UNIVERSITY OF SEOUL

2024 11th KIAS Workshop on Cosmology and Structure Formation

Investigating Halo Properties in the Frame of Evolving Filaments

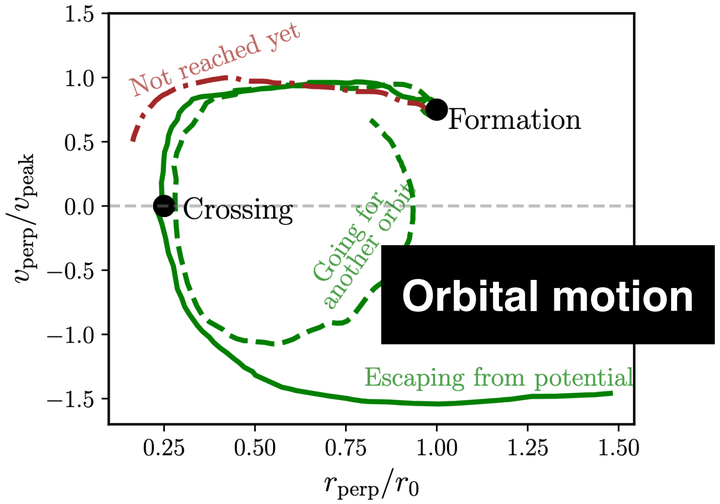
Hannah Jhee, Hyunmi Song & Clotilde Laigle

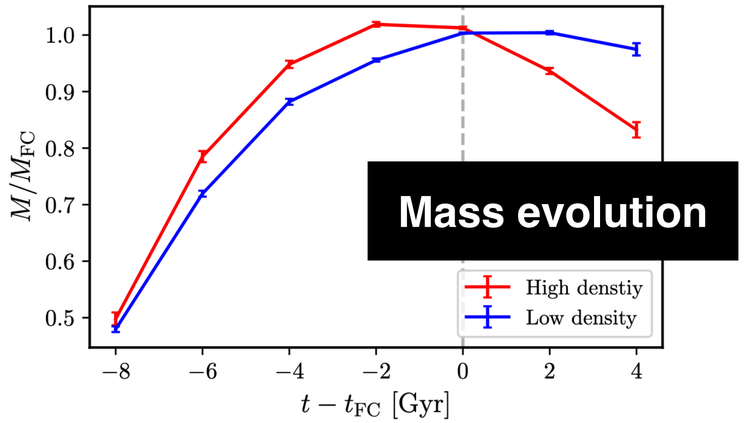
2024. 10. 31 경주힐튼호텔

Importance of environments

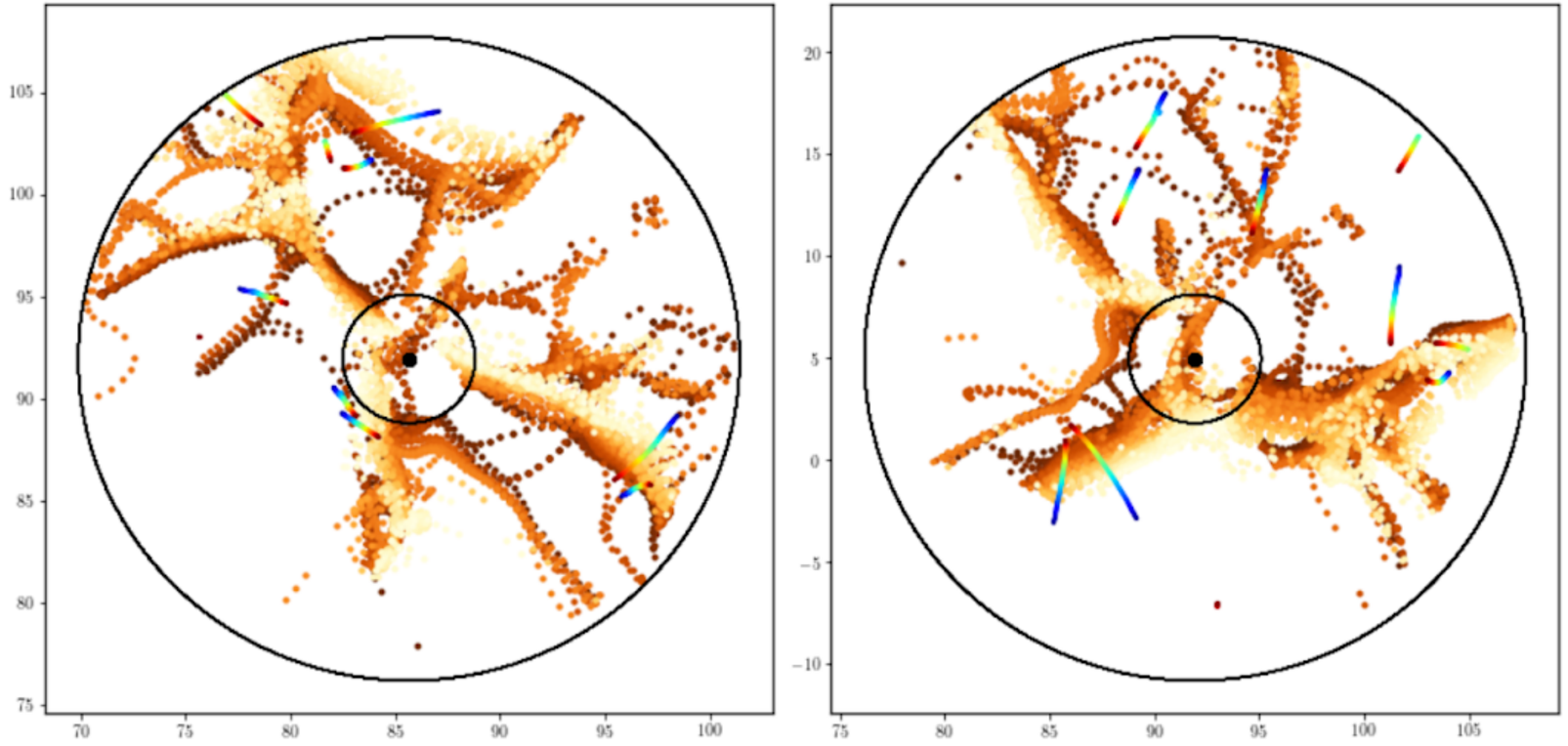
♠ Filament Environments

- In Jhee+2022, using N-body simulation…



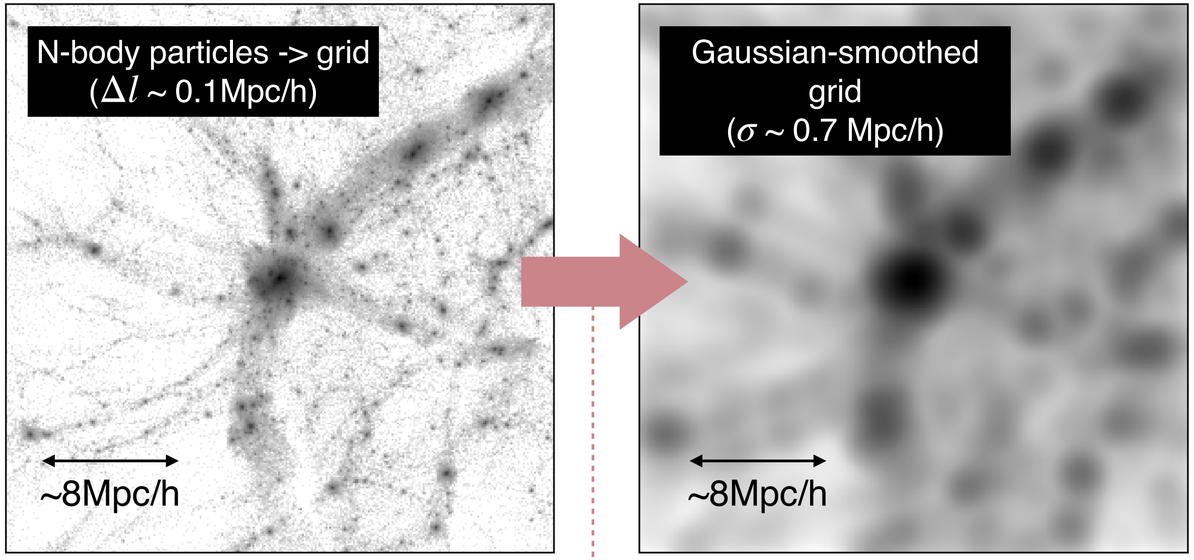


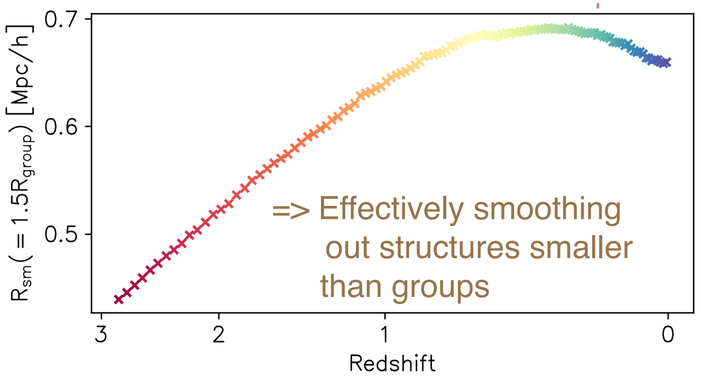
We want to bring the evolution of filaments in the discussion !!

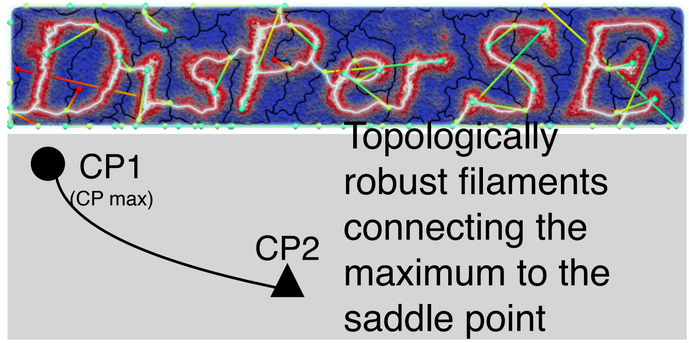


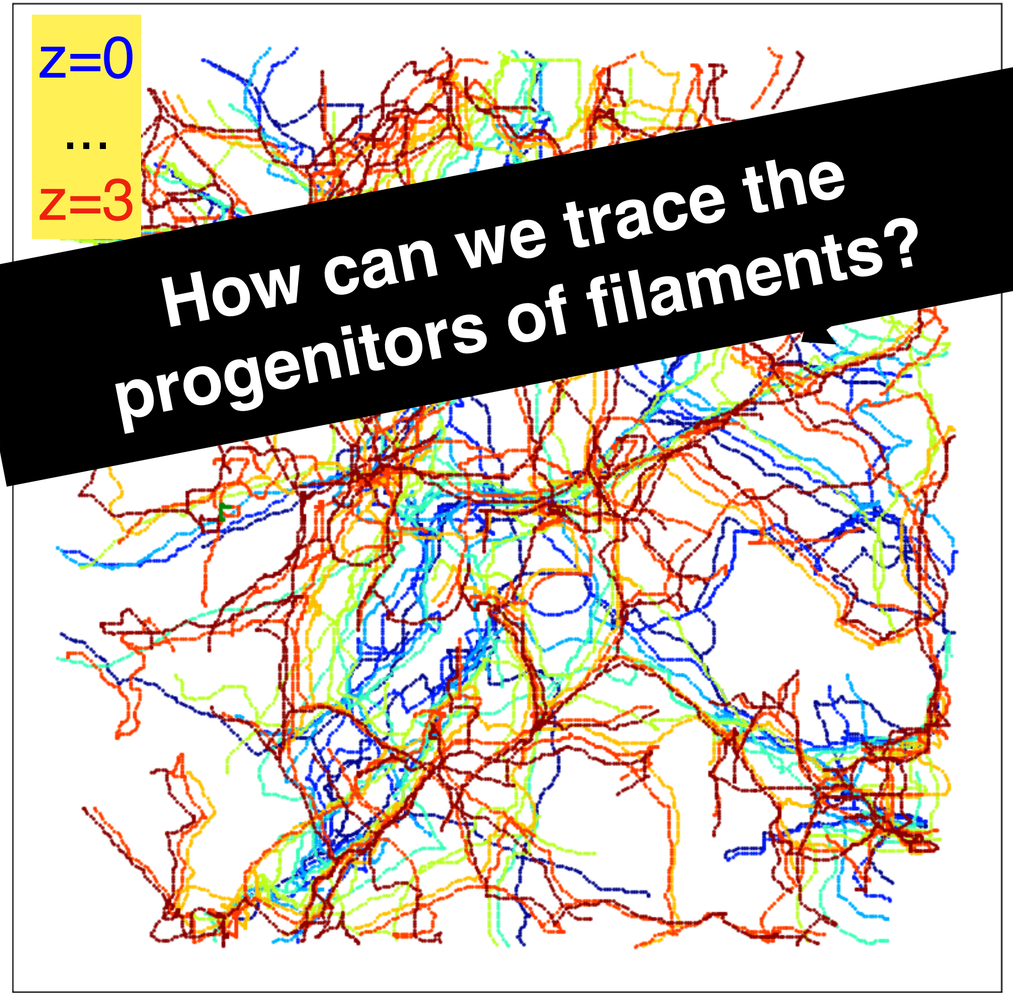
Extracting filaments

♠ **Smoothing the density fields**



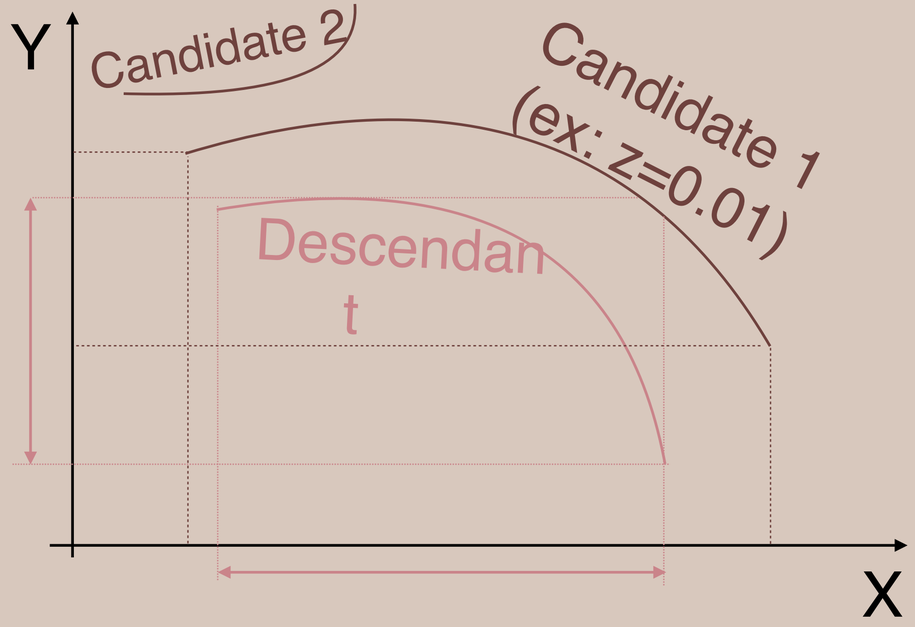




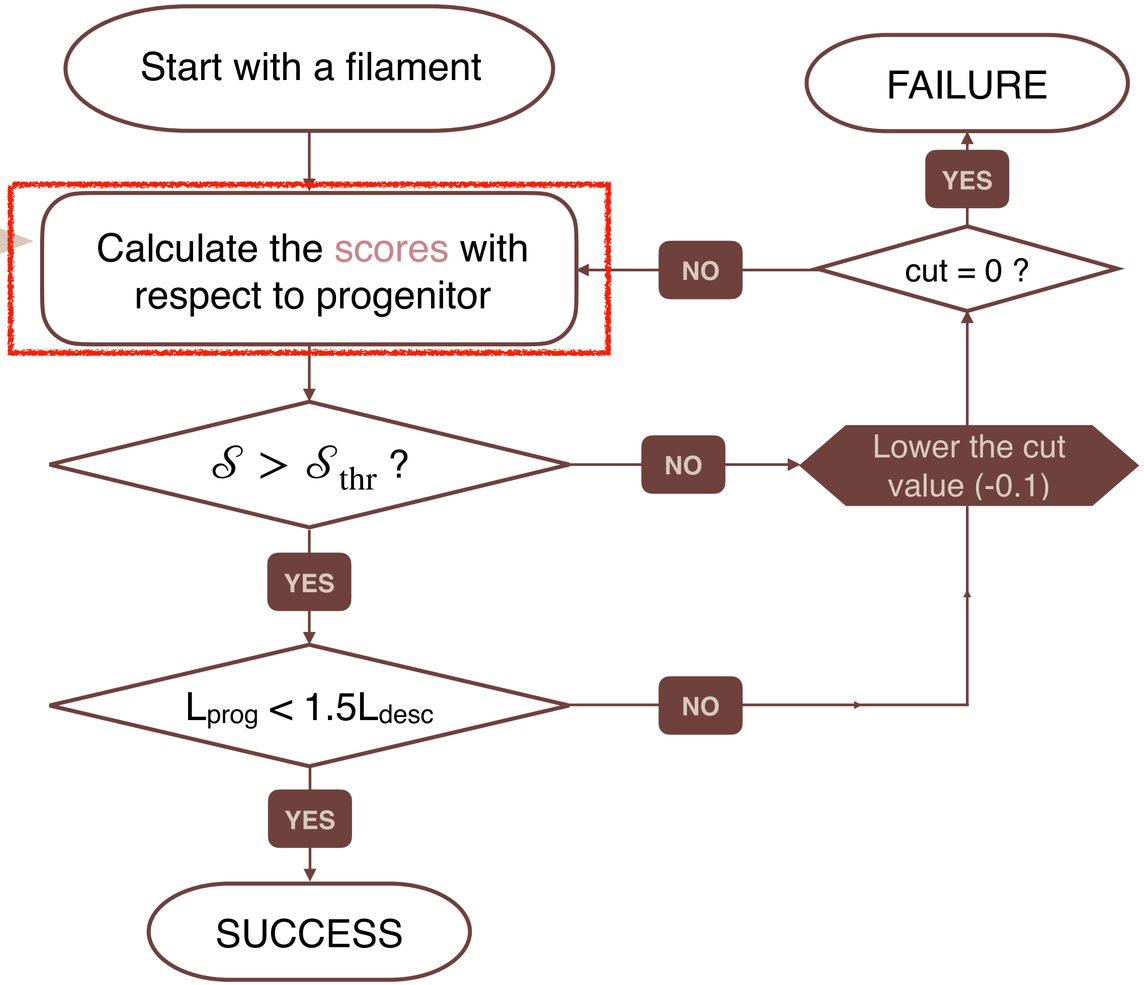


Algorithm to trace progenitors

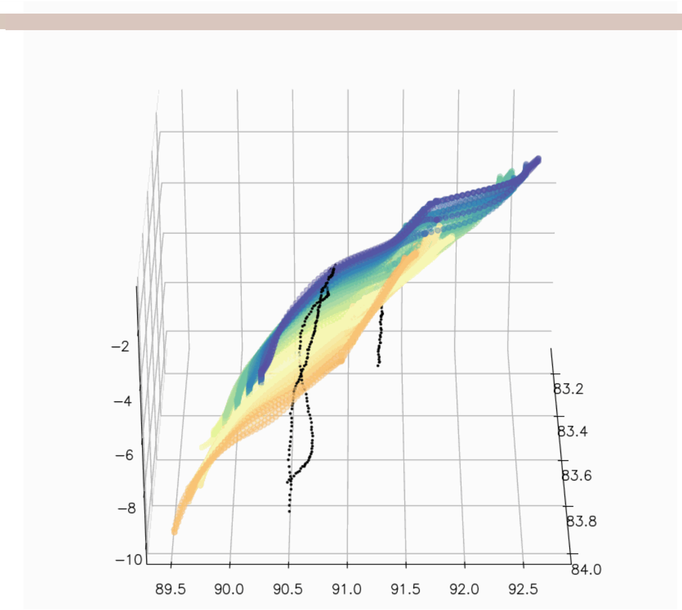
Calculating scores for spatial



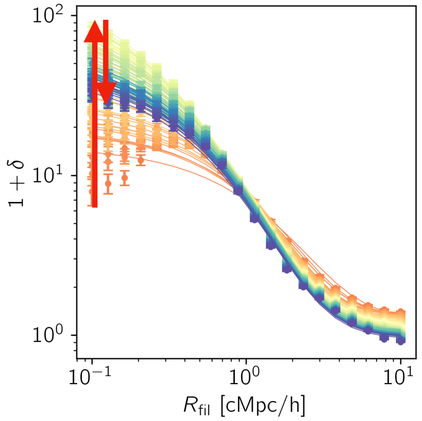
$$\mathcal{S}_x = \sum_{a=1}^{N} \frac{\Delta N_{\mathrm{desc}}}{\Delta x_a} \frac{\Delta N_{\mathrm{prog}}}{\Delta x_a} \longrightarrow \mathcal{S} = (S_x S_y S_z)^{1/3}$$



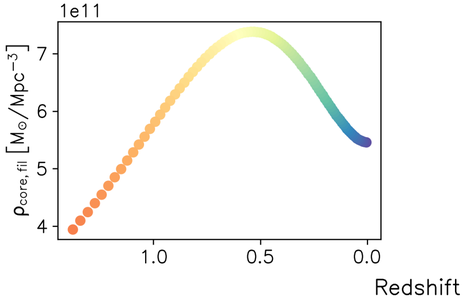
Evolution of filaments

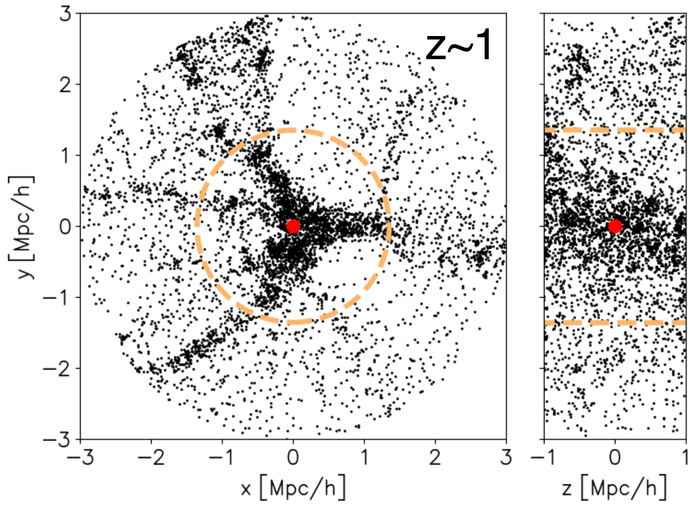


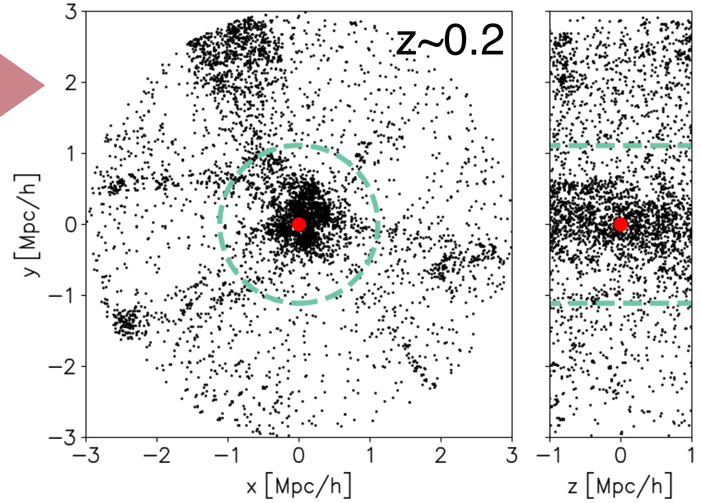
♠ **Radial density profile**

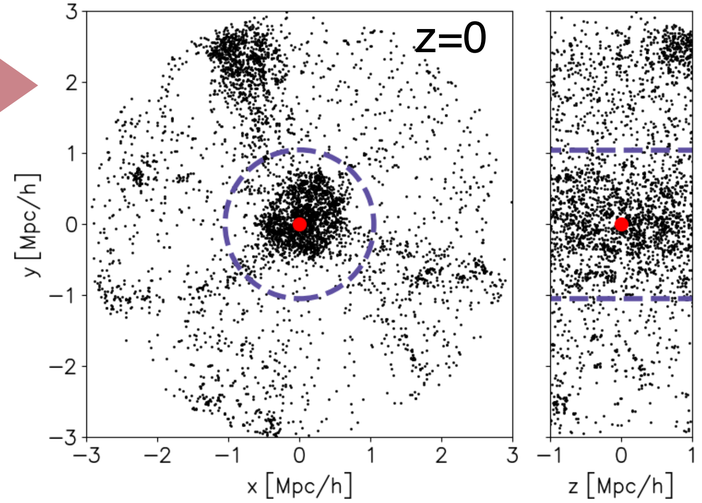


$$\rho_{\rm fil}(<R_{\rm fil}) = \rho_0 \left[1+\left(\frac{R_{\rm fil}}{R_s}\right)\right]^{-3\beta/2} + \rho_{\rm wall}$$



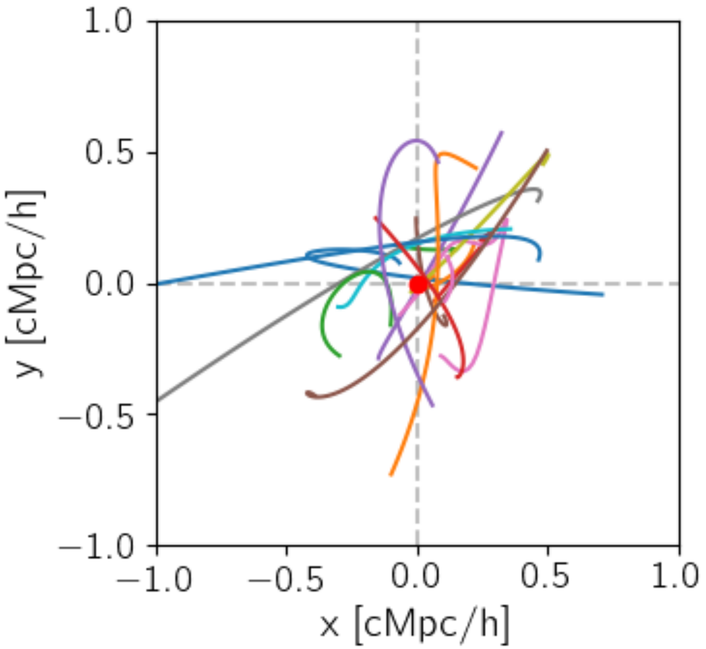


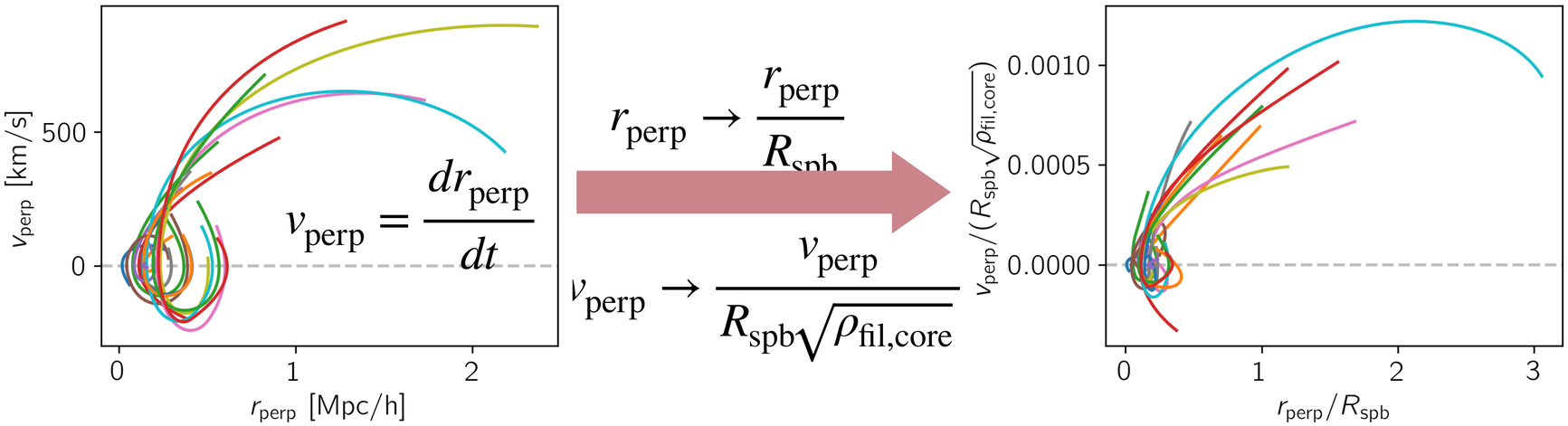




Halos around filaments

♠ **Phase-space normalization**

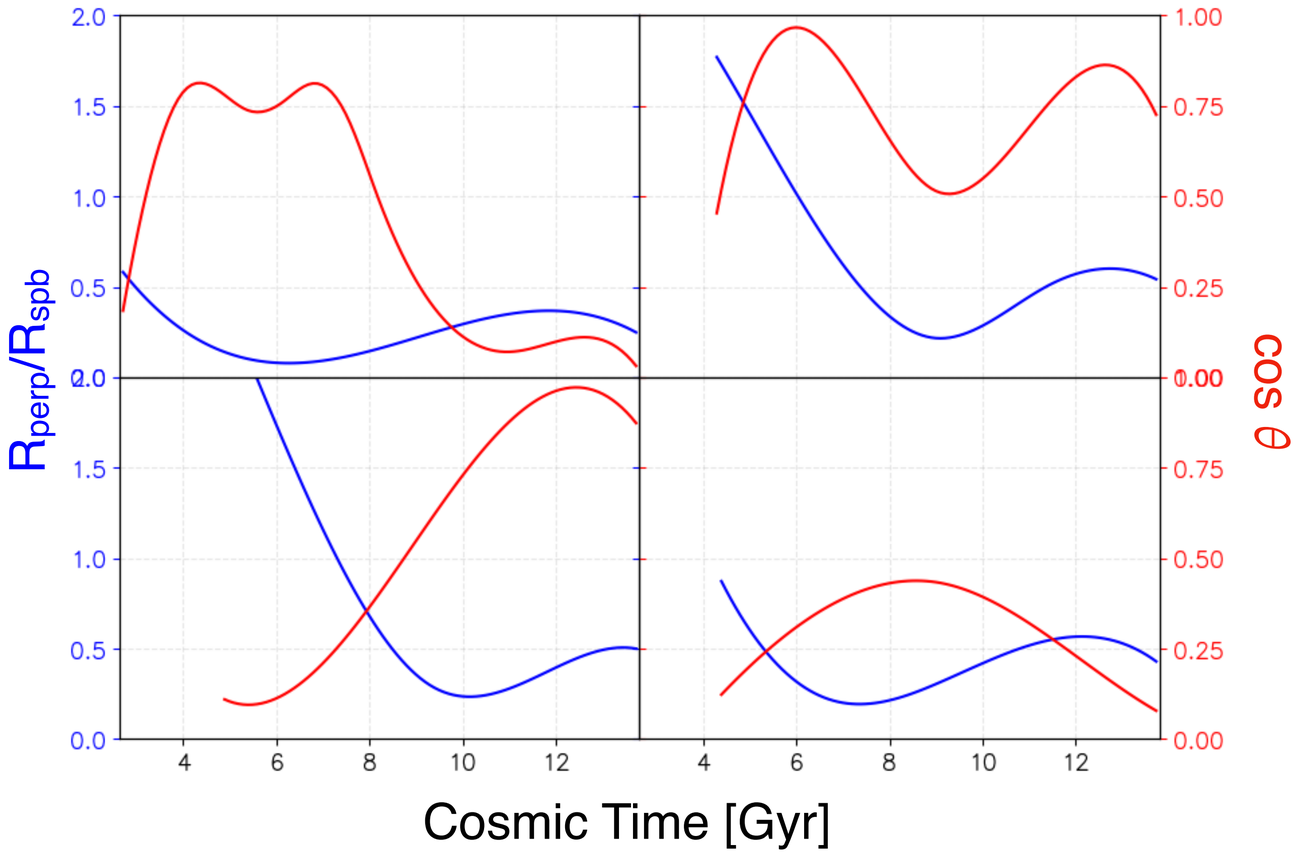


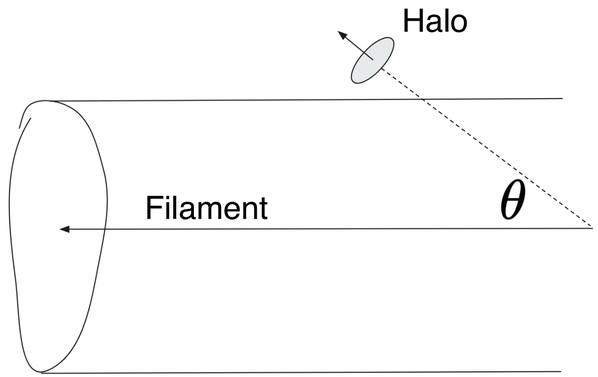


After normalization, their orbiting motions are well described in a common trajectory.

! VERY PRELIMINARY

♠ Spin alignment





Summary

1. We have tried tracing the progenitors of filaments based on spatial similarity.
2. The evolution of individual filaments can be tracked.
3. Halo motion around the filaments are well described using the evolution of filament properties.
4. It seems halo spin vectors change while they cross the filament pericenter, but more analysis is needed.

Coevolution of halos and large-scale filament structures

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[2]Department of Astronomy and Space Science, Chungnam National University, Deajeon xxxxx, Republic of Korea
[3]Sorbonne University, Institute d'Astrophysique de Paris, Paris, France

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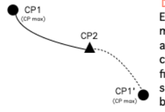
Abstract

Galaxy halos evolve differently depending on the environment they reside in, and the environment itself also evolves. Large-scale filament structures provide highly anisotropic environments, where mass flows both from walls to filaments and from filaments to nodes are significant. While it is well known that filaments affect halo properties such as dynamical states, morphology, spin or mass, the effect of their evolution has been not properly accounted for so far. In this work, using DisPerSE, we extract filament structures from dark matter density distribution from z=0 to z=3. The progenitors of the filaments at z=0 are traced back by scoring the spatial similarities between the descendant and progenitor candidates. From the set of the most prominent progenitors, we quantify the evolution of individual filaments by fitting the radial density profiles. It enables us to construct the normalized phase-space trajectories of halos. The dynamical evolution of halos are evaluated in the frame of the structures that are not only moving but also evolving.

Large-scale Filamentary Structures

Extracting filaments from the density fields

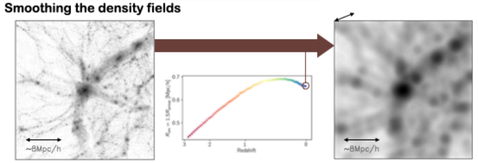
In the early universe, matter, which was distributed with slight density variations, began to collapse under the influence of gravity. Because the rate of gravitational collapse locally varies along different spatial axes, it leads to the formation of highly anisotropic structures, such as walls or filaments.



DisPerSE(Sousbie 2011), Discrete Persistent Structures Extractor, uses the fact that filaments are the pathways of matter towards the maxima (or nodes).. DisPerSE identifies an individual, local filament structure that starts from one critical point (CP1, node) to another (CP2, 1st saddle). A full filament can be identified by connecting a counterpart that shares the CP2. -cut parameter, the density contrast between CP1-CP2, determines the shape of the filaments.

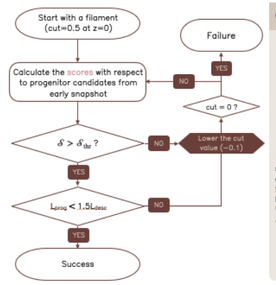
Tracing Filament Progenitors

Smoothing the density fields

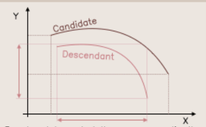


We smoothed the density field to the scale of (present-day) group-sized halos to set a minimal scale for the filament that we are extracting. At z=0, halos with $M > 10^{13}h^{-1}M_{\odot}$ comprises the most massive 0.2% of the population, and this fraction was assumed to remain constant at higher redshifts to determine the virial radius of group-scale halos at each epoch. Following More et al. (2015), we smoothed the density field up to 1.5 times the virial radius of these group halos, to get the splashback radius of the halo.

Algorithm to trace back



Calculating scores for spatial similarity



For a target descendant, the score representing the spatial similarity is assigned to each progenitor candidate. Similar to Bhattacharyya distance (Bhattacharyya 1946), which measures the similarity between two probability distributions, we compute the spatial similarity $\mathcal{S}_x$ along each axis with user-defined bin width Δx_c:

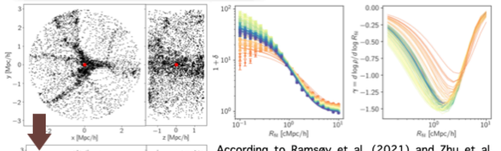
$$\mathcal{S}_x = \sum_{i=1}^{N} \frac{\Delta N_{desc}}{\Delta x_c} \frac{\Delta N_{prog}}{\Delta x_c}$$

The final score incorporates the three scores as:

$$\mathcal{S} = (\mathcal{S}_x \mathcal{S}_y \mathcal{S}_z)^{1/3}$$

Starting with a filament at z=0, we calculate the score representing how similar the descendant and a progenitor candidate (see the box). With an empirically determined threshold $\mathcal{S}_{thr} = 0.7$ we can choose a candidate with the highest score, and if no problem is detected in node identification (length), we choose the candidate as a progenitor. If no candidate meets the condition, we identify less prominent candidates and repeat.

Evolution of Filaments

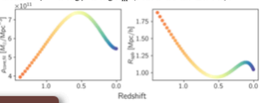


According to Ramsøy et al. (2021) and Zhu et al. (2021), the radial profile of a filament embedded within a wall can be represented as:

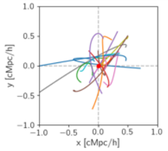
$$\rho_{fil}(< R_{fil}) = \rho_0 \left[1 + \left(\frac{R_{fil}}{R_s}\right)^2\right]^{-3/2} + \rho_{wall}$$

The density profiles are fitted well by assuming a constant contribution of the wall on top of the filament profile(see the figure above). In this way, we have traced the evolution of 28 filaments around the 3 most massive clusters in the simulation.

We present one of the examples for the evolution of the core densities ρ_0 and the splashback radii, which minimizes $\gamma = d \log \rho / d \log R_{fil}$ (More et al. 2015).



Halos around Filaments



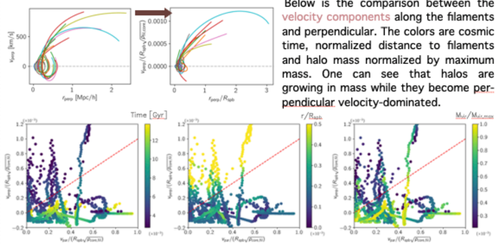
As in Jhee et al. (2022), the phase-space trajectories of halos orbiting around the filaments are constructed. Because now the filament structures are also moving, the perpendicular velocities of halos are now calculated as the time derivative of the distance between halos and filaments. Moreover, we can further normalize the trajectory using the evolution of filaments:

$$r_{perp} \rightarrow \frac{r_{perp}}{R_{sph}}$$

$$v_{perp} \rightarrow \frac{v_{perp}}{R_{sph}\sqrt{\rho_{fil,core}}}$$

The orbital motions of selected halos are better generalized on the phase-space after normalization. The characteristic radius is at $\sim 0.2R_{sph}$.

Below is the comparison between the velocity components along the filaments and perpendicular. The colors are cosmic time, normalized distance to filaments and halo mass normalized by maximum mass. One can see that halos are growing in mass while they become perpendicular velocity-dominated.



Summary

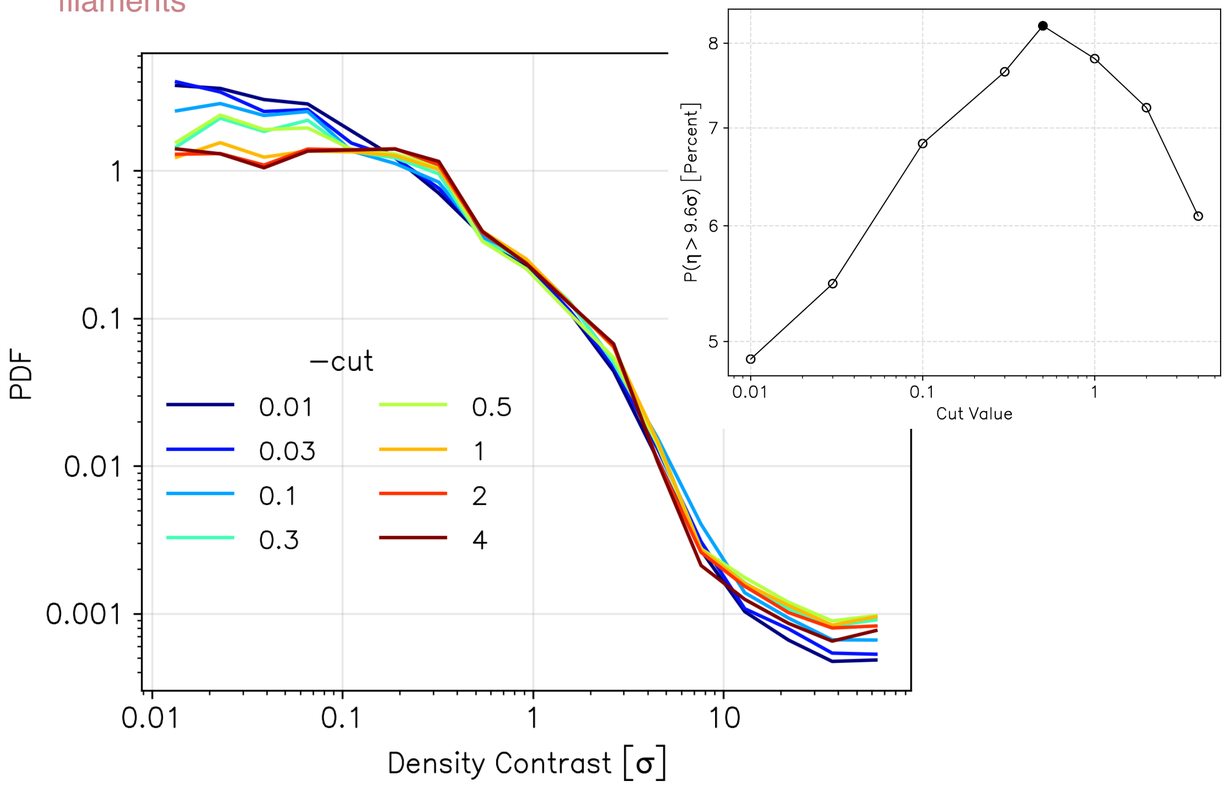
1. We have traced the filament structures from z=3 to z=0 from smoothed density field of N-body simulation. Starting from z=0, we have traced the progenitors of filaments until z>1.
2. The tracing is done by scoring the spatial similarity, interpreting the filament extension along each 3 axis as probability distribution and calculating the distances between the distribution.
3. We have fitted the evolution of density profiles of filament progenitors, and it seems like some of them undergoes two phases of evolution.
4. Halos orbiting around the filaments can now be normalized, and their evolution can be understood in the frame of evolving filaments.

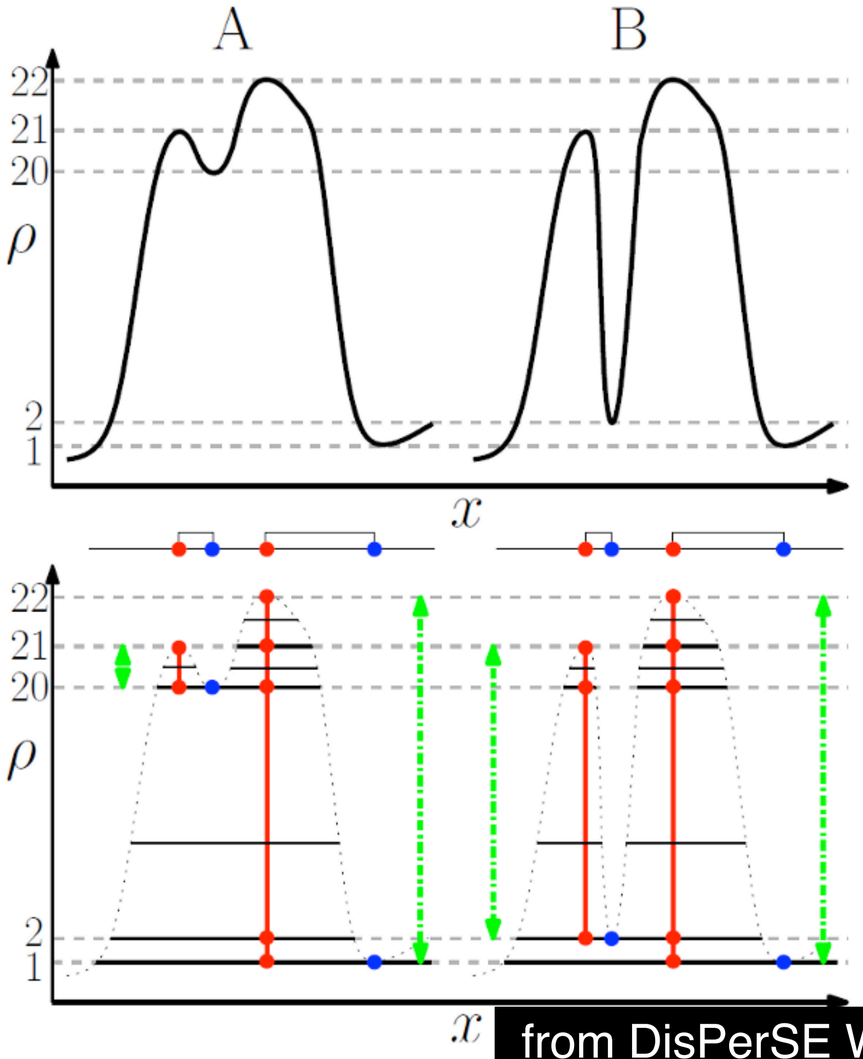
Reference

Sousbie 2011 (DisPerSE)
More et al. 2015 (Splashback radius)
Bhattacharyya 1946 (Scoring similarity)
Ramsøy et al. 2021 (Filament profiles)
Zhu et al. 2021 (Filament profiles)
Jhee et al. 2022 (Our previous work)

BACK UP :: running DisPerSE

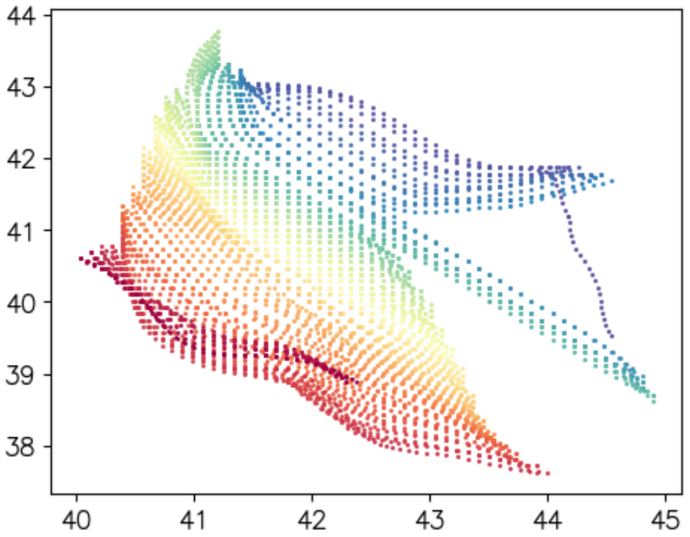
- The connectivity and the number of critical points can be different according to the choice of persistence thresholds
- We start from the threshold that maximizes the fraction of high density filaments

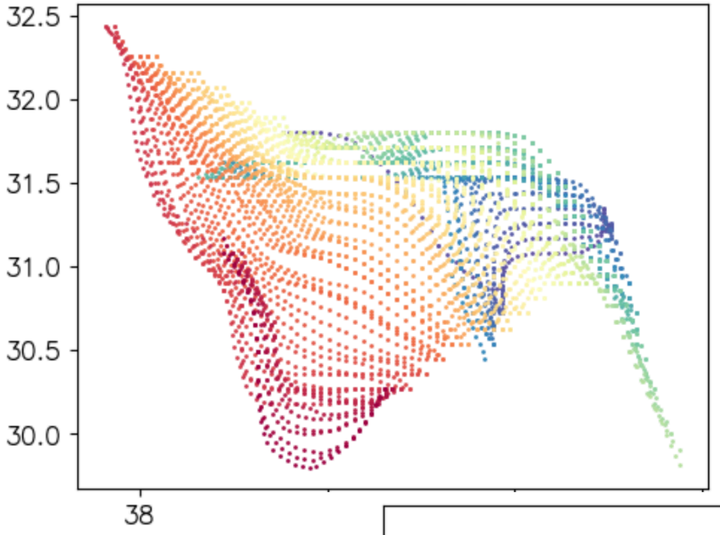


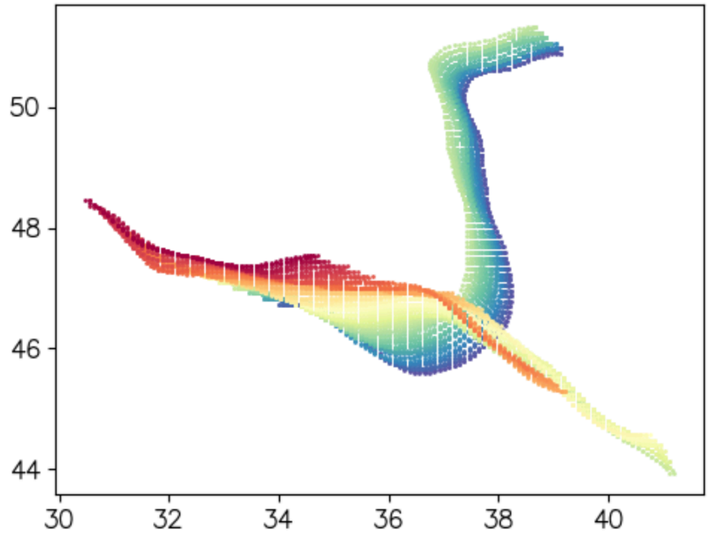


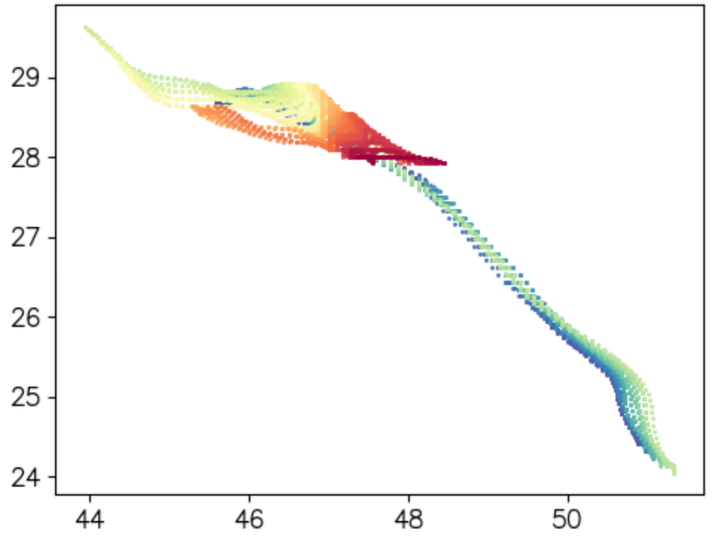
from DisPerSE Website

BACK UP :: ugly cases









BACK UP :: other filaments

