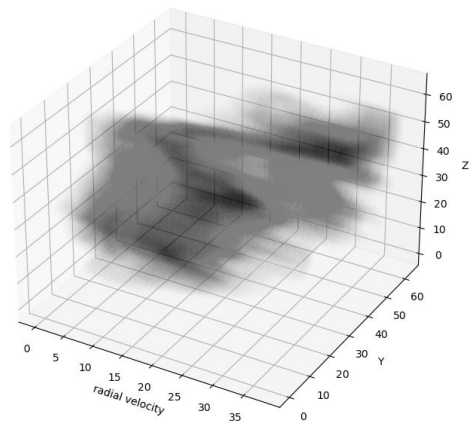
peak of leaves



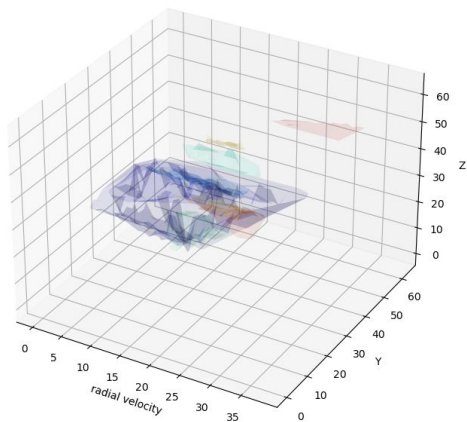
# Results: m2200 (3D map)

min\_value = 50, min\_delta = 20, min\_npix = 50

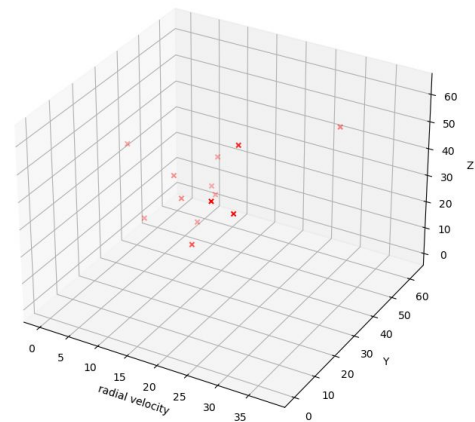
3D map



contour of leaves



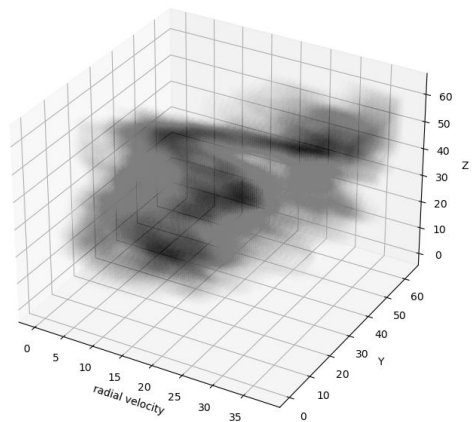
peak of leaves



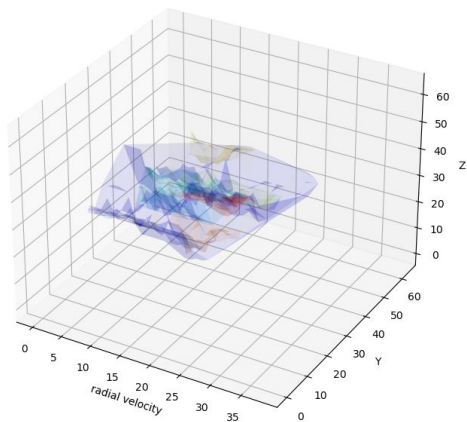
# Results: m2800 (3D map)

min\_value = 50, min\_delta = 20, min\_npix = 50

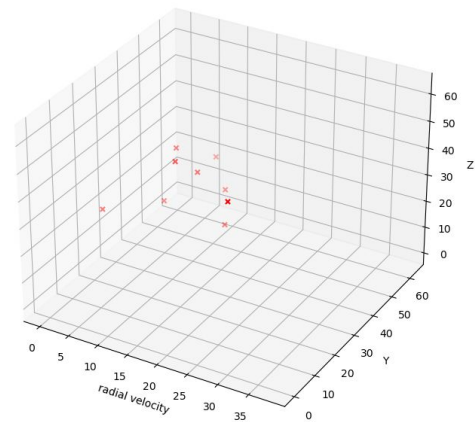
3D map



contour of leaves

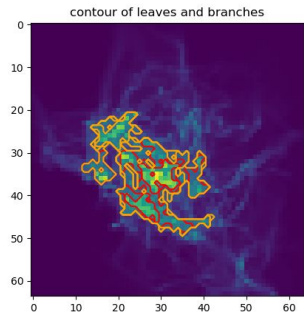
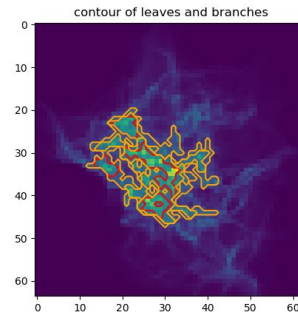
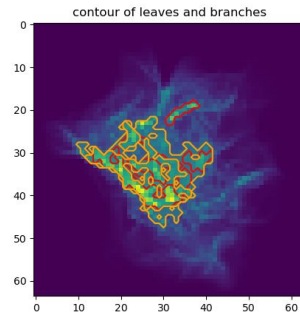
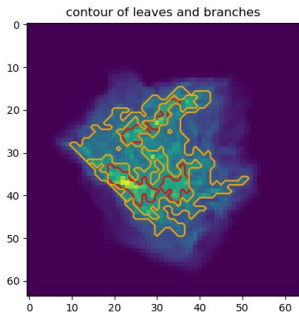


peak of leaves



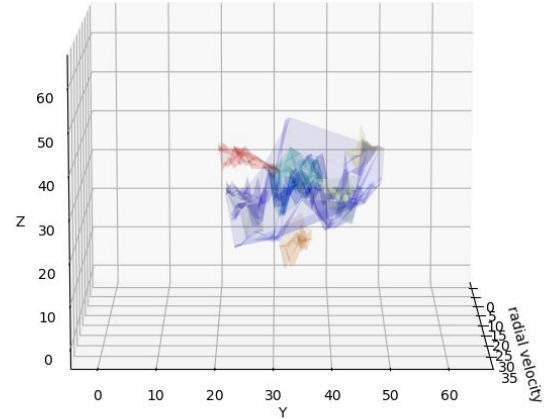
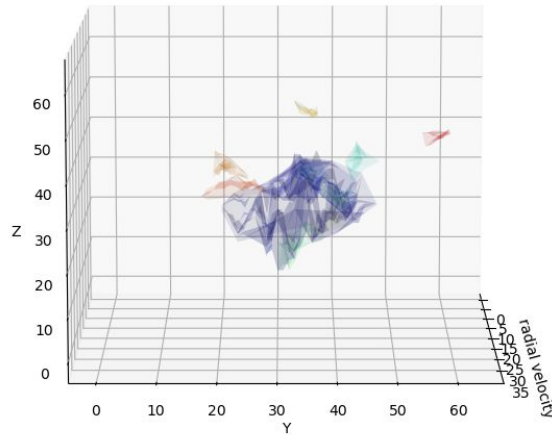
# Discussion: leaf size variation in 2D

- Dendrogram analysis of both the integrated intensity and 3D scatter plots shows that as time evolves, the gas contracts and localized areas of mass concentration are generated.
- The size of the trunk decreases from m400 to m2200 while the size of the trunk increases from m2200 to m2800.



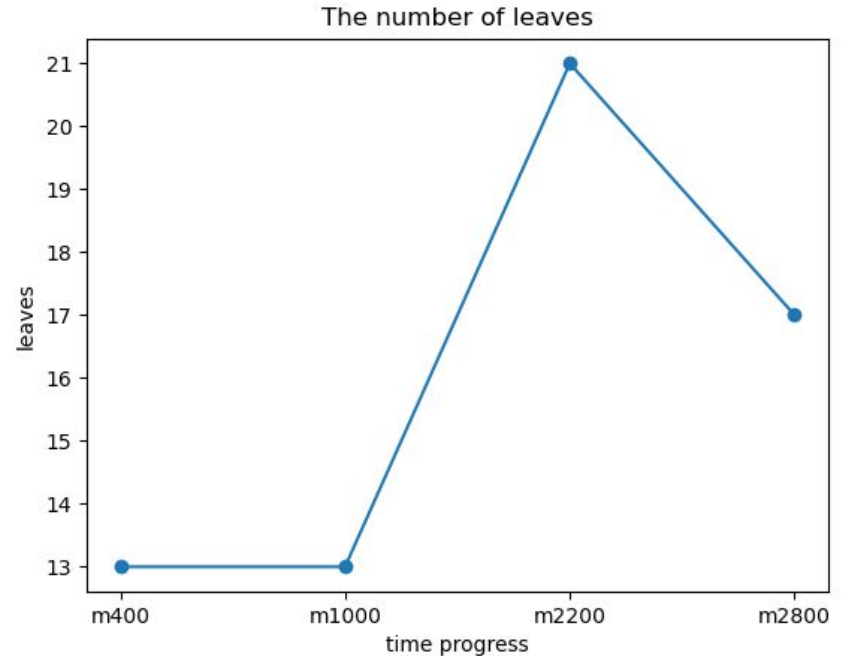
# Discussion: leaf size variation in 3D

- The same trend of larger leaves from m2200 to m2800 is observed in the dendrogram analysis of the three-dimensional scatter plots.



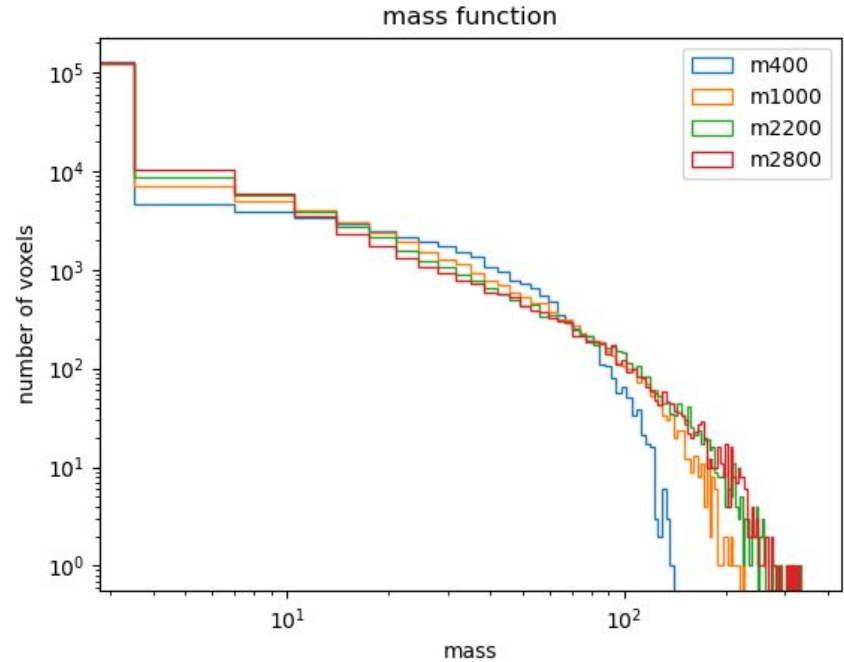
# Discussion: the number of leaves is extreme at m2200

- In the dendrogram analysis of the 3D scatter plots, the number of leaves peaks at m2200 and decreases during the period up to m2800. This trend was observed even after changing the conditions to some extent.
- It is possible that the leaves are dissipating for some reason, or that different leaves are merging with each other.



# Discussion: comparison with mass function

- The mass function shows that the speed of mass increase is gradually slowing down.



# Summary

- In order to understand the process of star formation by molecular clouds, simulated gas cloud data were analyzed.
- The results of dendrogram analysis showed gas accumulation.
- From changes in the number and size of leaves, there was a possibility of collapse or collision in the high-mass areas.

## Future:

- Temperature-related analysis using BDF
- Comparison with observed data