Cosmic Web Reconstruction through Density Ridges

Yen-Chi Chen

Shirley Ho Peter E. Freeman
Christopher R. Genovese Larry Wasserman

Department of Statistics
McWilliams Center for Cosmology
Carnegie Mellon University

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Outline

- Introduction
- Model and Algorithm
- Analysis

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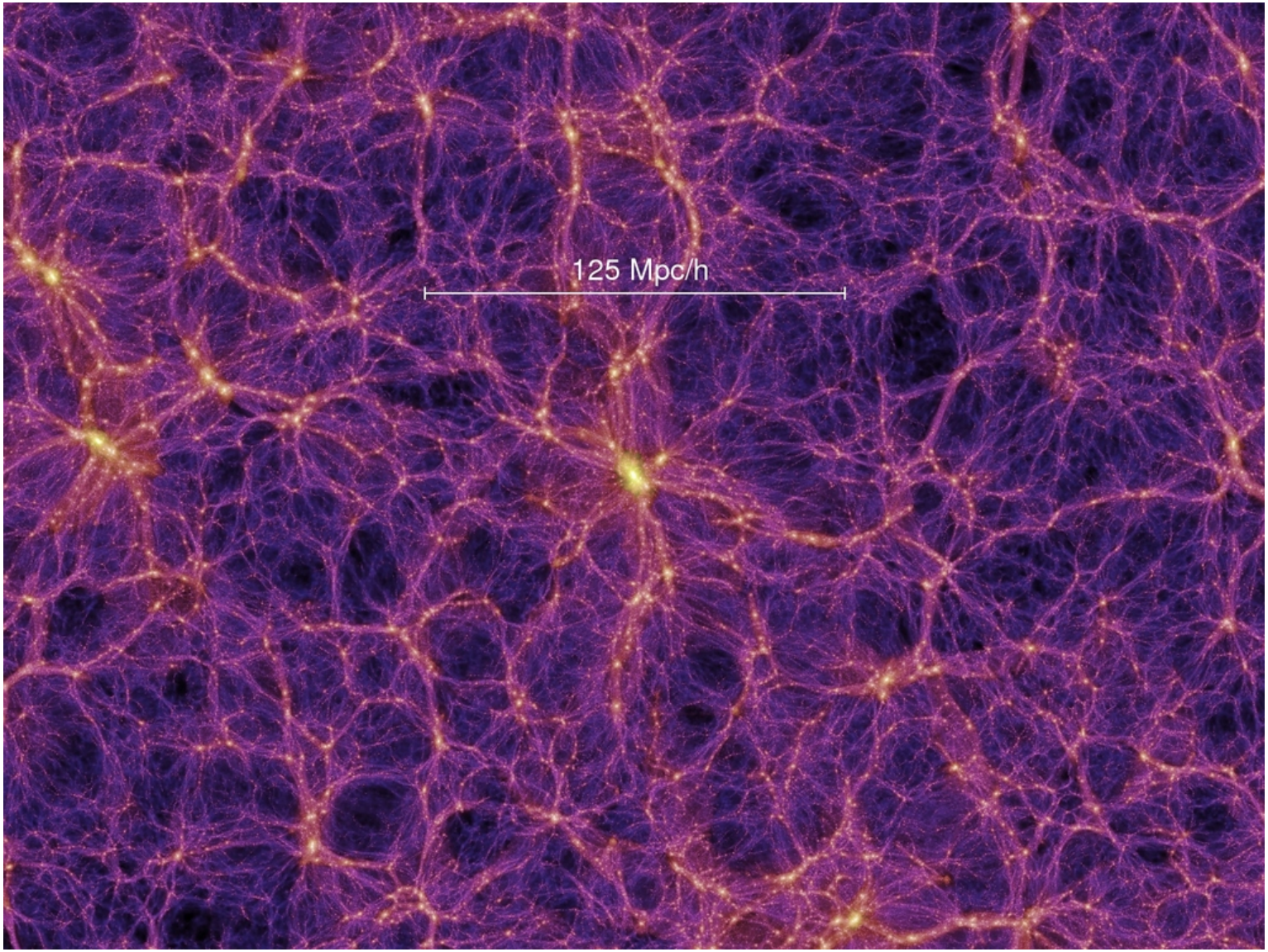
Cosmic Web: What Does Our Universe Look Like



Credit: Millennium Simulation

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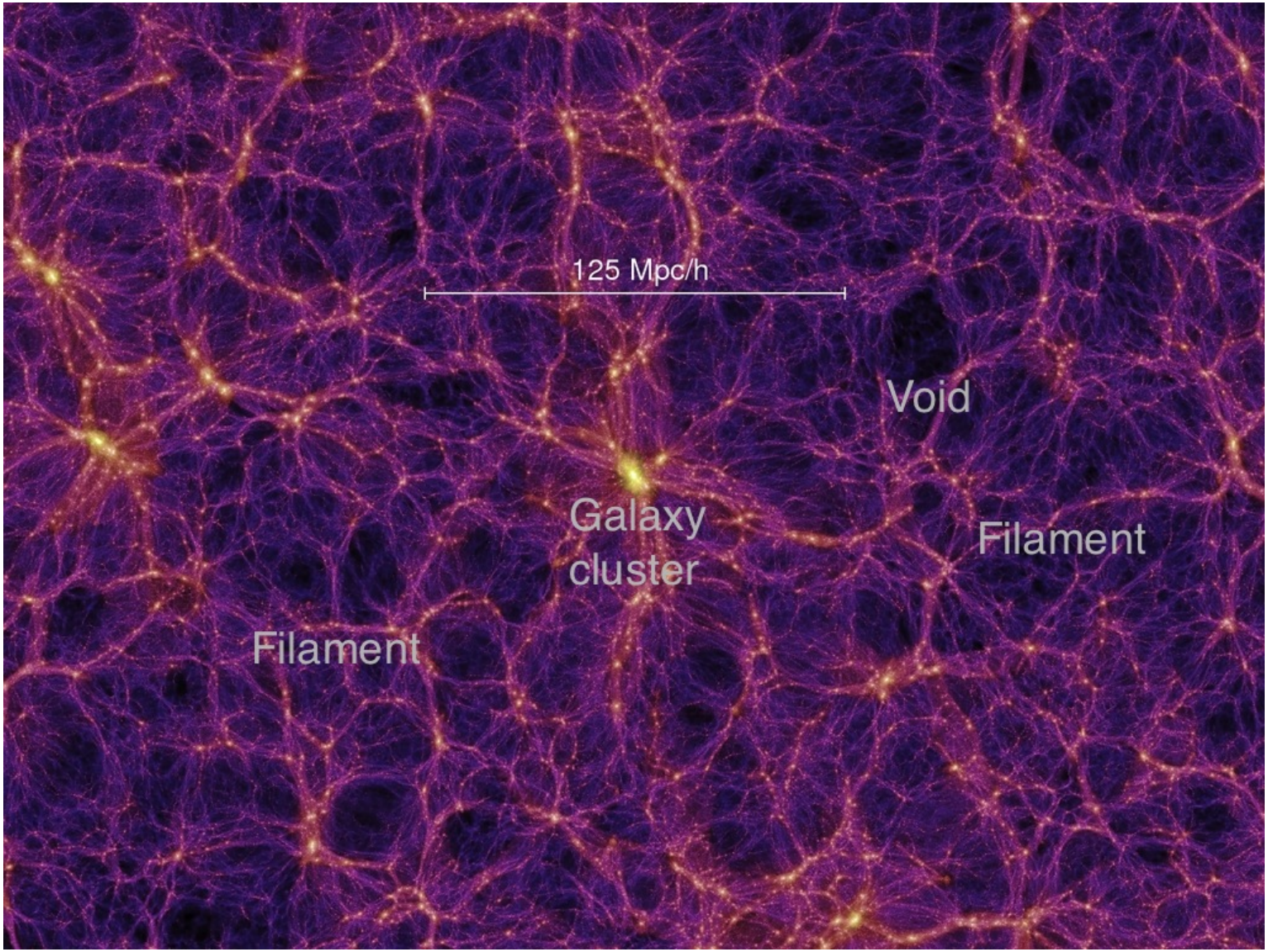

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Focus of the Research: Filaments

Why filament?

- Galaxies tend to concentrate around filaments.

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- Several properties of a galaxy are influenced by filaments.

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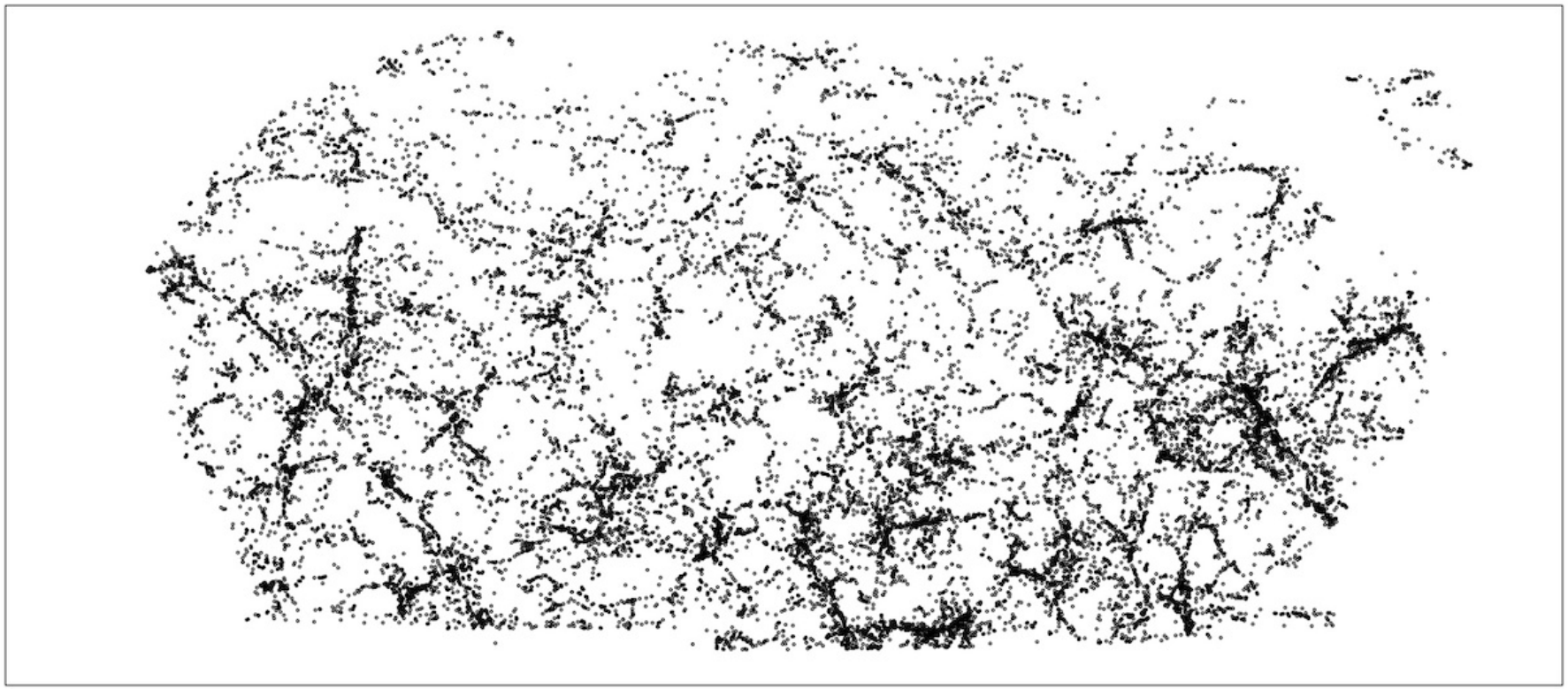
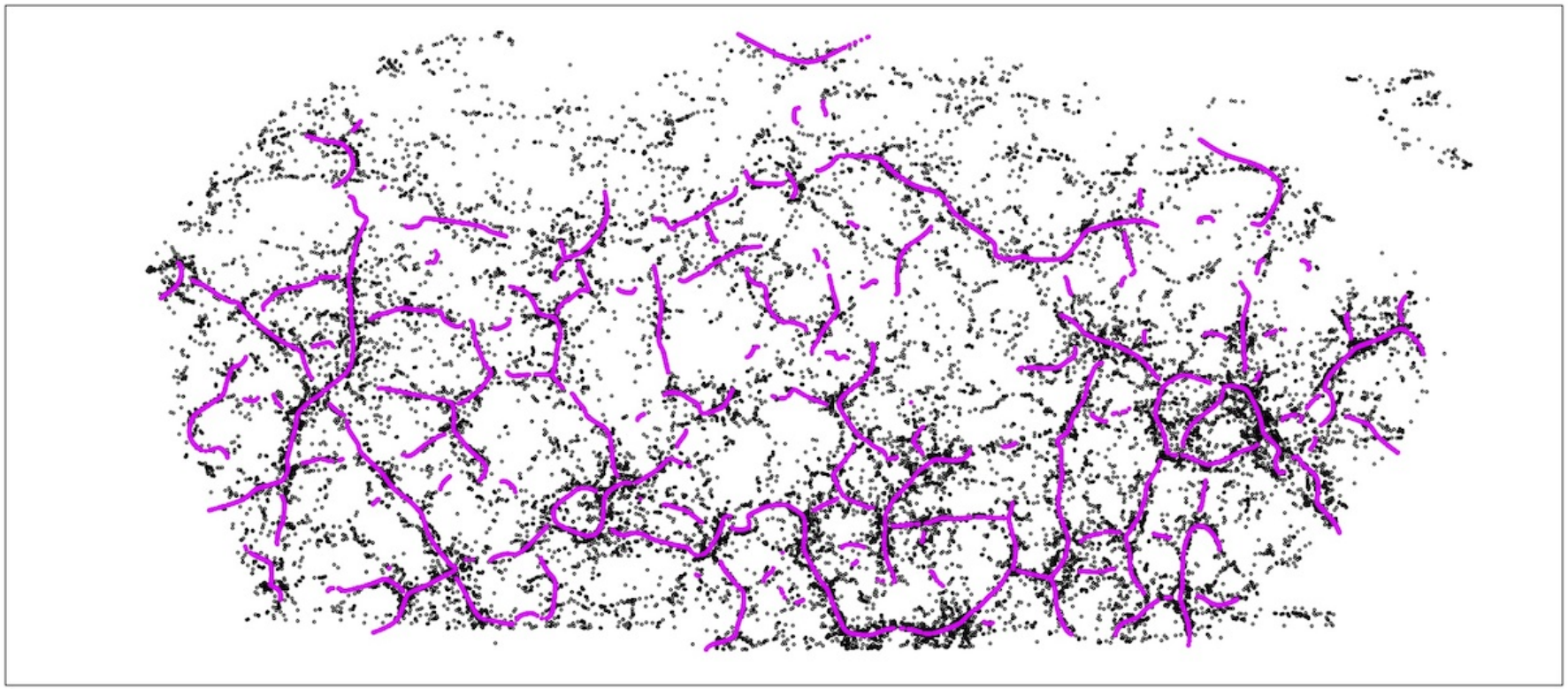
An Example



An Example



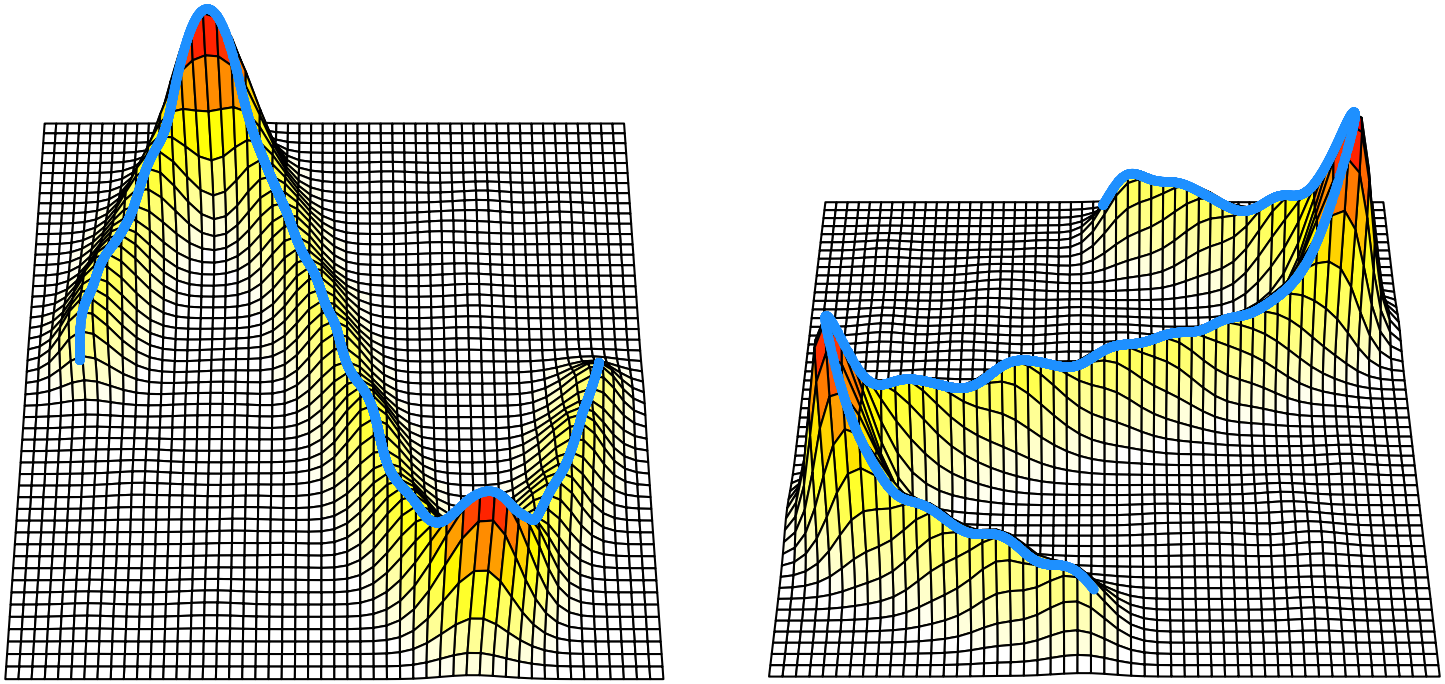
Statistical Model for Filaments: Density Ridges

Formally, we define a filament to be a **ridge** of the density.

Example: Ridges in Mountains

Credit: Google

Example: Ridges in Smooth Functions



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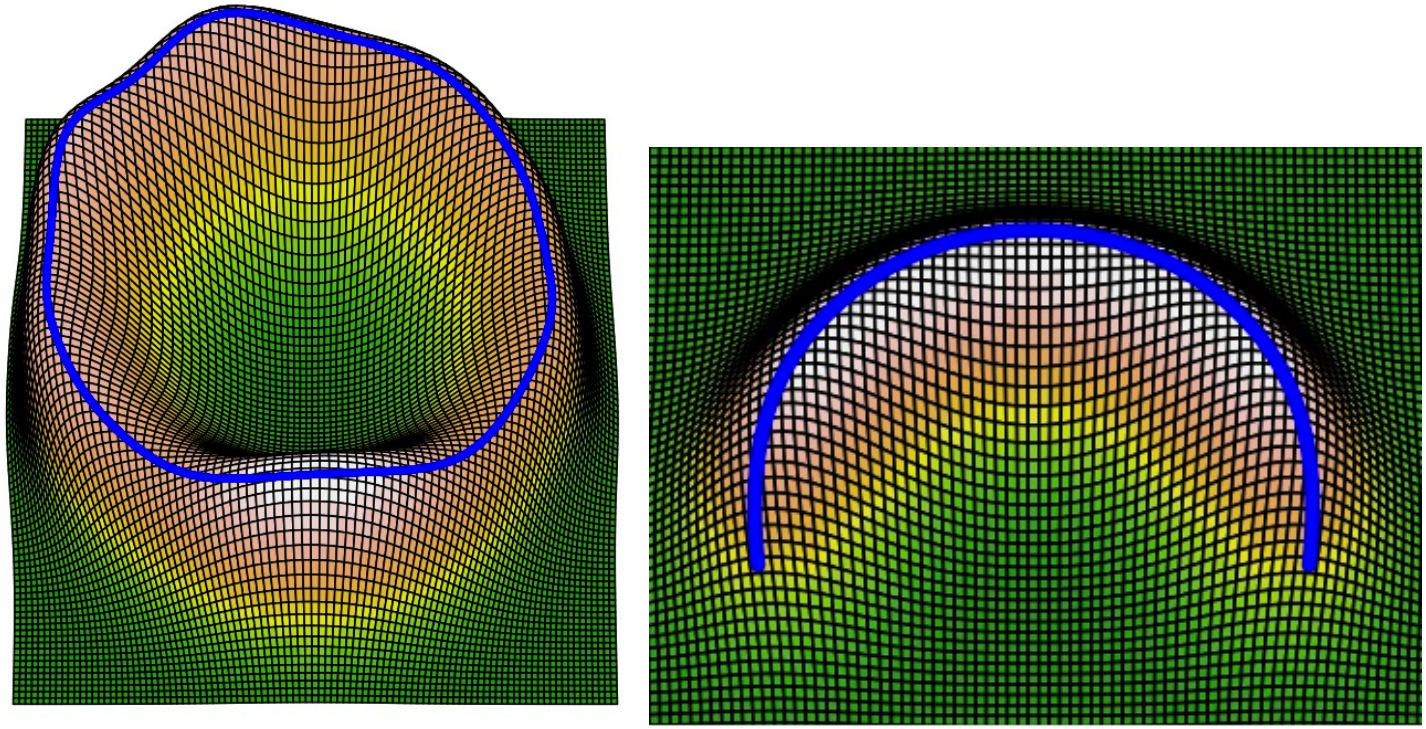
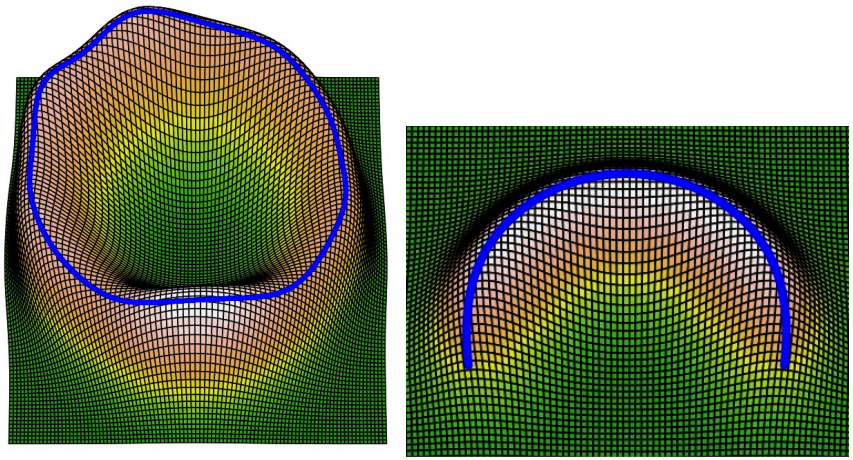


Ridges: Local Modes in Subspace



- A generalized local mode in a specific 'subspace'.

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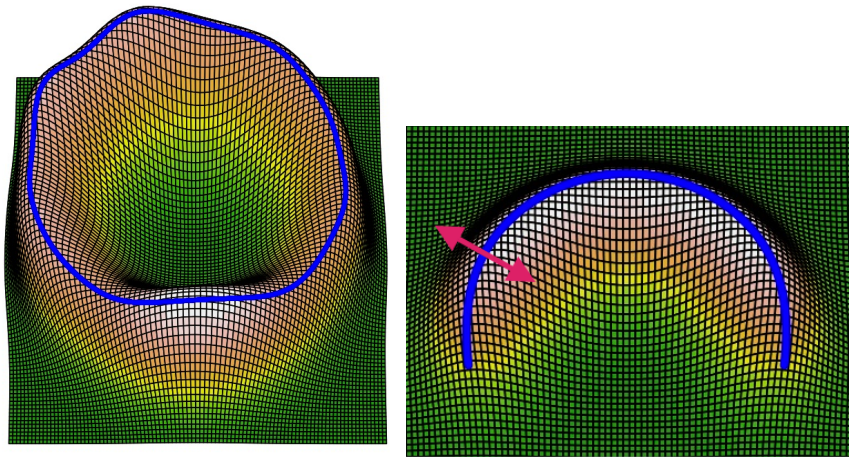

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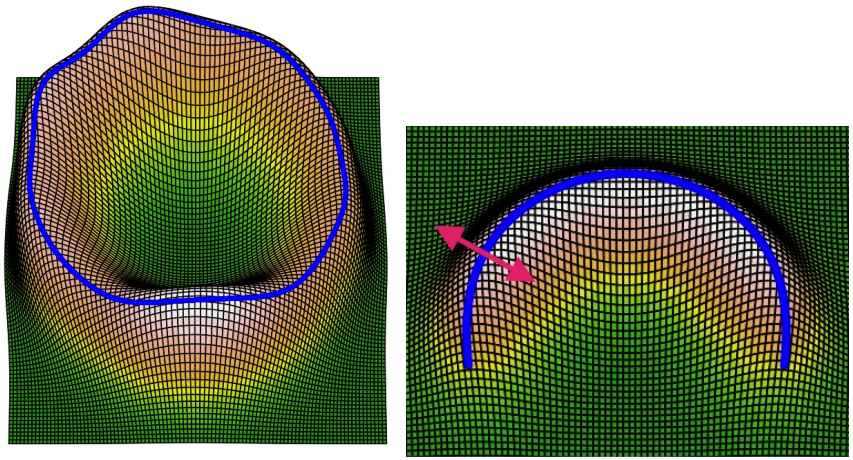

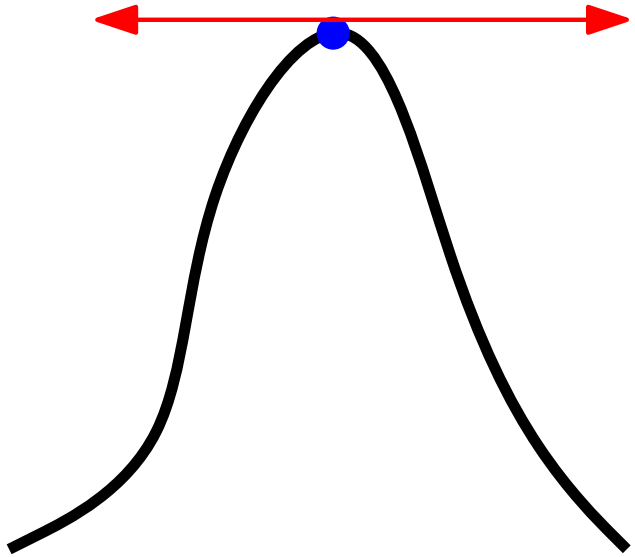

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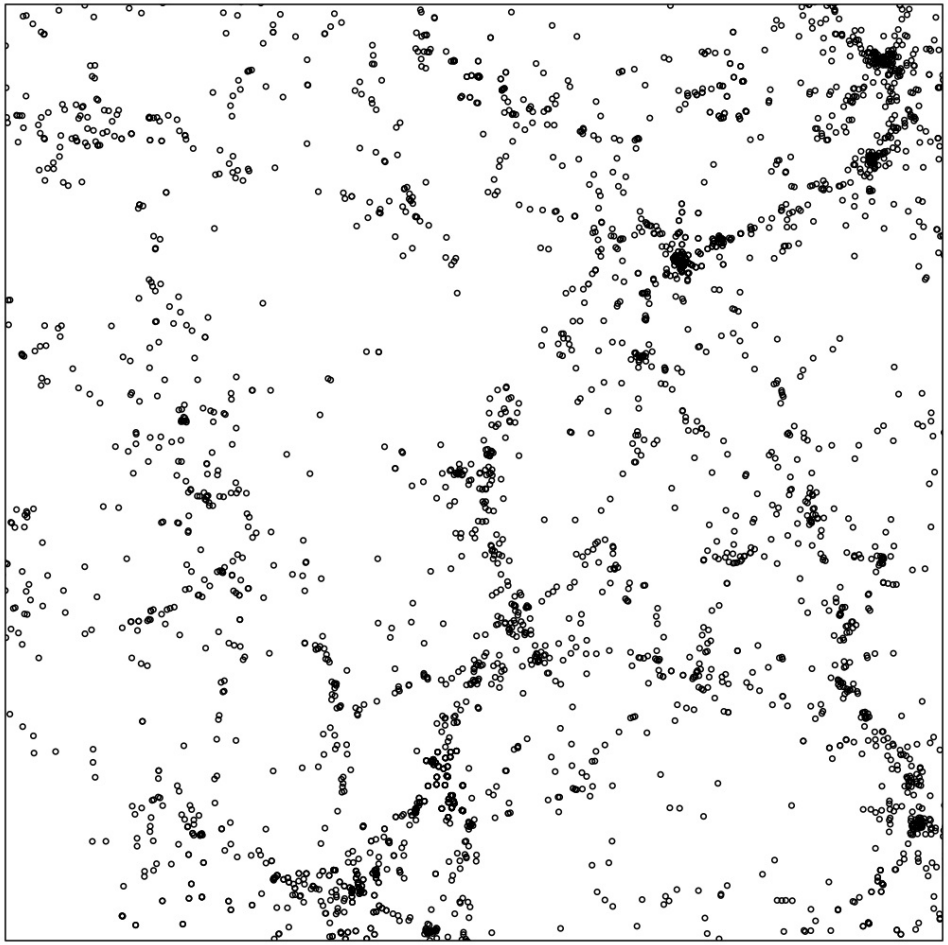
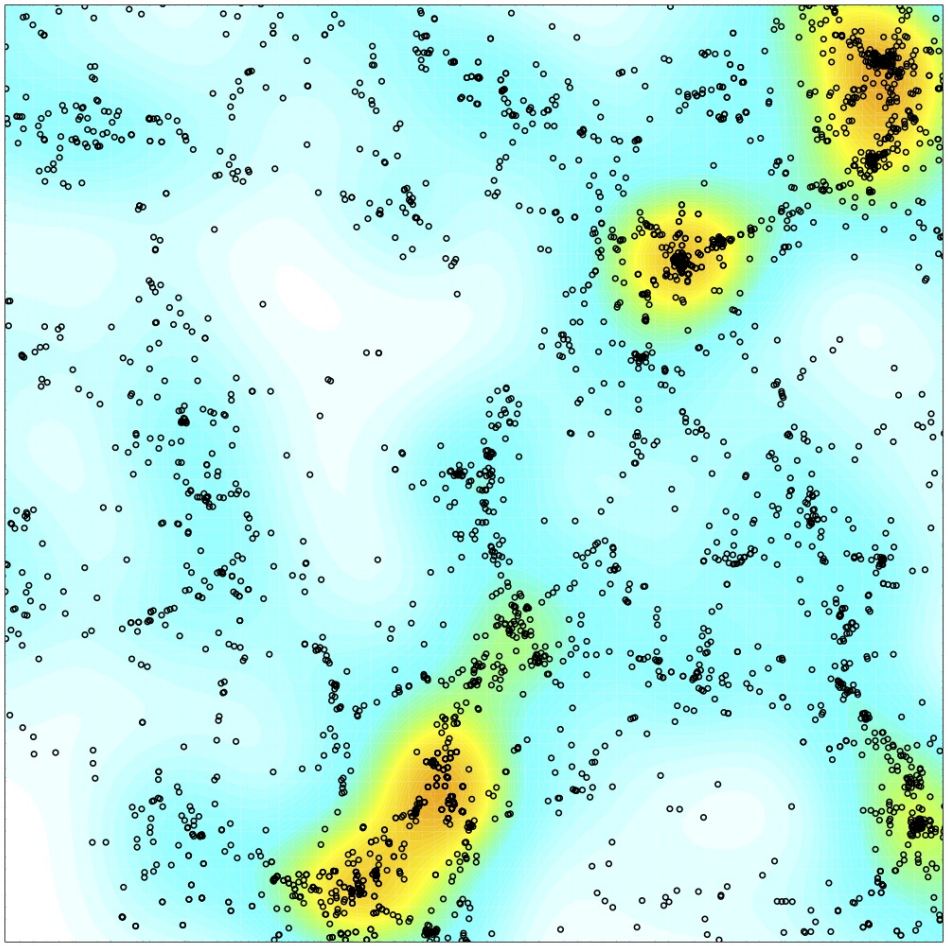
Algorithm

1. Rawdata



Algorithm

1. Rawdata
2. Density Reconstruction



Algorithm

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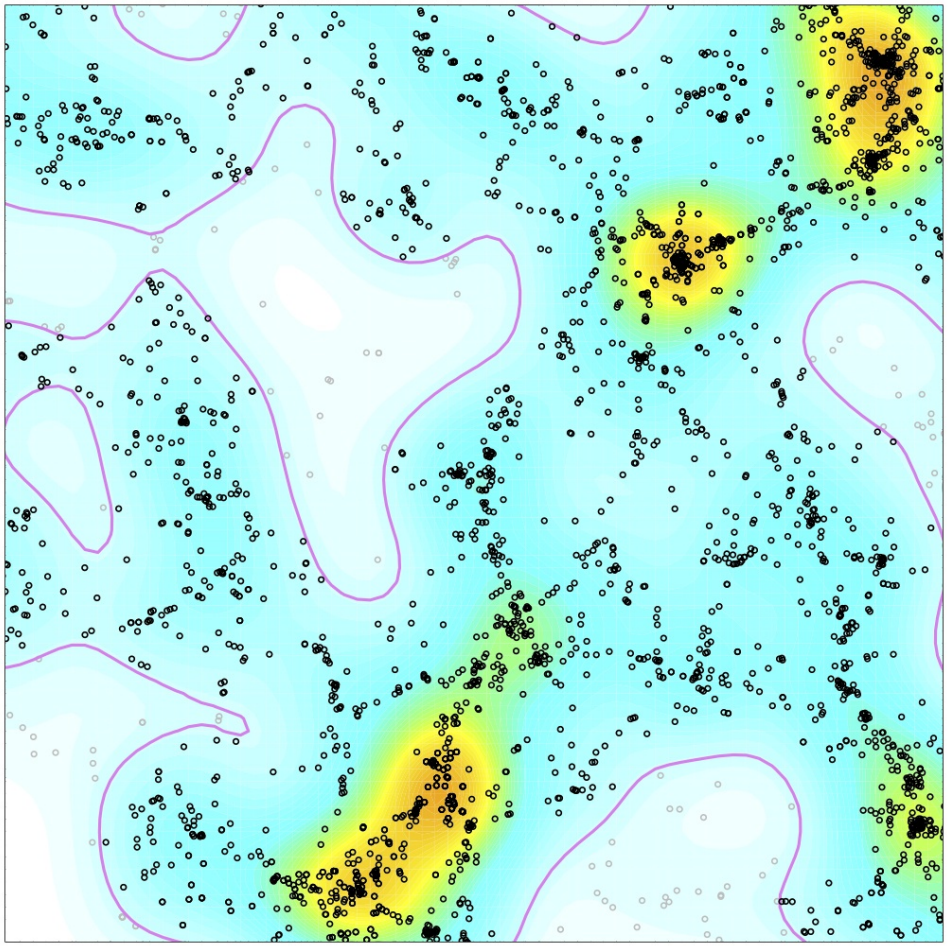
3. Thresholding



Algorithm

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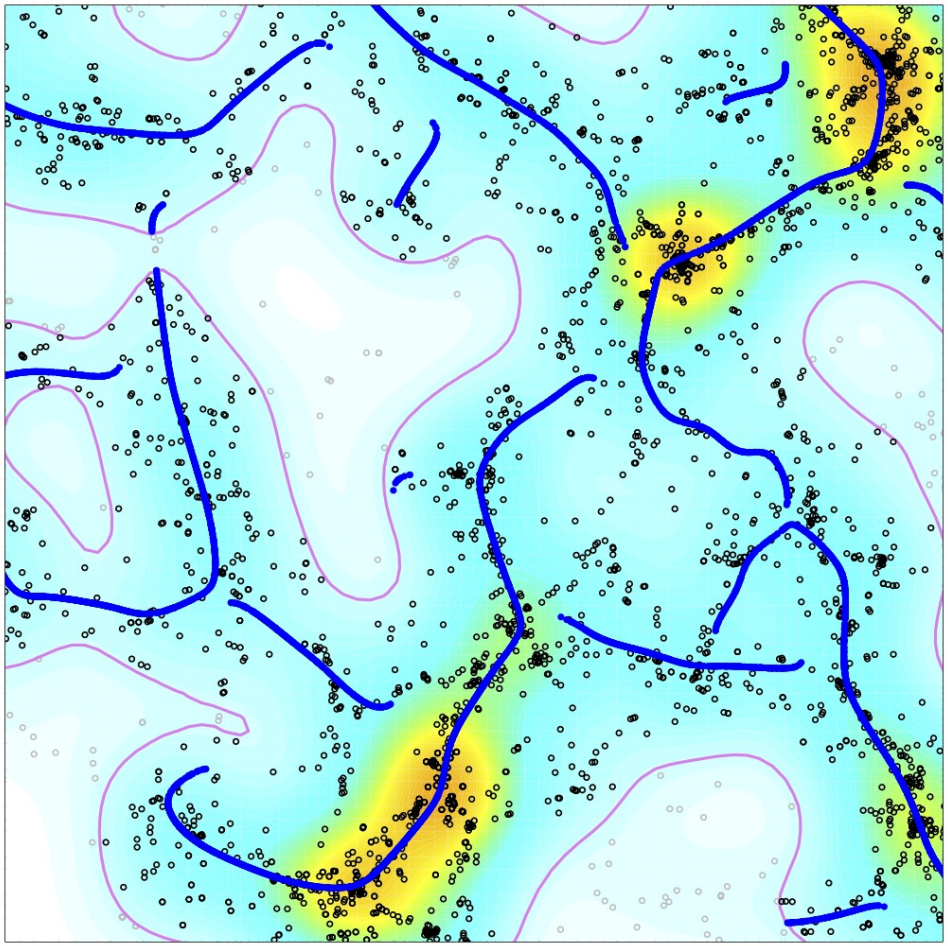
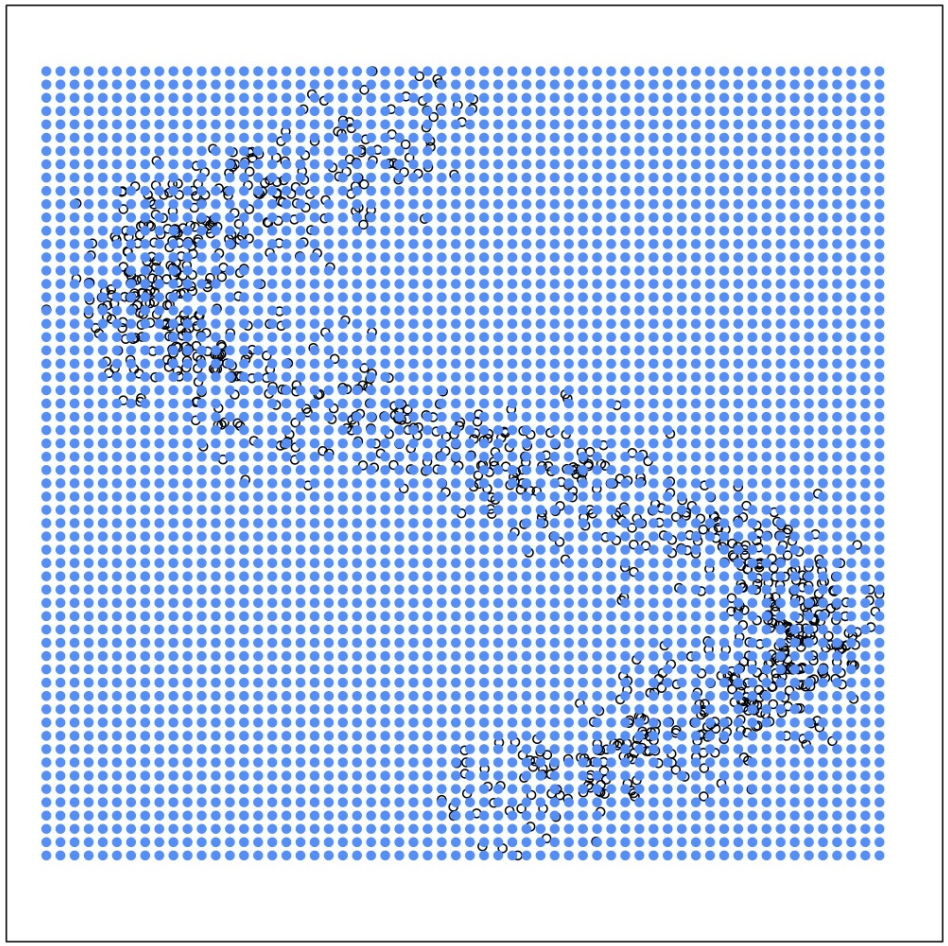
2. Density Reconstruction
3. Thresholding
4. Ridge Recovery



SCMS: Ridge Recovery Algorithm



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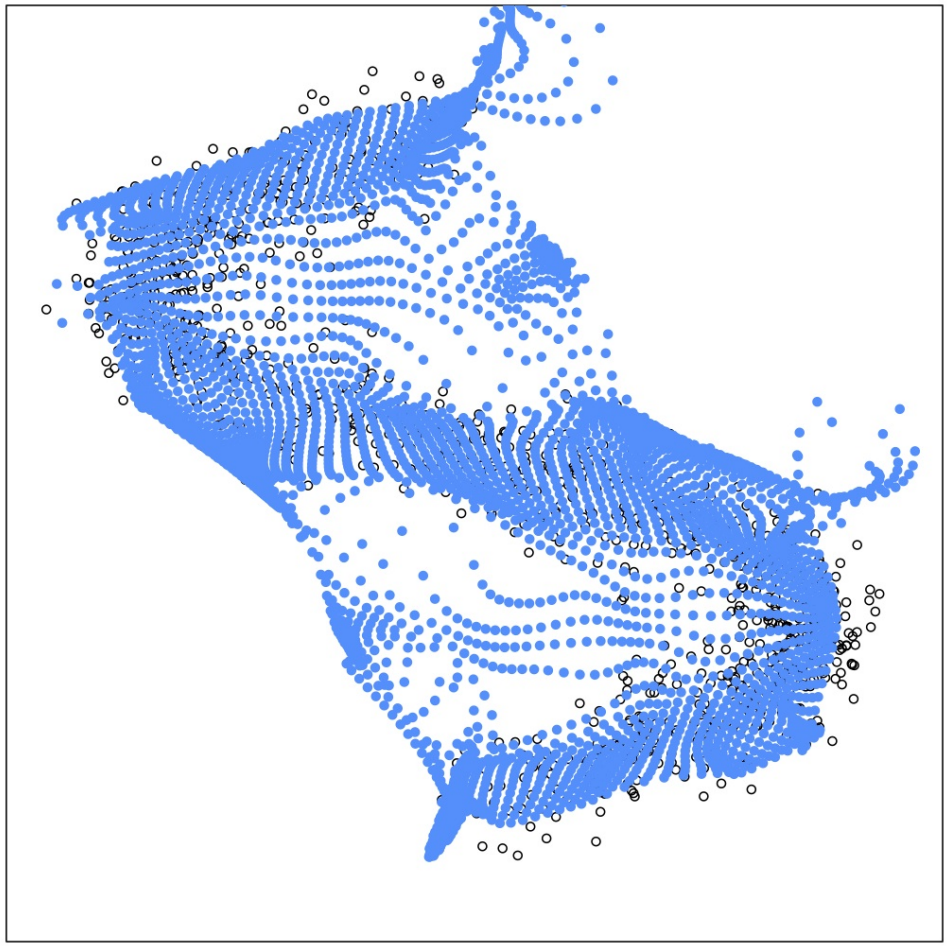

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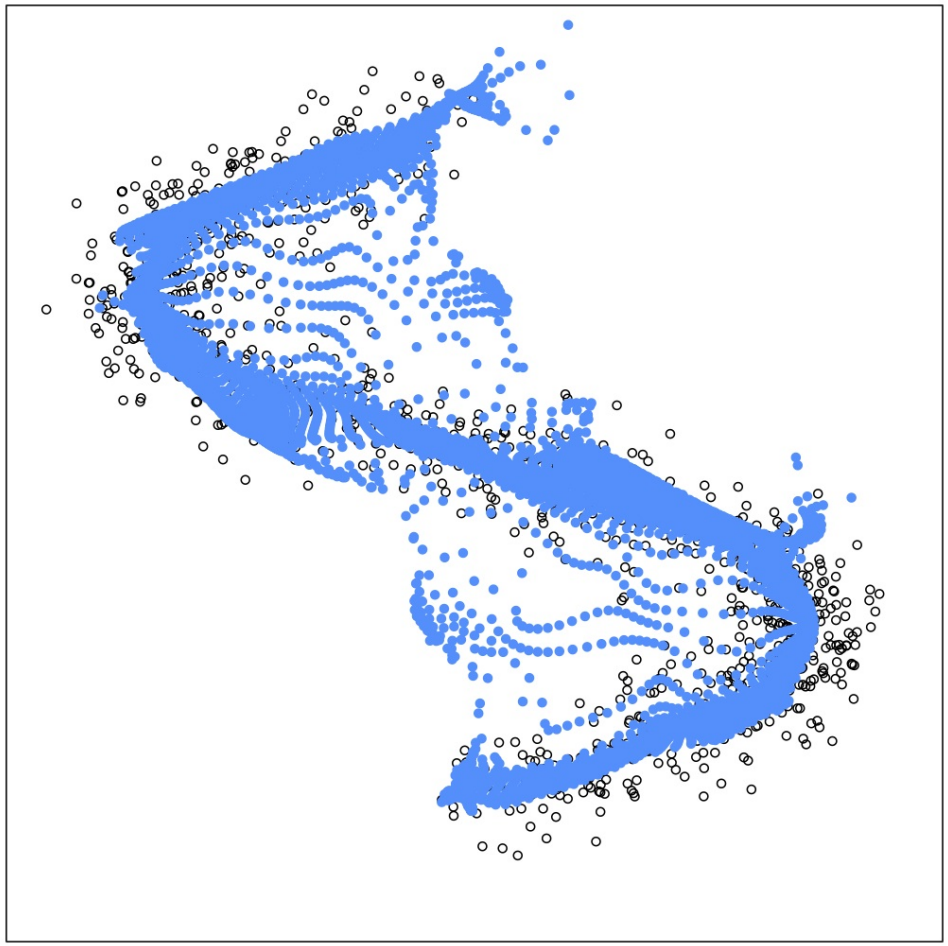

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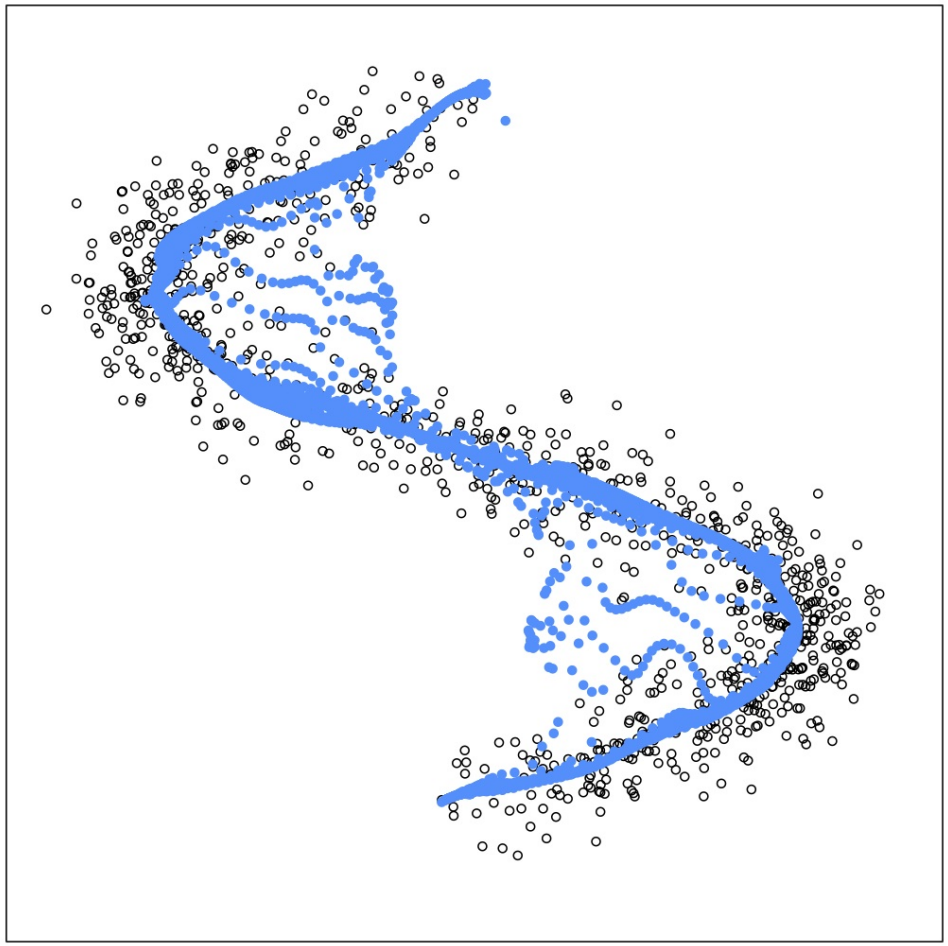

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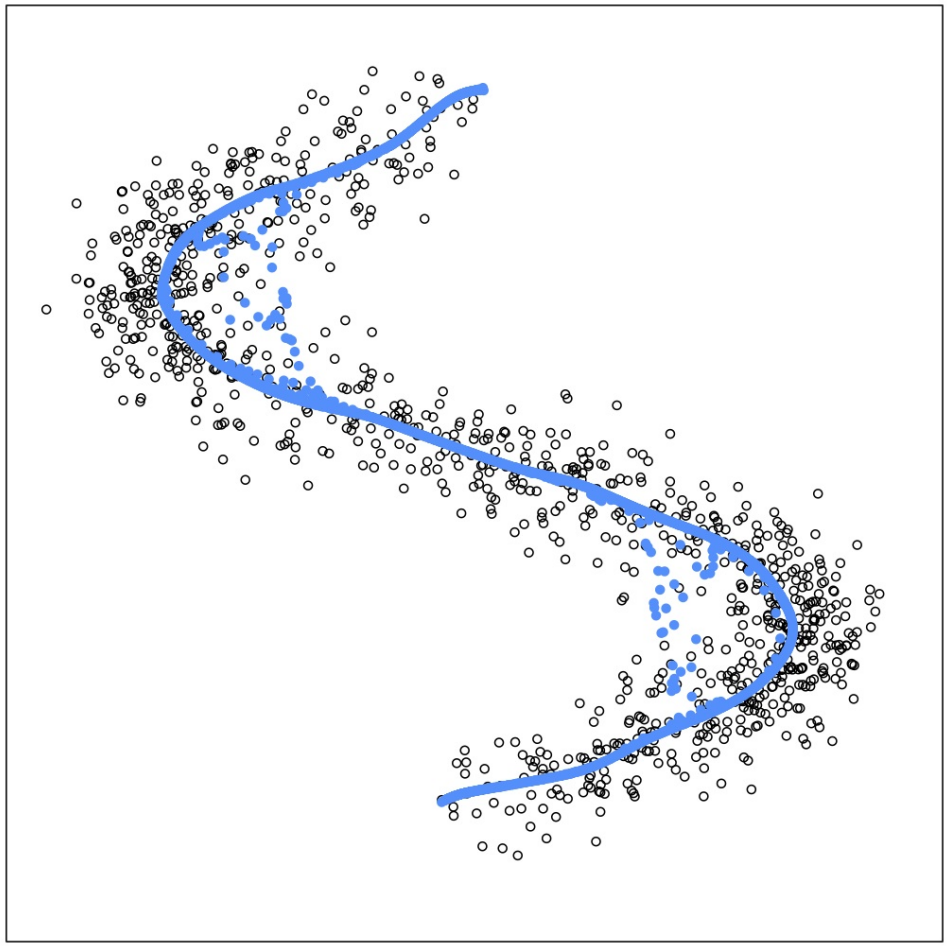

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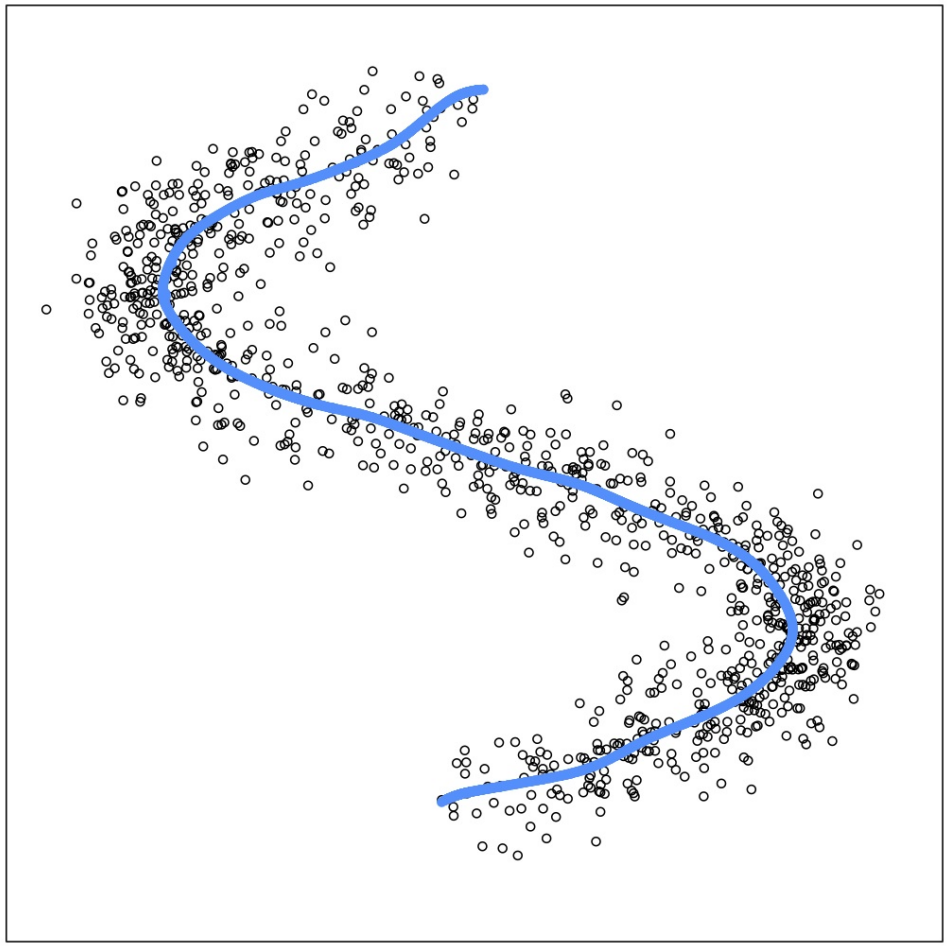

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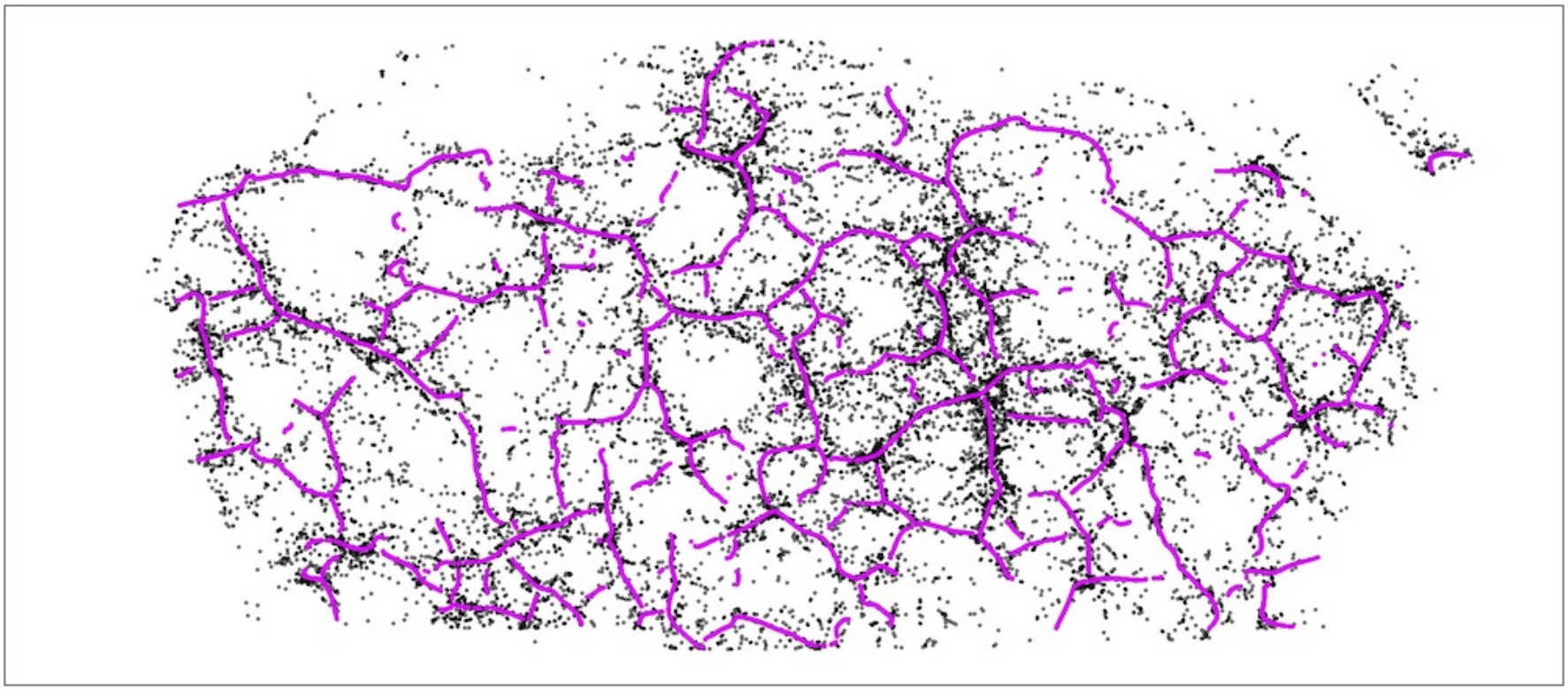
Density Ridges on an Example



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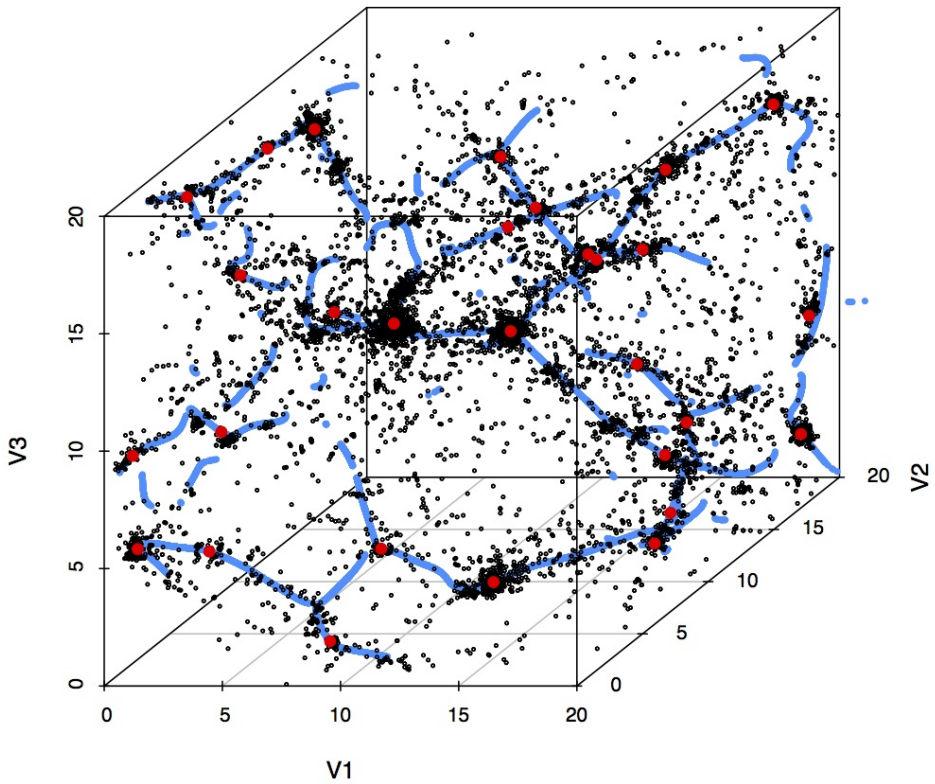
MassiveBlack-II Simulation

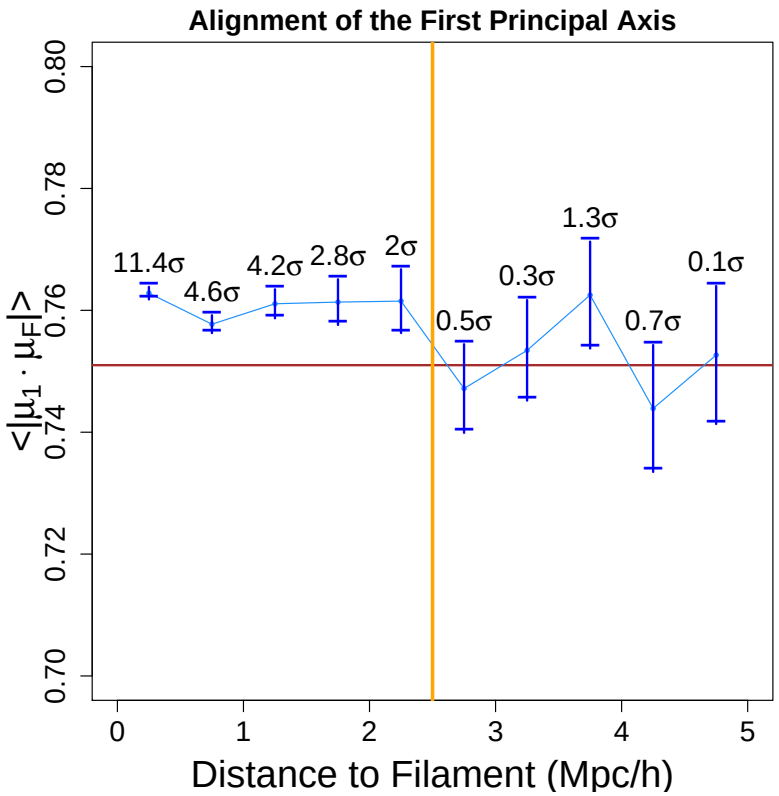
- Method: smoothed particle hydrodynamics.



This is a joint work with Ananth Tenneti, Rachel Mandelbaum, Rupert Croft, and Tiziana DiMatteo.

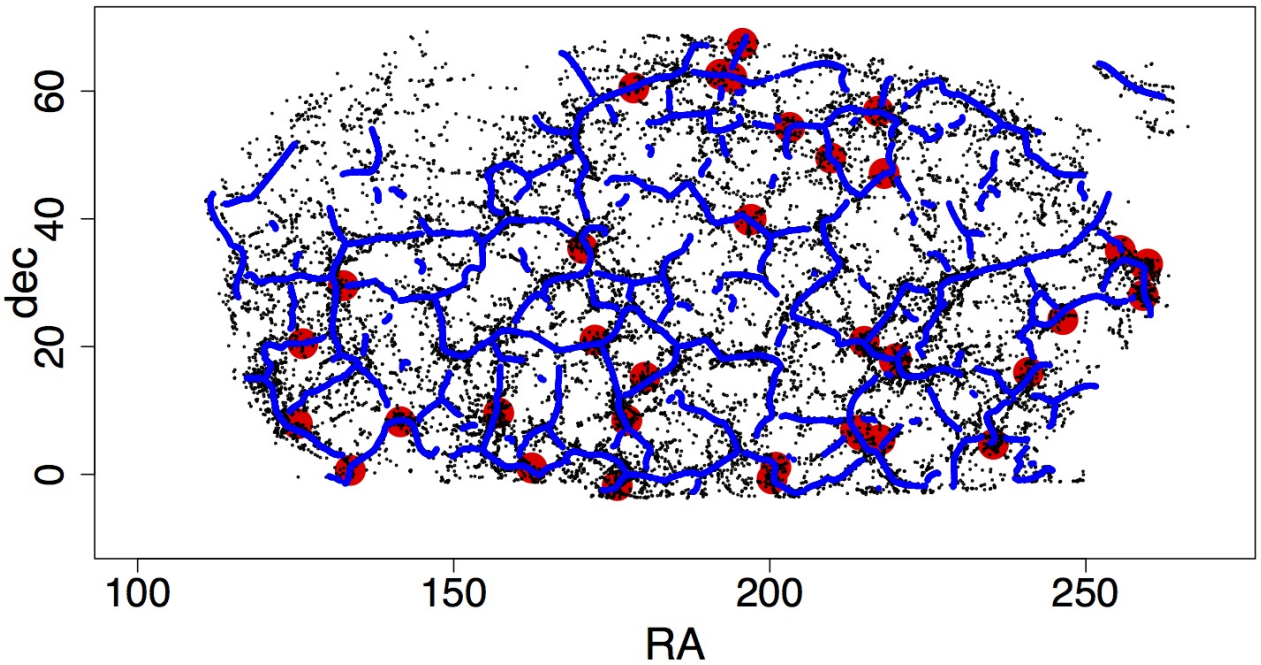
Galaxy Alignment to Filaments

- Principal axes for a galaxy (μ_1).
- Orientation of the nearest filament (μ_F).
- Distance to the nearest filament (d_F).



Sloan Digital Sky Survey

- Data: the Sloan Digital Sky Survey, data release 12.
- We take 2-D slices of the Universe to detect filaments ($\Delta z = 0.005$).
- Blue: filaments. Red: galaxy clusters (redMaPPer).



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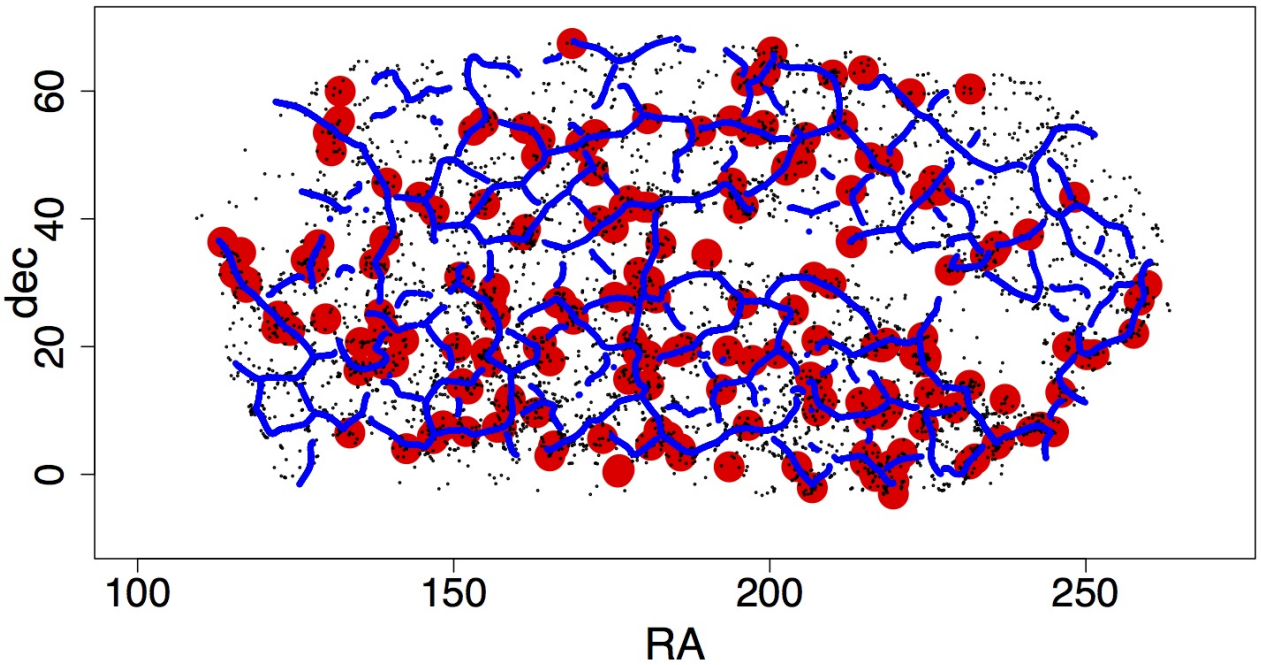

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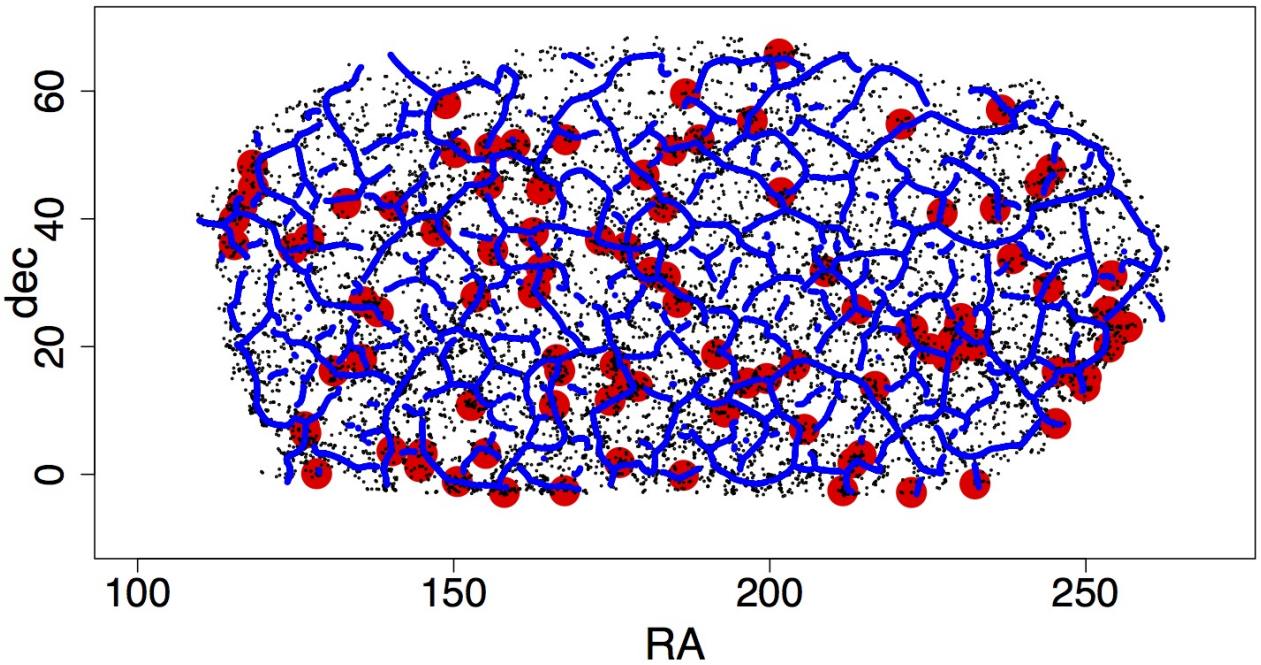

SDSS: Stellar Mass of Galaxies

- Mass from Flexible Stellar Population Synthesis method [Conroy, Gunn, and White 2009].
- We partition galaxies into three mass-bins according to their mass.
- We compare the average distance to filaments from each bin.

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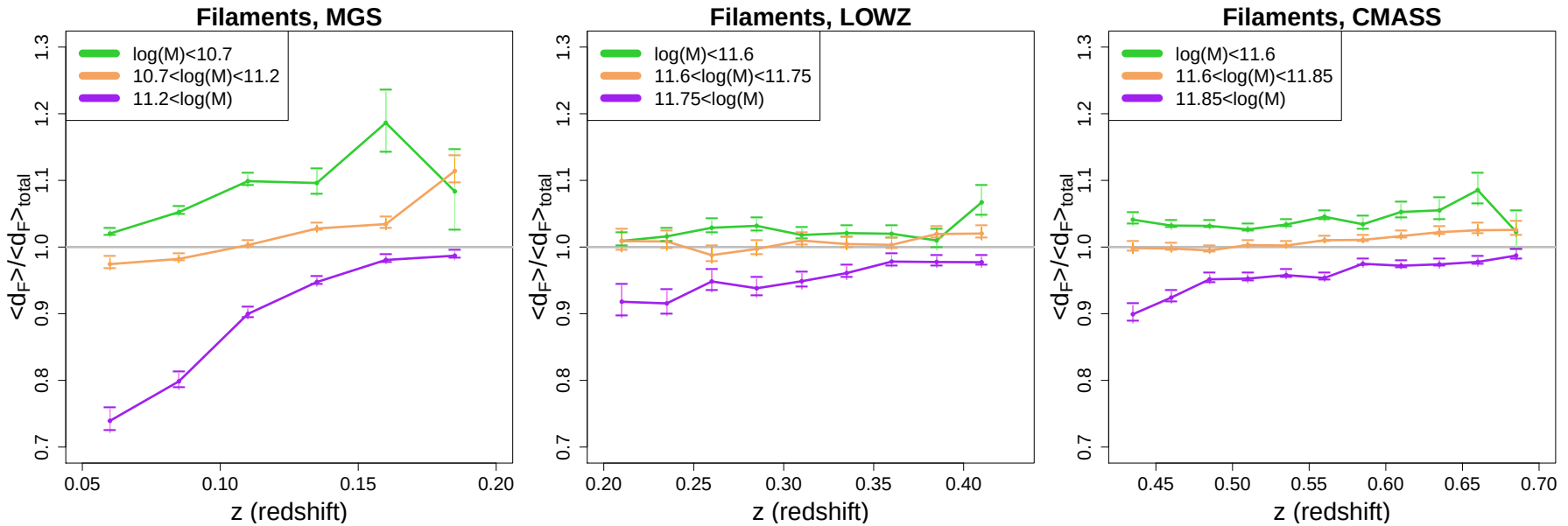

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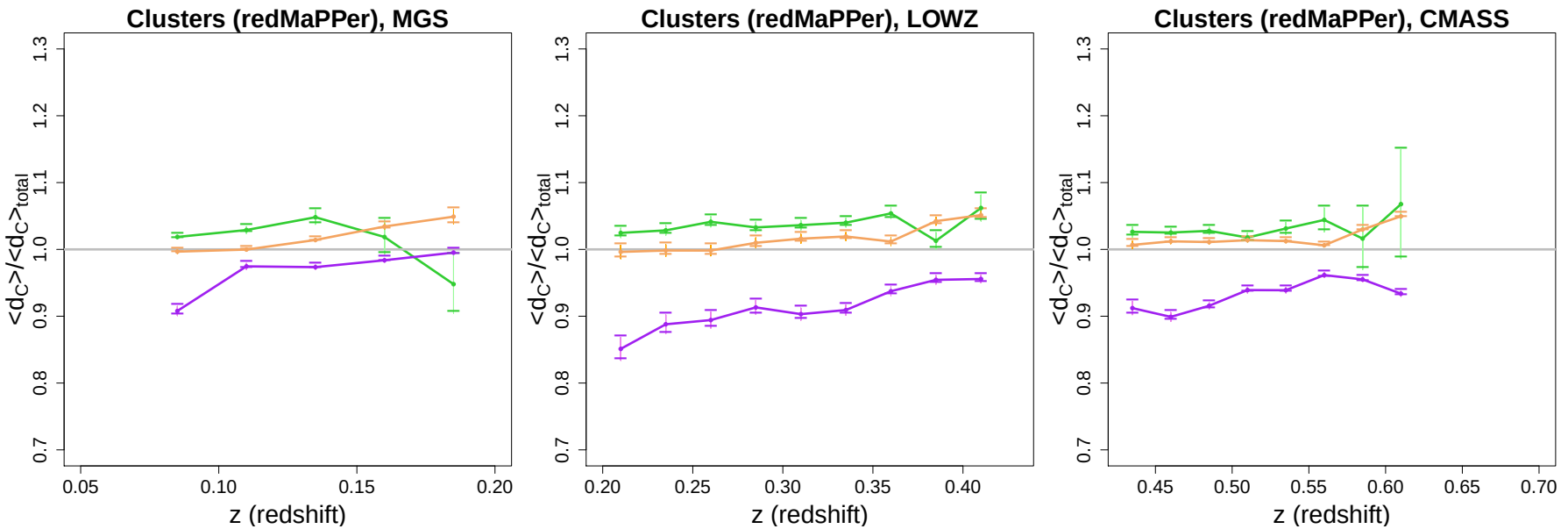

A Filament Catalogue for the SDSS

Cosmic Web Reconstruction

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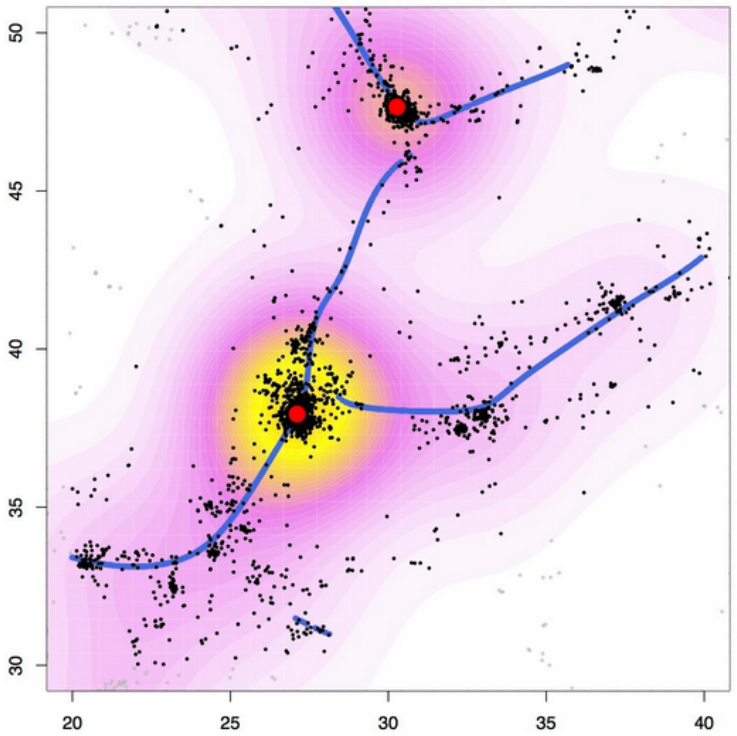
A filament is a one-dimensional, smooth, connected structure embedded in a multi-dimensional space that characterizes the high density regions. Matter in the Universe tend to aggregate around these filaments which weave our Universe into an intricate network structure. We use ridges of density function (density ridges) as tracers for the filaments and apply our method to the SDSS DR12 to construct a filament catalogue.

This is a joint project of department of Statistics, department of Physics, and the McWilliams center for Cosmology at Carnegie Mellon University. This is also a project of the astrostatistics group at Carnegie Mellon University.

References:

Cosmology--

1. Chen, Yen-Chi, Shirley Ho, Peter E. Freeman, Christopher R. Genovese, and Larry Wasserman. ``*Cosmic Web Reconstruction through Density Ridges: Method and Algorithm.*" arXiv: 1501.05303
2. Chen, Yen-Chi, Shirley Ho, Peter E. Freeman, Christopher R. Genovese, and Larry Wasserman. ``*Cosmic Web Reconstruction through Density Ridges: Catalogue.*" (In progress)
3. Chen, Yen-Chi, Shirley Ho, Ananth Tenneti, Rachel Mandelbaum, Rupert Croft, Tiziana DiMatteo, Christopher R. Genovese, and Larry Wasserman. ``*Investigating Galaxy-Filament Alignment in Hydrodynamic Simulations using Density Ridges.*" arXiv: 1508.04149
4. Chen, Yen-Chi, Shirley Ho, Rachel Mandelbaum, Peter E. Freeman, Christopher R. Genovese, and Larry Wasserman. ``*Detecting Effects of Filaments on Galaxy Properties in Sloan Digital Sky Survey III.*" (In progress)



Data: the MBII simulation, we thank Ananth Tenneti for proving this data.

https://sites.google.com/site/yenchicr/

Thank you!

References

1. Chen, Yen-Chi, Shirley Ho, Peter E. Freeman, Christopher R. Genovese, and Larry Wasserman. "Cosmic Web Reconstruction through Density Ridges: Method and Algorithm." To appear in Monthly Notices of the Royal Astronomical Society..
2. Chen, Yen-Chi, et al. "Investigating Galaxy-Filament Alignments in Hydrodynamic Simulations using Density Ridges." arXiv preprint arXiv:1508.04149 (2015).
3. Chen, Yen-Chi, Christopher R. Genovese, and Larry Wasserman. "Asymptotic theory for density ridges." The Annals of Statistics 43.5 (2015): 1896-1928.
4. Conroy, Charlie, James E. Gunn, and Martin White. "The propagation of uncertainties in stellar population synthesis modeling. I. The relevance of uncertain aspects of stellar evolution and the initial mass function to the derived physical properties of galaxies." The Astrophysical Journal 699.1 (2009): 486.
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6. Genovese, Christopher R., et al. "Nonparametric ridge estimation." The Annals of Statistics 42.4 (2014): 1511-1545.
7. Ozertem, Umut, and Deniz Erdogmus. "Locally defined principal curves and surfaces." The Journal of Machine Learning Research 12 (2011): 1249-1286.

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- Local modes:

$$\text{Mode}(p) = \{x : \nabla p(x) = 0, \lambda_1(x) < 0\}.$$

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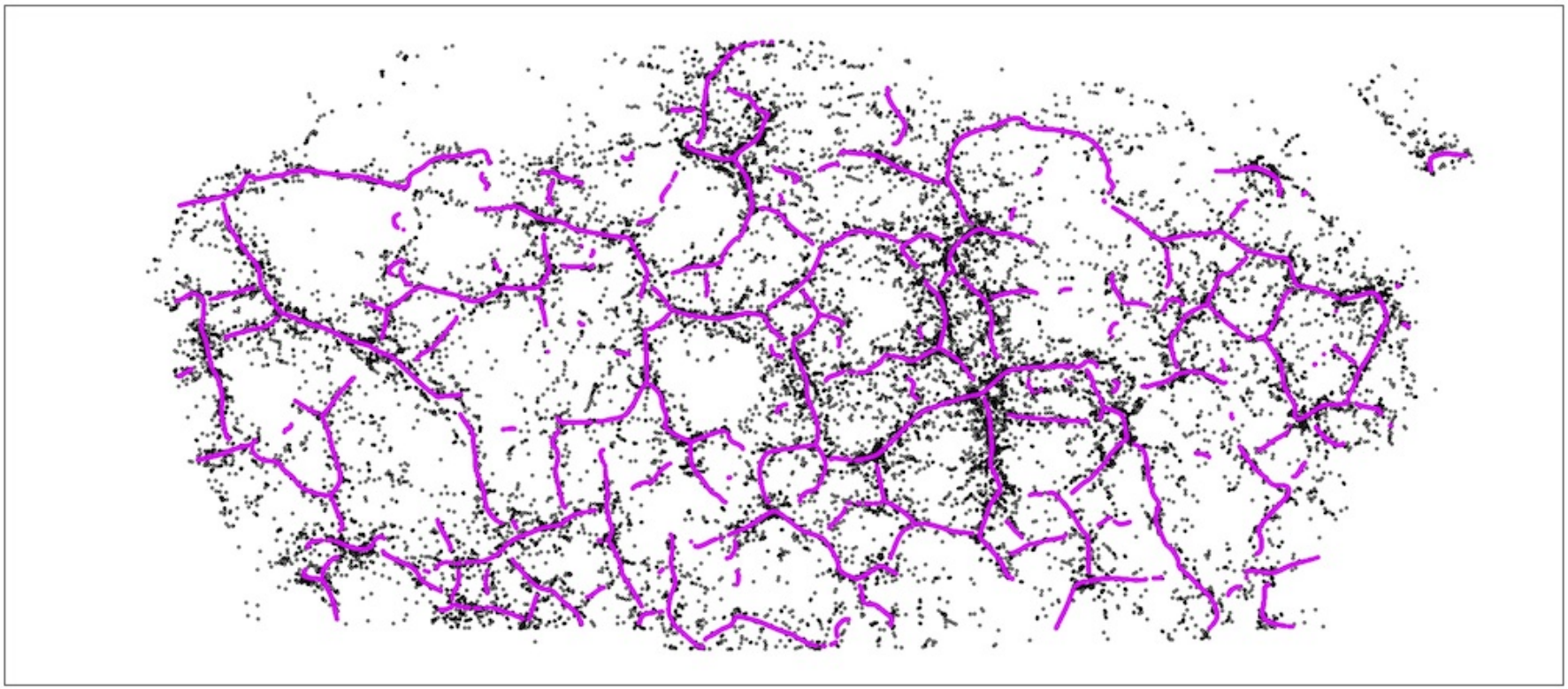
- $\rightarrow$Subspace Constrained Mean Shift Algorithm [Ozertem and Erdogmus 2011].

Density Ridges on the SDSS data



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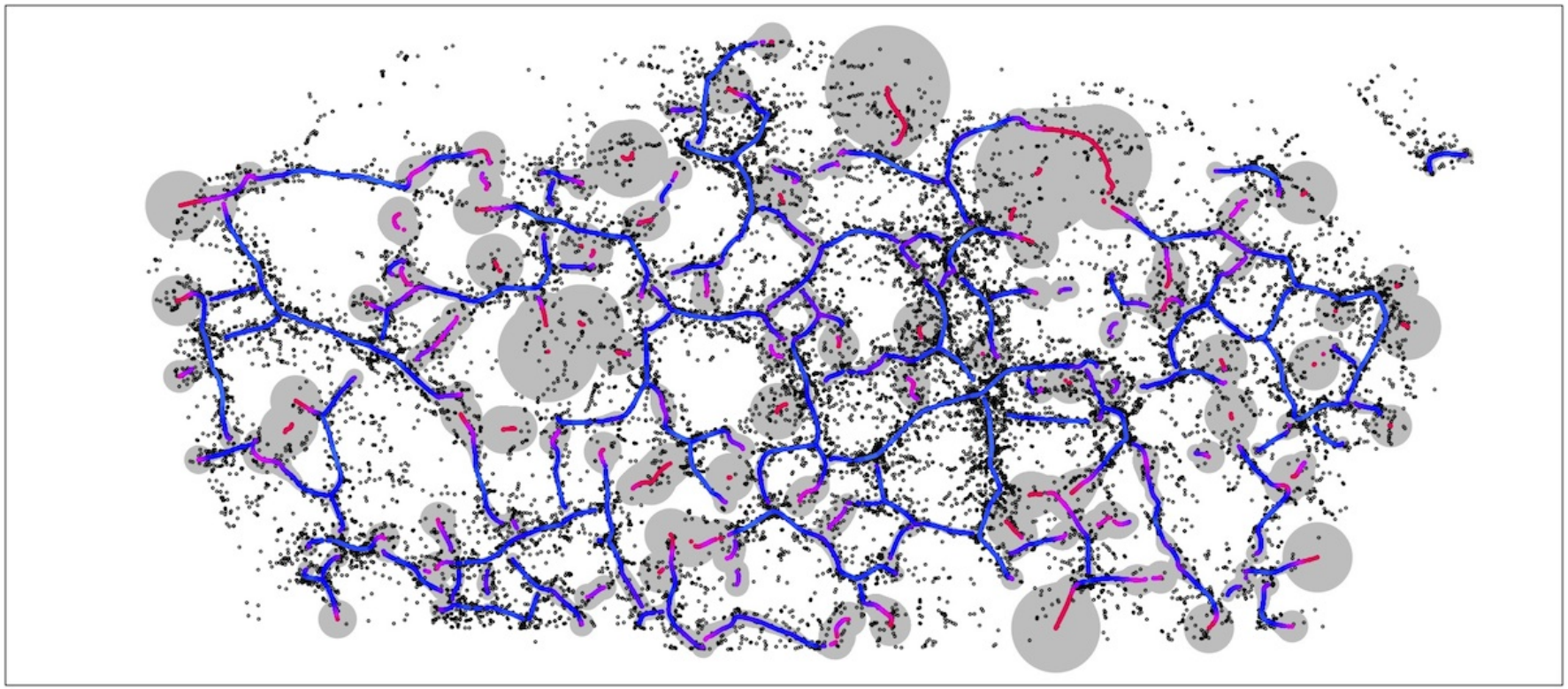
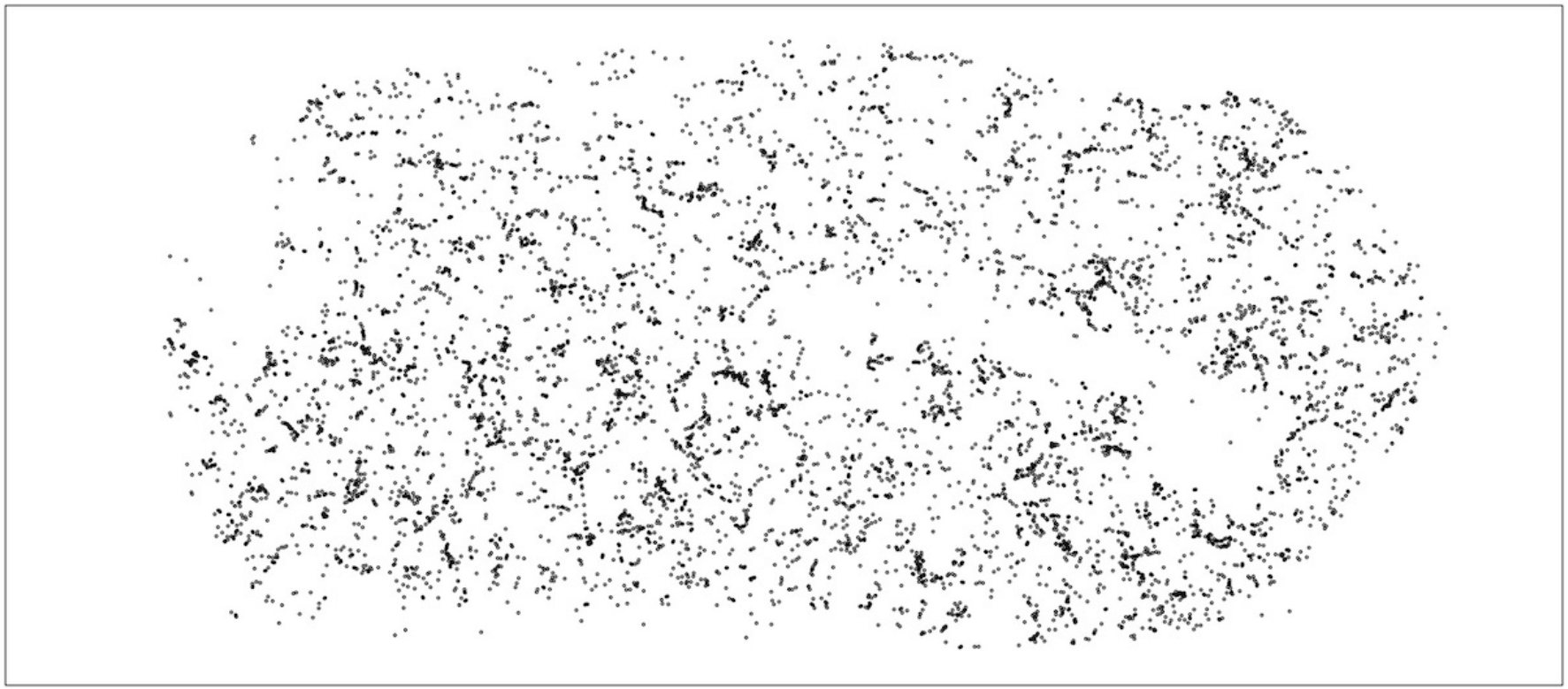


Curse of Number Density



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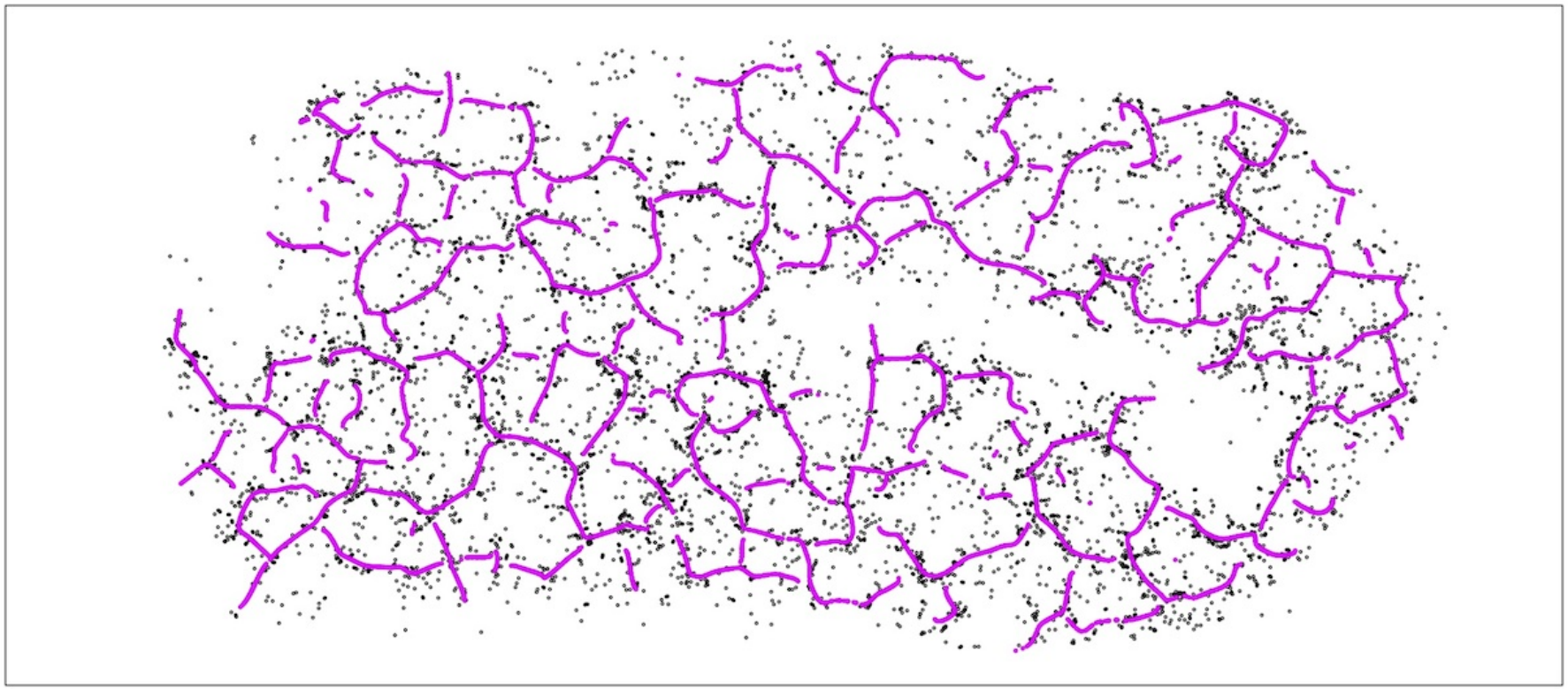

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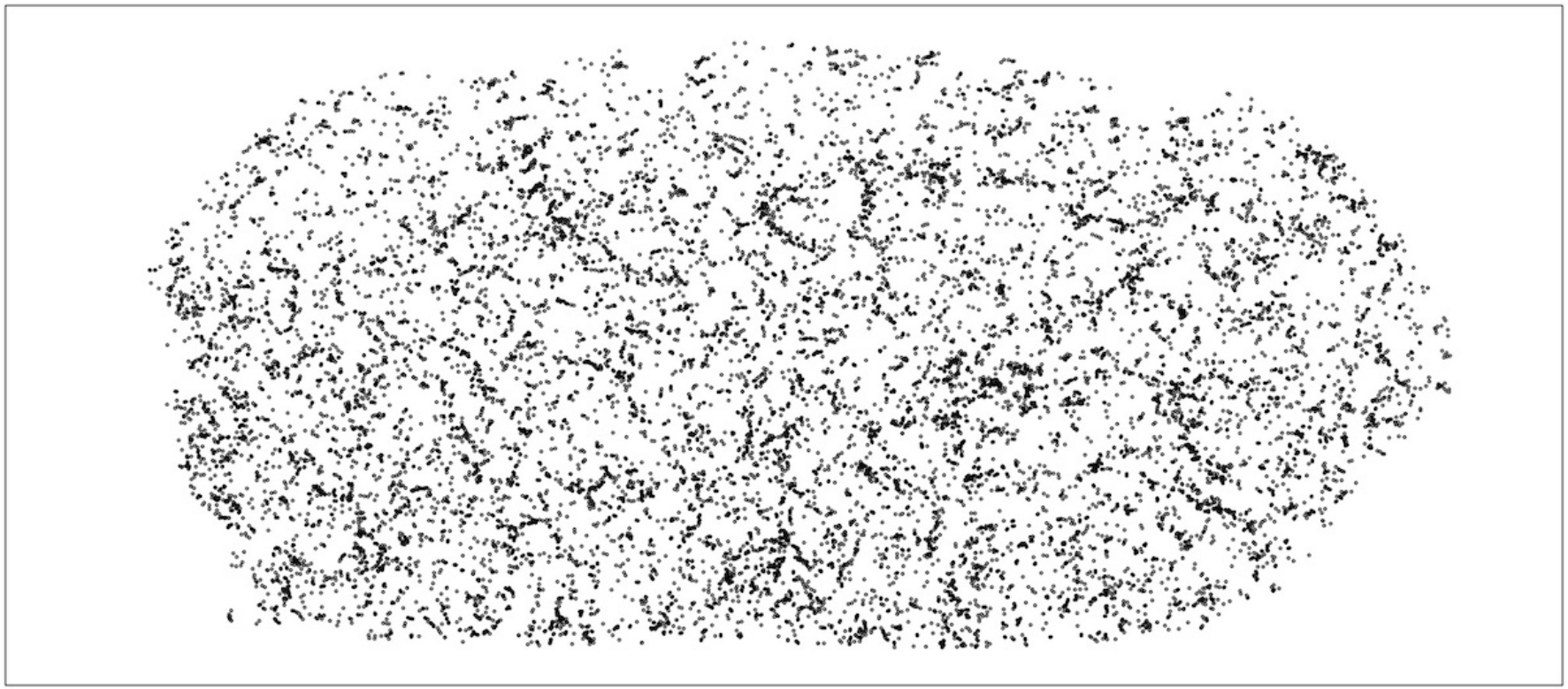

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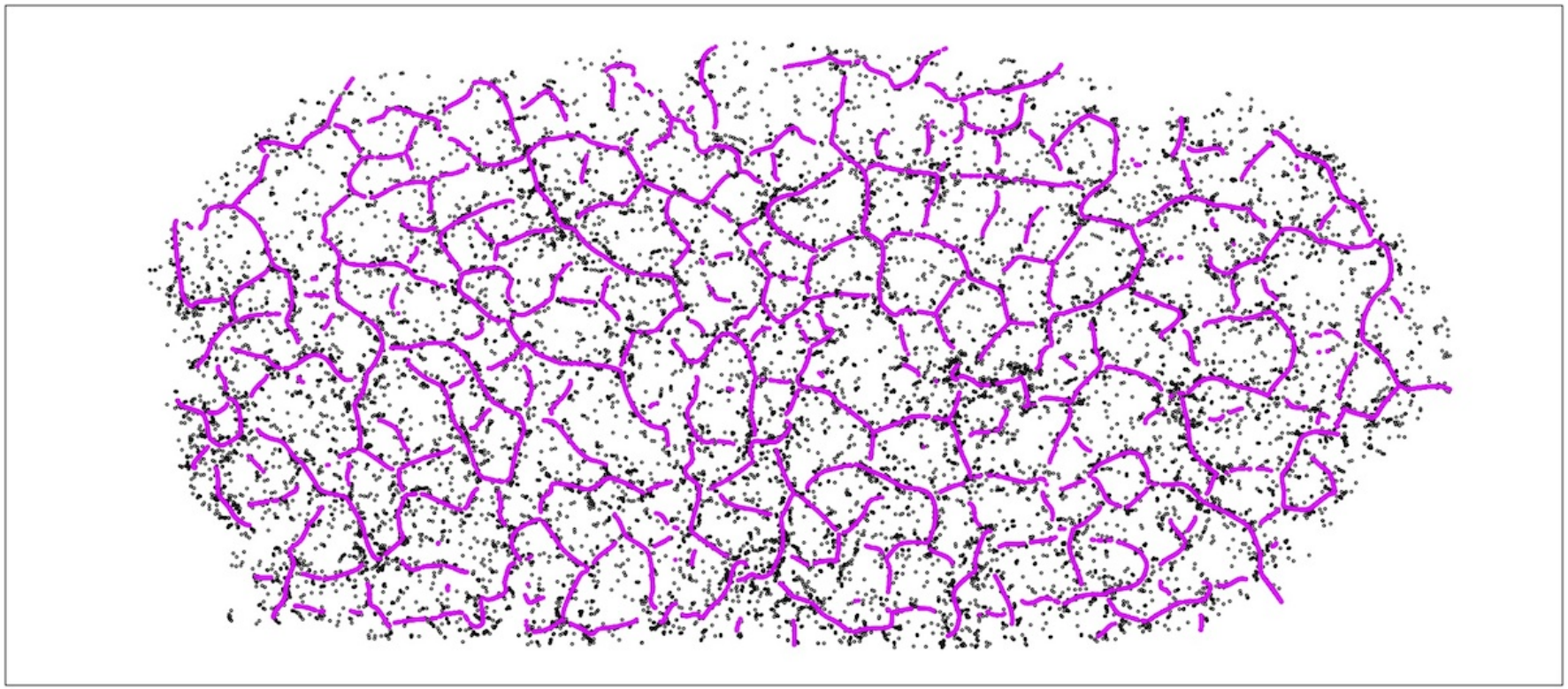

SDSS: Red and Blue Galaxies

- Redshift range: $0.05 < z < 0.20$ (main sample galaxy).
- Color cut: $(g - r) = 0.8$.

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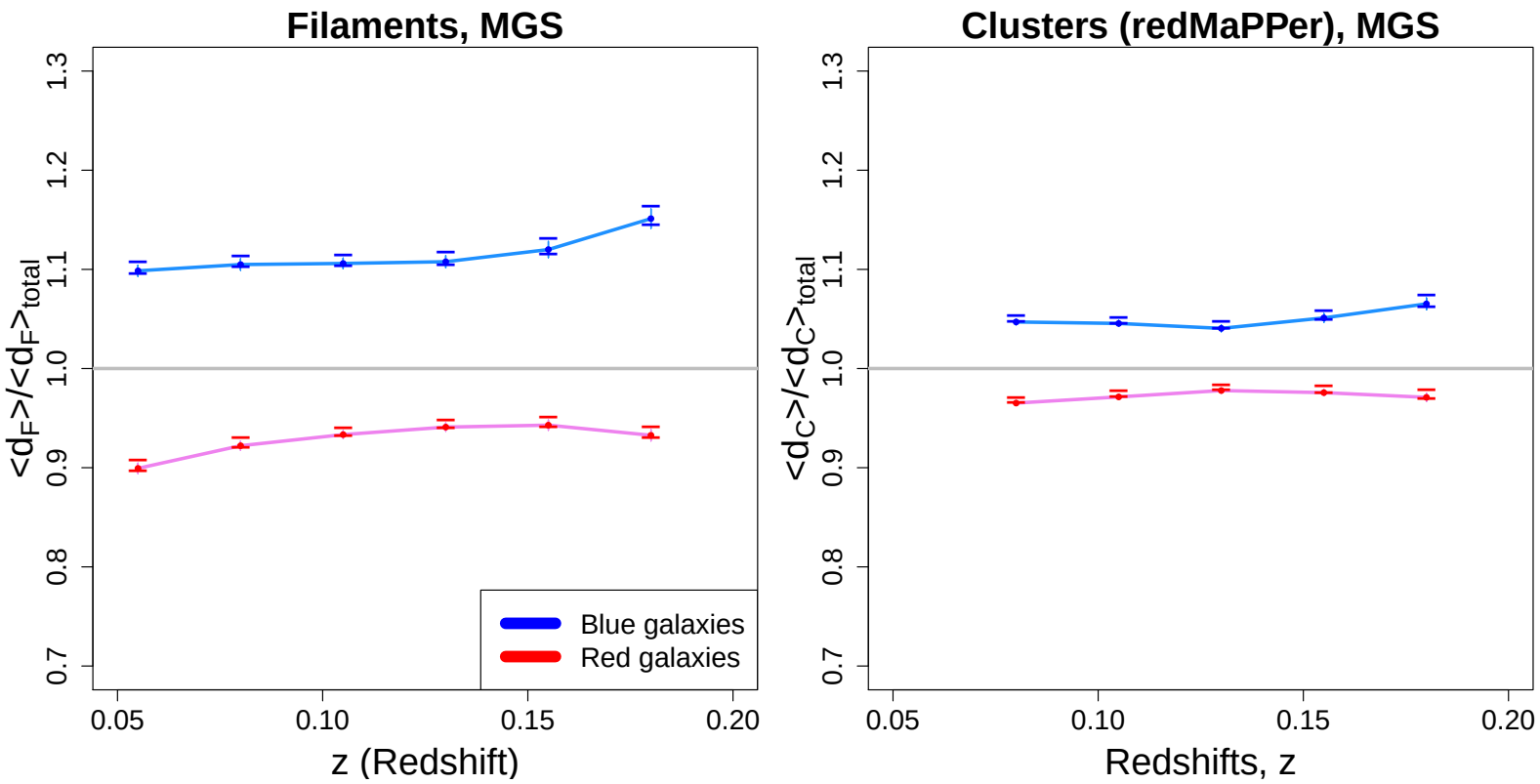
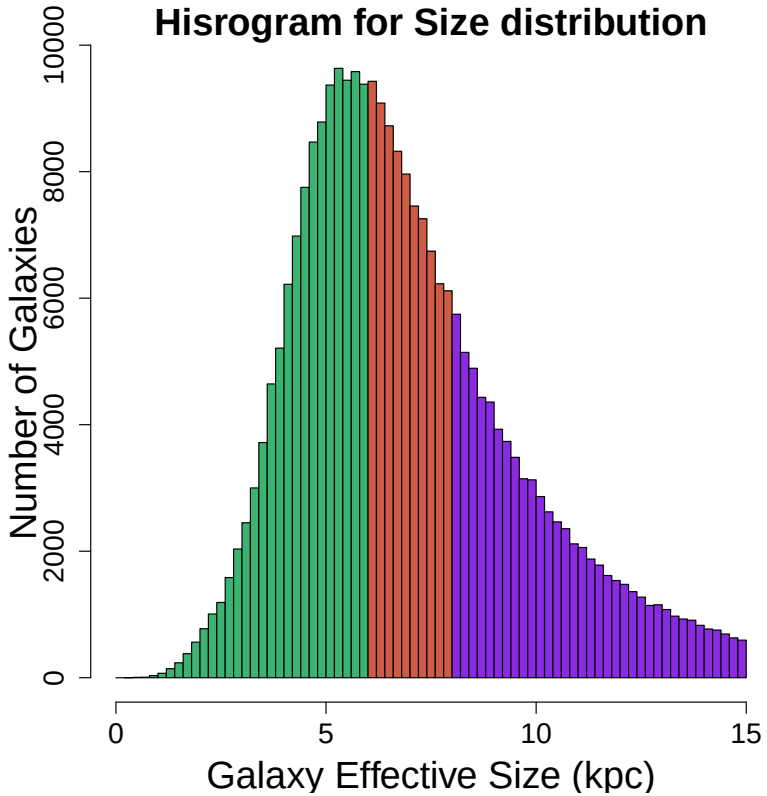


SDSS: Size for Galaxies

1. Size: Effective Radii.
2. Data: LOWZ ($0.20 < z < 0.43$)
3. Partitioning galaxies into three groups according to their size.



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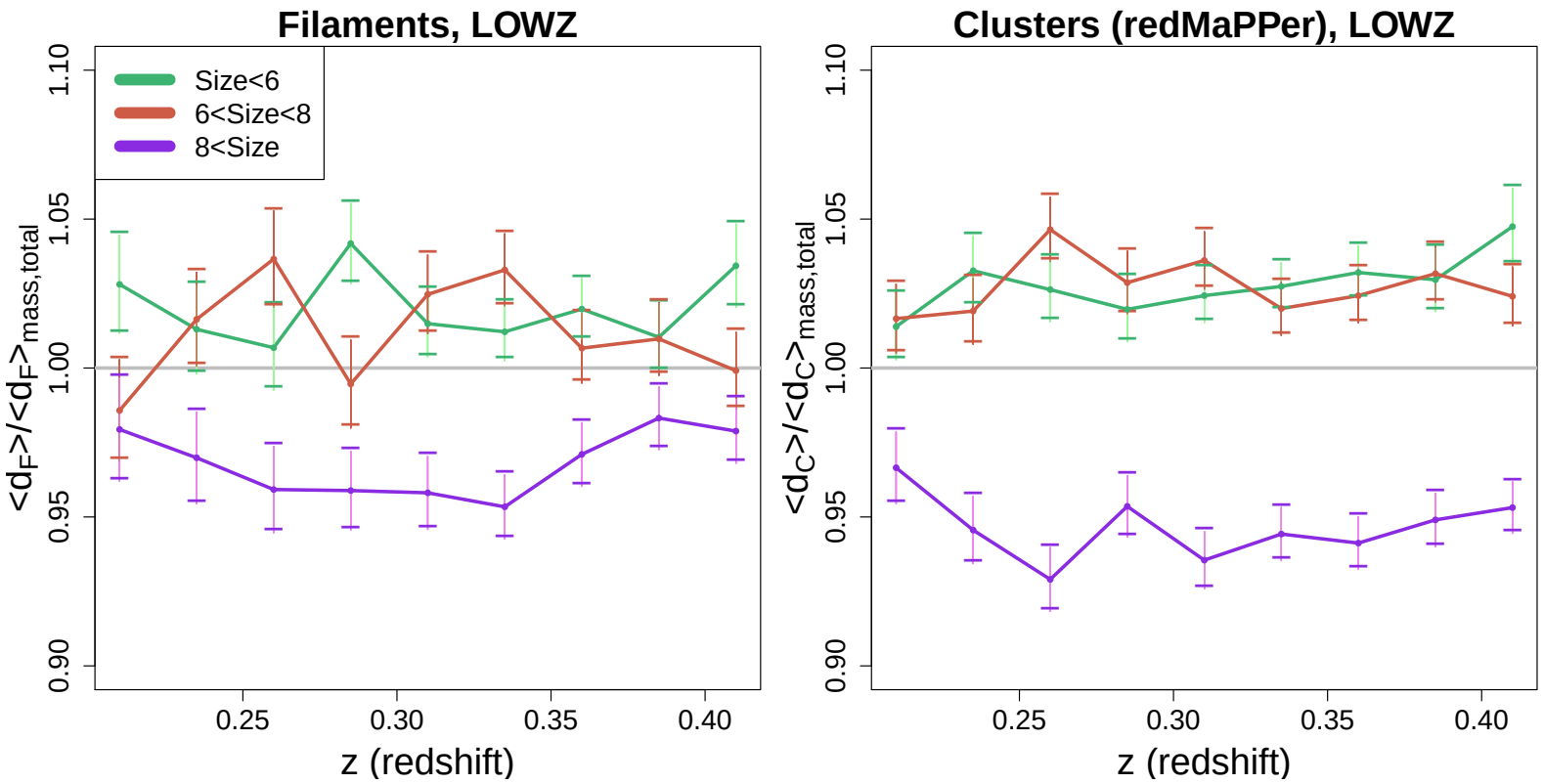

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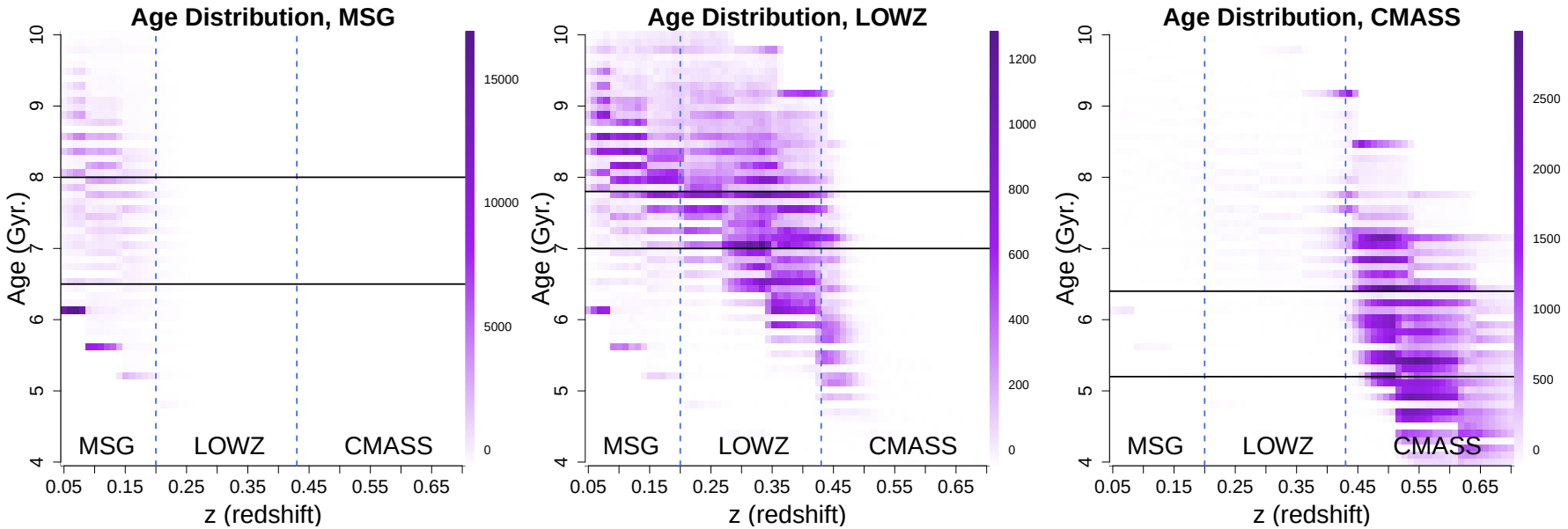

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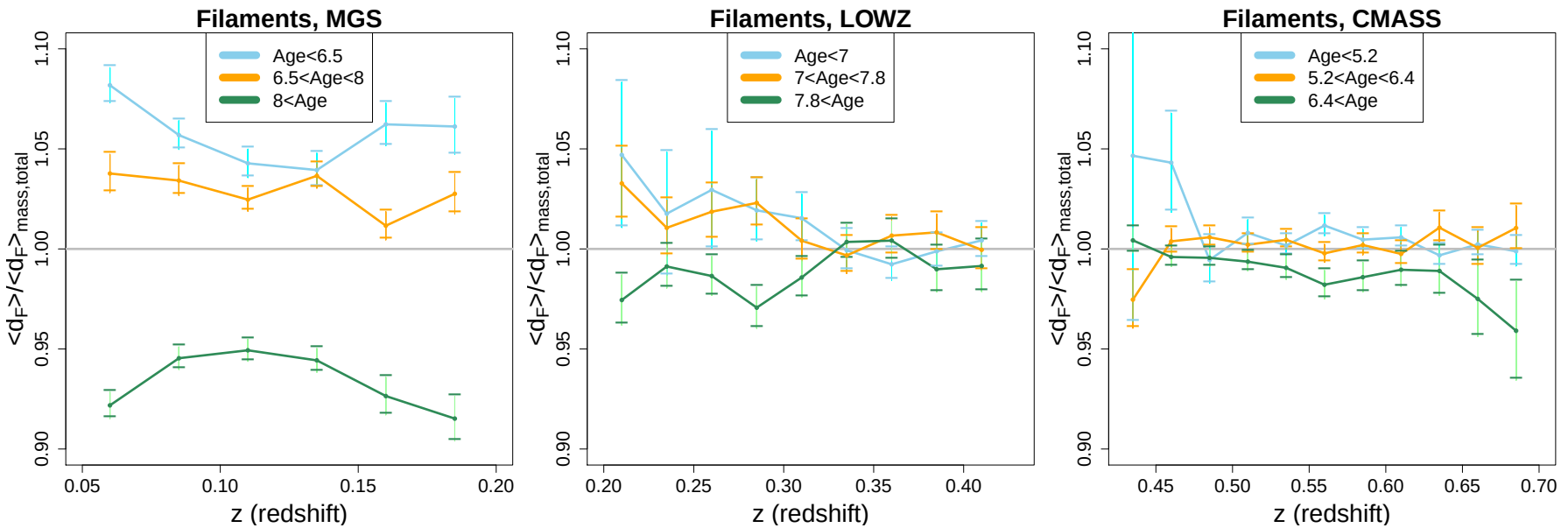
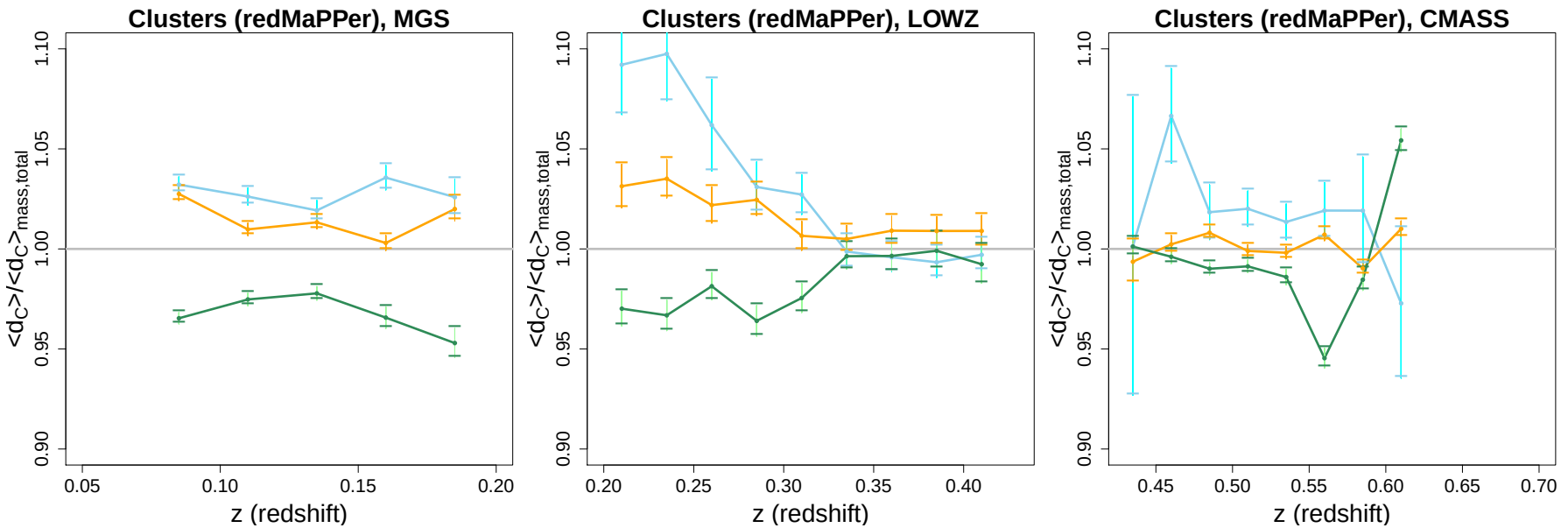
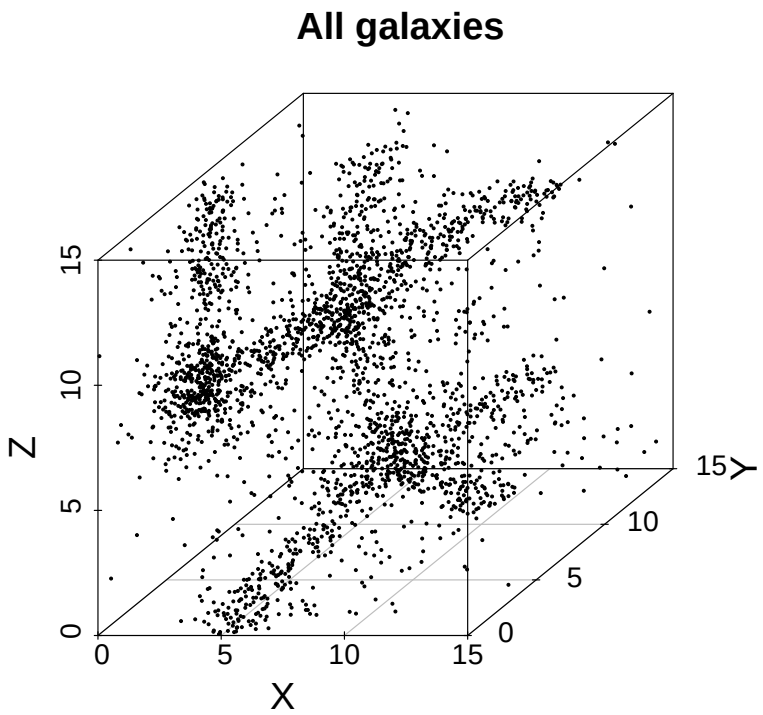


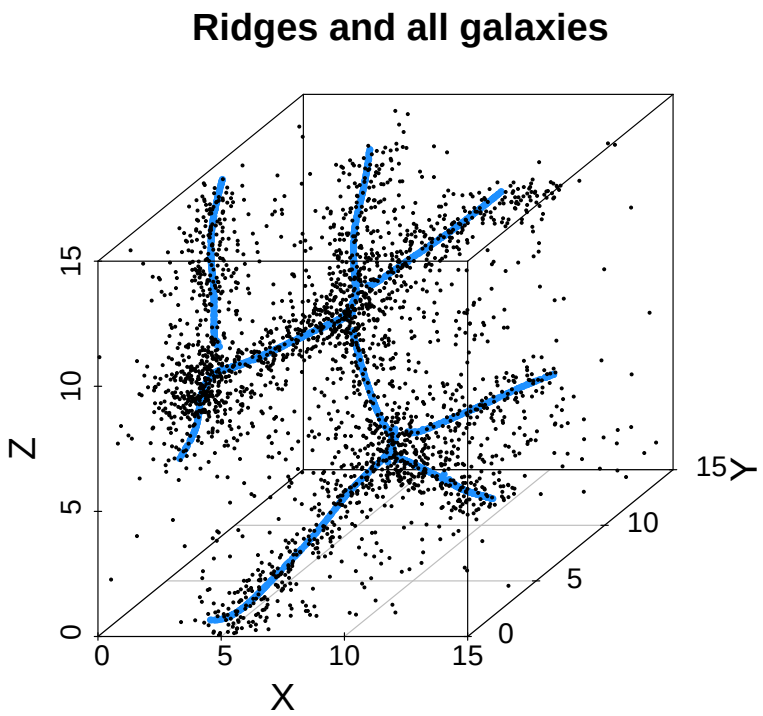
Age for Galaxies



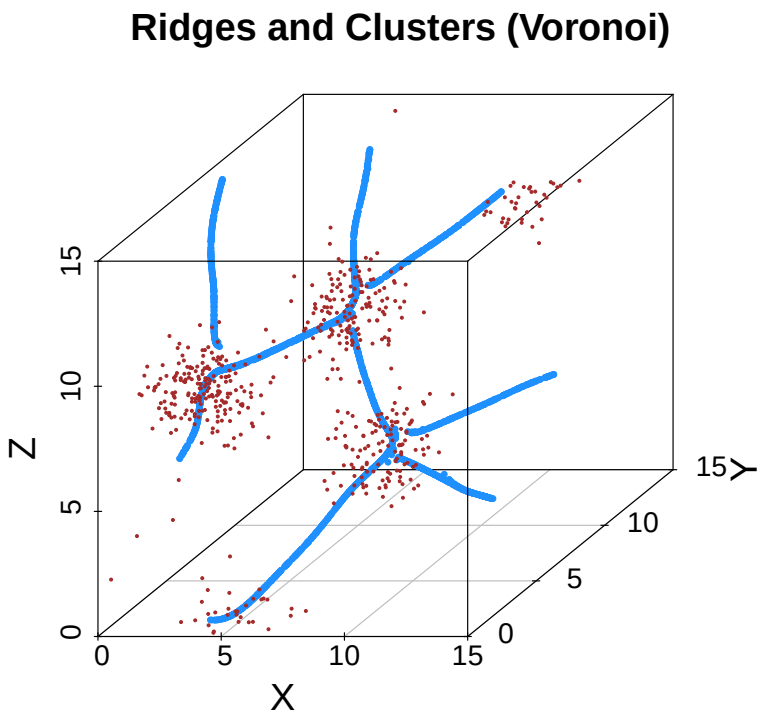
Comparison: Voronoi Model



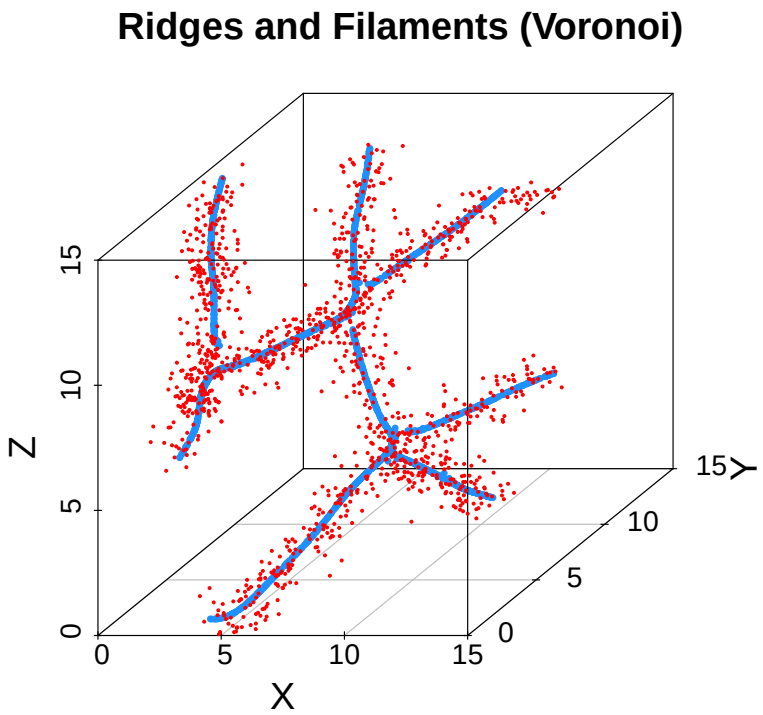
Comparison: Voronoi Model



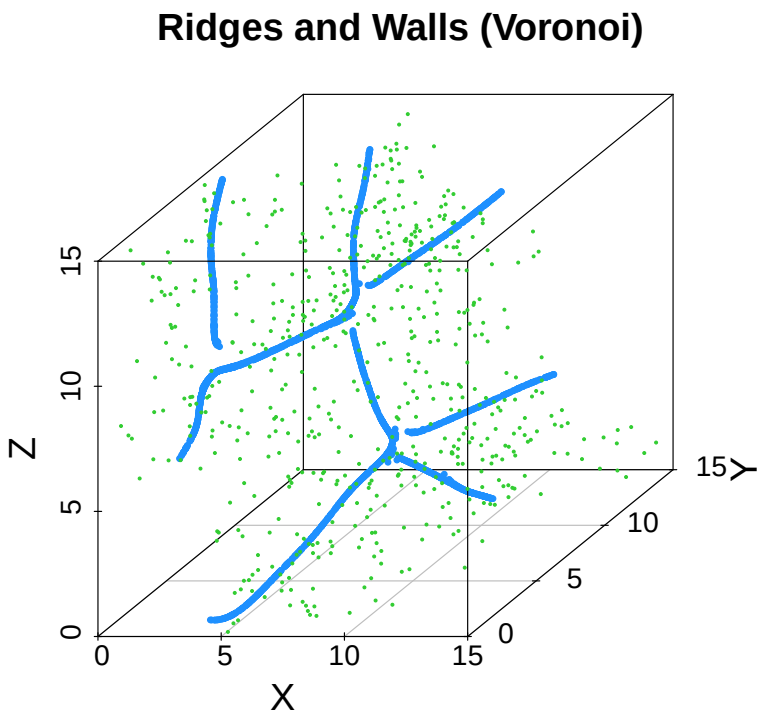
Comparison: Voronoi Model



Comparison: Voronoi Model



Comparison: Voronoi Model



Comparison: Voronoi Model