The one-dimensional Universe. Investigating filaments in observations and simulations with 1-DREAM, from GAIA to the Cosmic Web.

M. Canducci[1]

P. Awad[2], A. Taghribi[2], M. Mohammadi[2], M. Mastropietro[3],

S. De Rijcke[3], R. Peletier[2], R. Smith[4], K. Bunte[2], P. Tino[1]

1. University of Birmingham, School of Computer Science, UK;
2. University of Groningen, Kapteyn Astronomical Institute, NL;
3. University of Groningen, Bernoulli Institute, NL;
4. Ghent University, Department of Physics and Astronomy, BE;
5. Universidad Technica Frederico de Santa Maria, Santiago, CL.

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SUNDIAL
H2020 Innovative Training Network

UNIVERSITY OF BIRMINGHAM

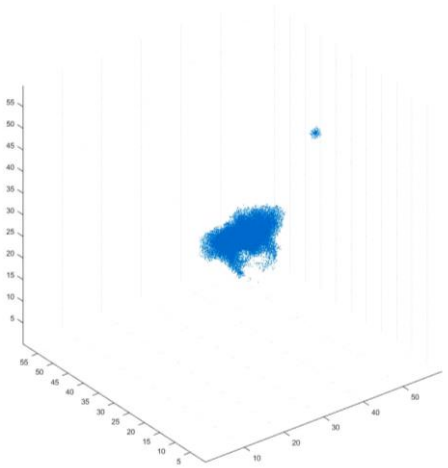
university of groningen

UNIVERSIDAD TECNICA FEDERICO SANTA MARIA

Astronomical particle data sets

Simulated

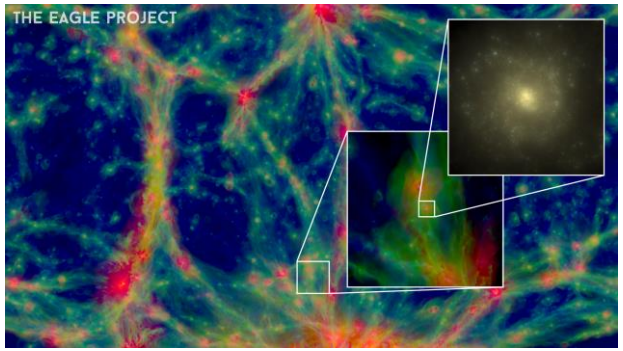
- Dwarf galaxy in interaction with Fornax-like cluster halo.



Smoothed Particle Hydrodynamics (SPH) simulations with GADGET2 + Moving Box

Mastropietro M., De Rijcke S., Peletier R.F.
A tale of two tails: insights from simulations into the formation of the peculiar dwarf galaxy NGC 1427A
Mon. Not. R. Astron. Soc., 504 (3) (2021), pp. 3387-3398, 10.1093/mnras/stab1091

- Large scale formation, Dark Matter only.



N-body simulation with GADGET-3

Observed

Astronomical particle data sets

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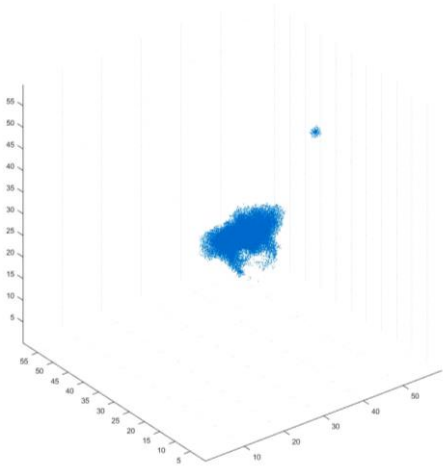
- Dwarf galaxy in interaction with Fornax-like cluster halo.



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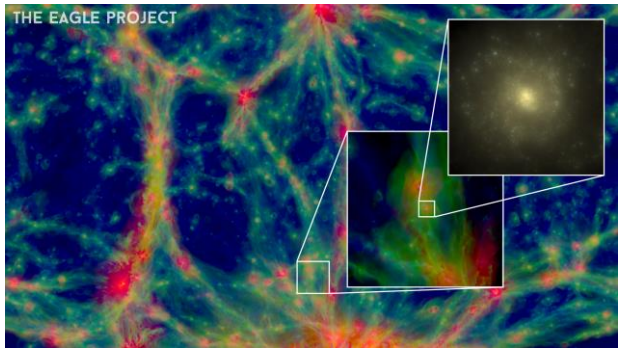
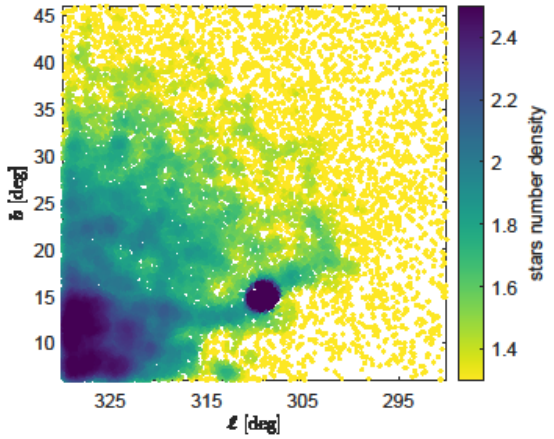


N-body simulation with GADGET-3

Observed

GAIA DR2, Omega Centauri

Particles are stars observed by GAIA.



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arXiv:1902.09544

1-DREAM:
1D Recovery, Extraction and Analysis of Manifolds in noisy environments.

M. Canducci, P. Awad, A. Taghribi, M. Mohammadi, M. Mastropietro, S. De Rijcke, R. Peletier, R. Smith, K. Bunte, P. Tiňo,
1-DREAM: 1D Recovery, Extraction and Analysis of Manifolds in noisy environments, Astronomy and Computing, Volume 41, 2022, 100658, ISSN 2213-1337, https://doi.org/10.1016/j.ascom.2022.100658.

Gitlab public repo: https://git.lwp.rug.nl/cs.projects/1DREAM

1-DREAM

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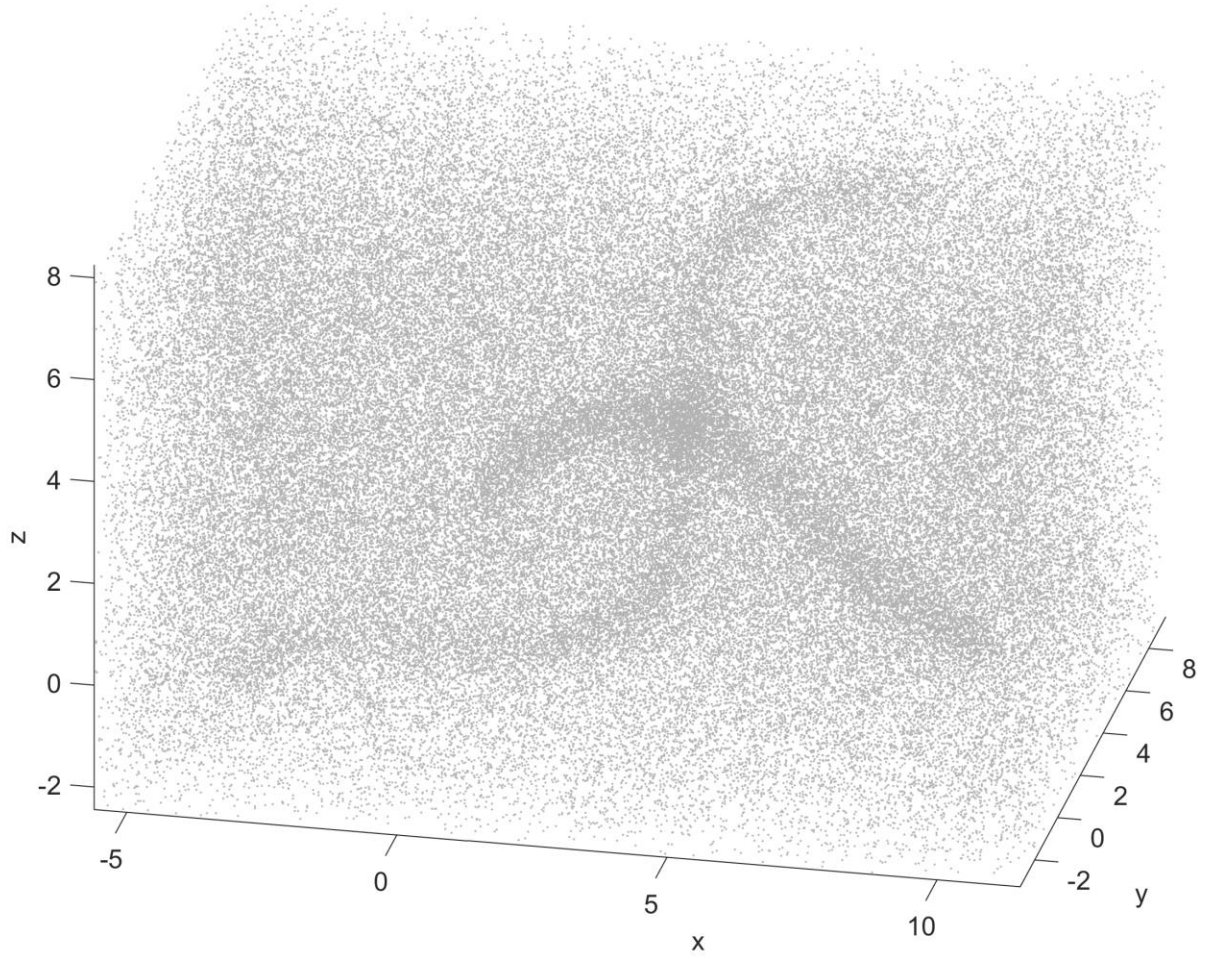

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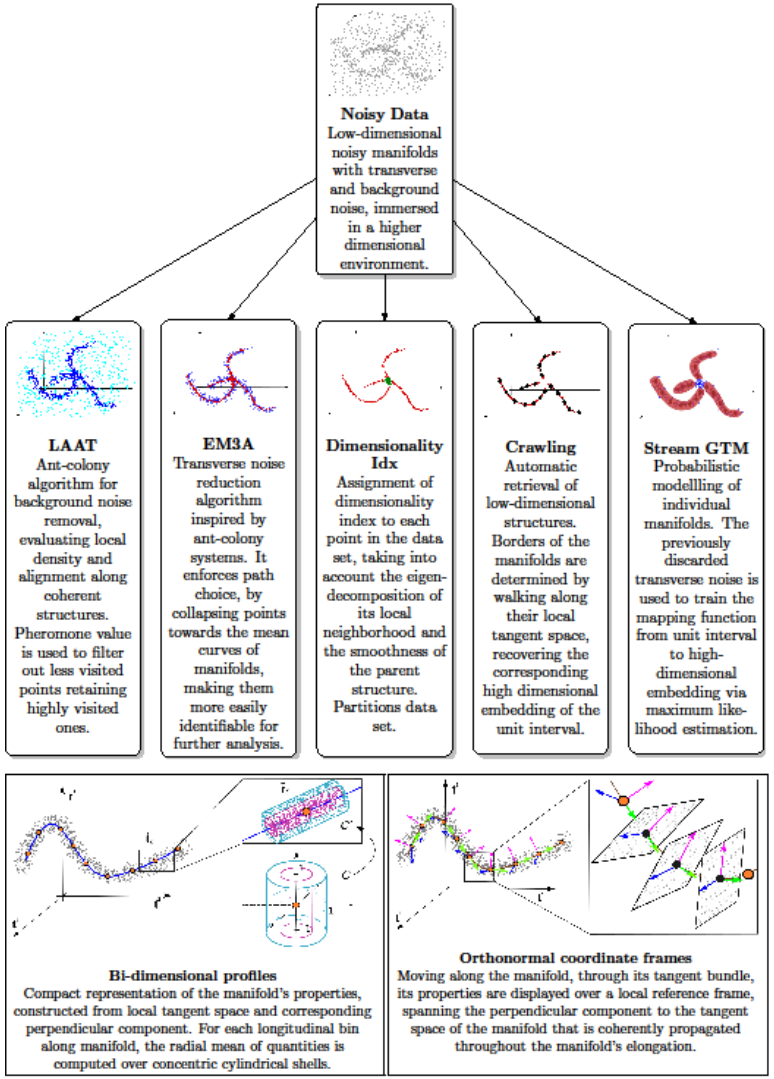

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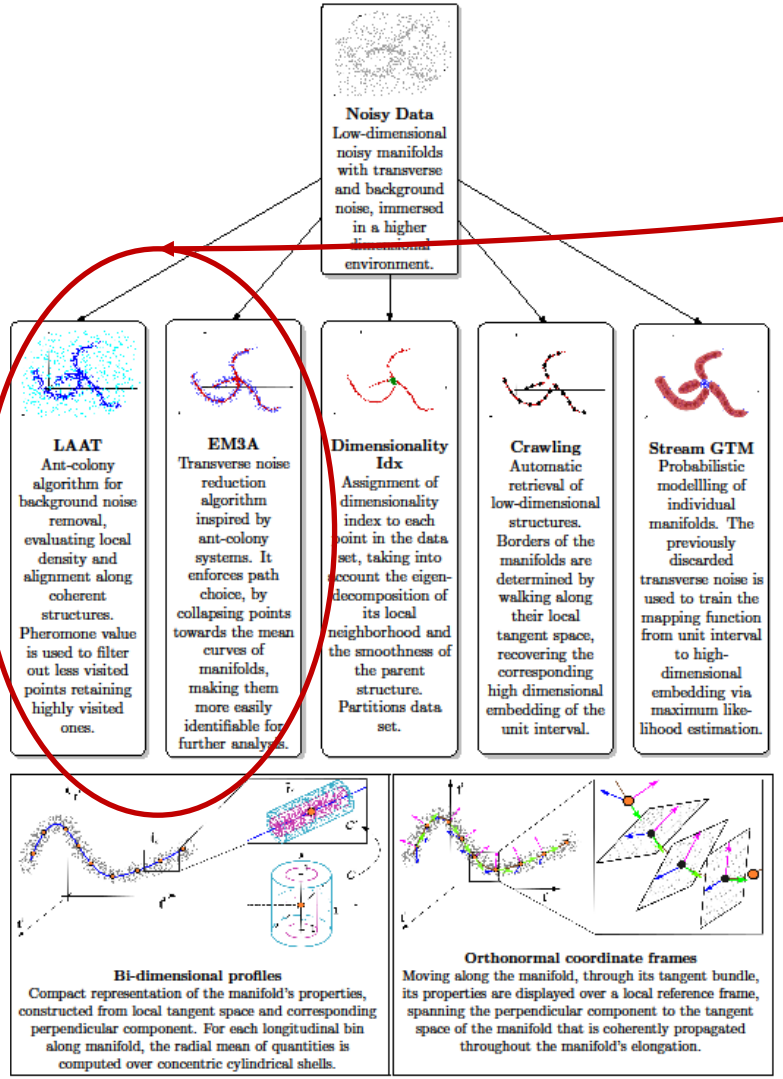

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LAAT

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LAAT: Locally aligned ant technique for discovering multiple faint low dimensional structures of varying density
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- Taghribi, A. (2022).
Natural computation techniques for uncovering low-dimensional topological structures in large scale astronomical simulations. University of Groningen.
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EM3A

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Multi-agent based manifold denoising
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Manifold alignment aware ants: a Markovian process for manifold extraction
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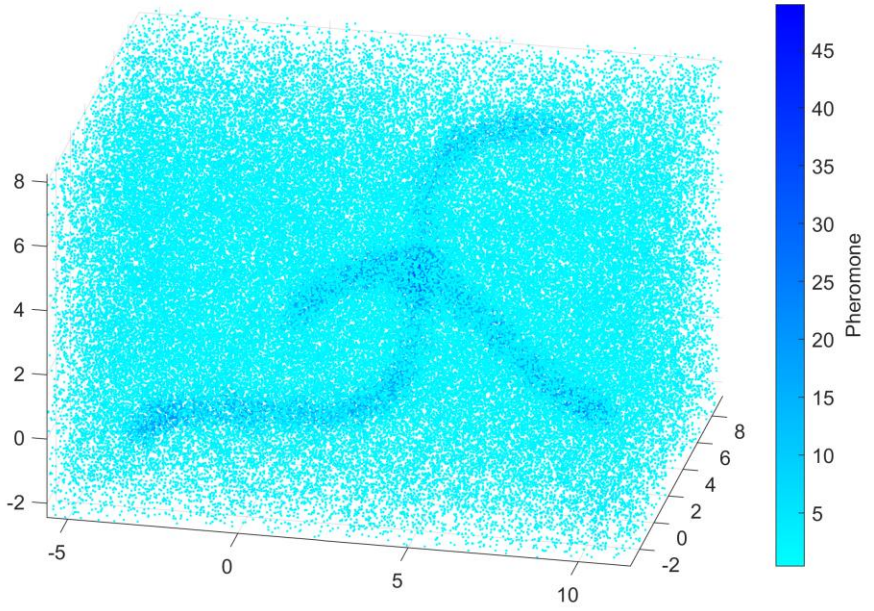
1-DREAM: LAAT



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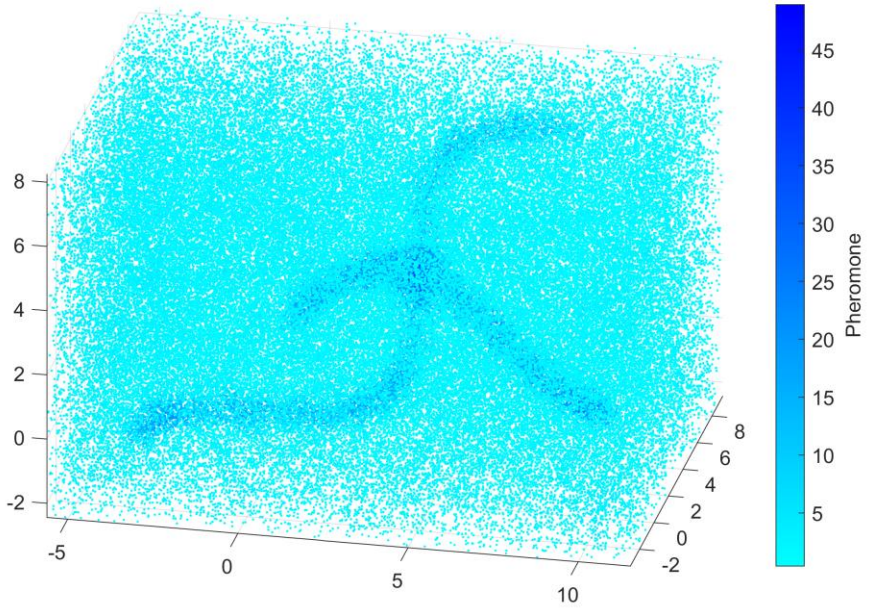

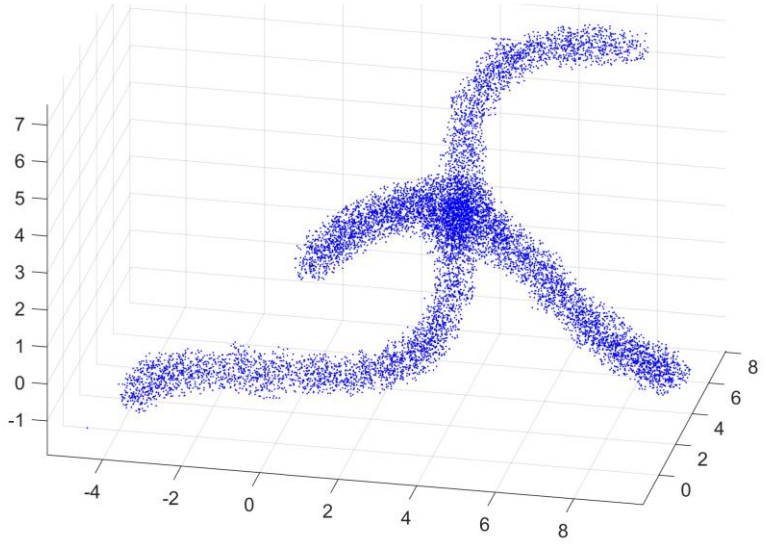

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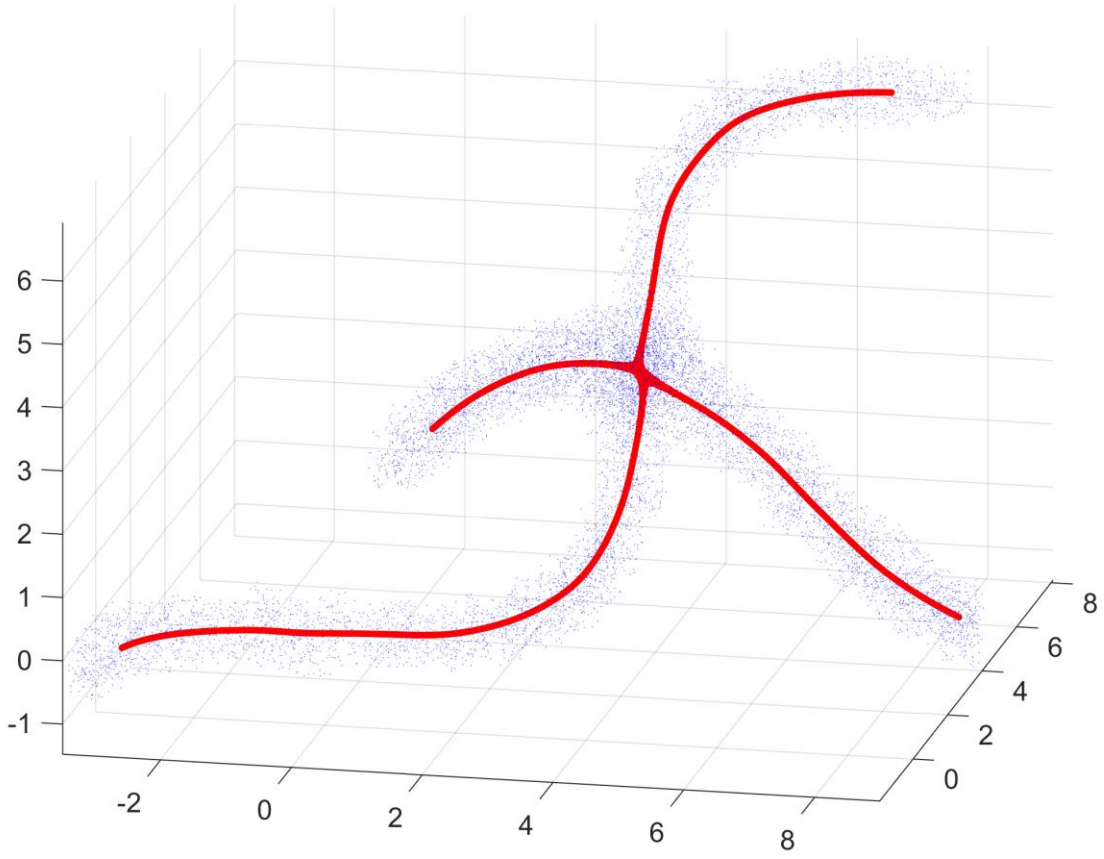
1-DREAM: EM3A

EM3A: Multi-agent based manifold denoising



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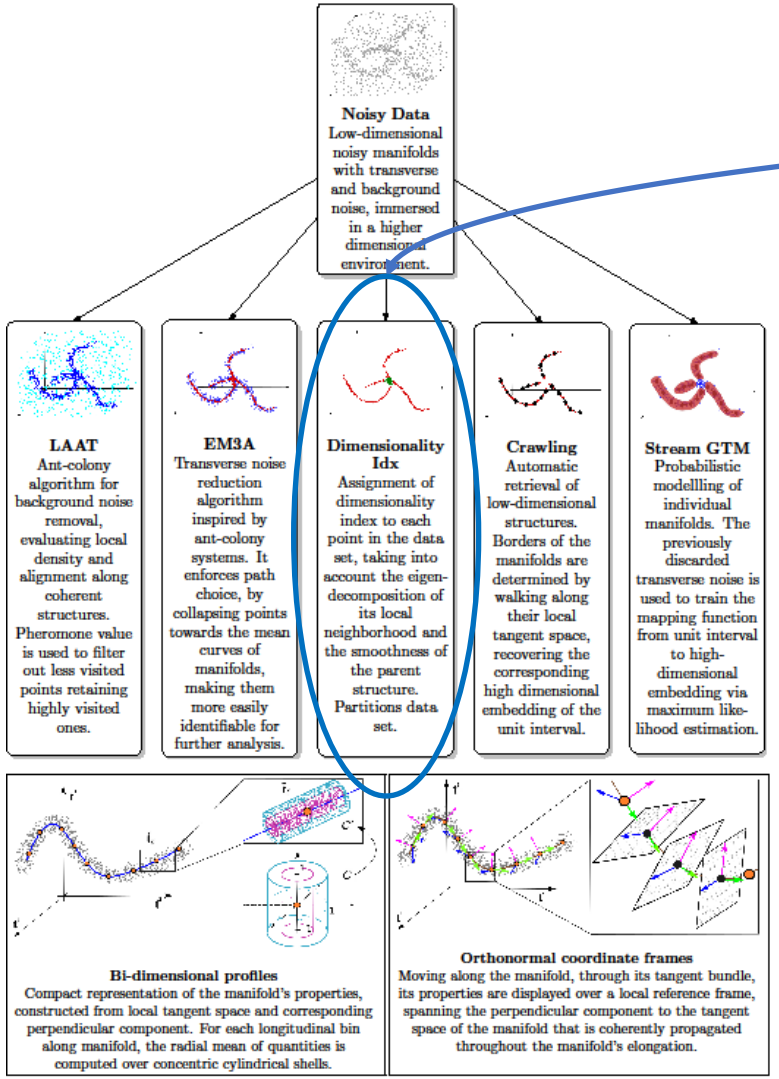
1-DREAM: Dim Index



Dimensionality Index

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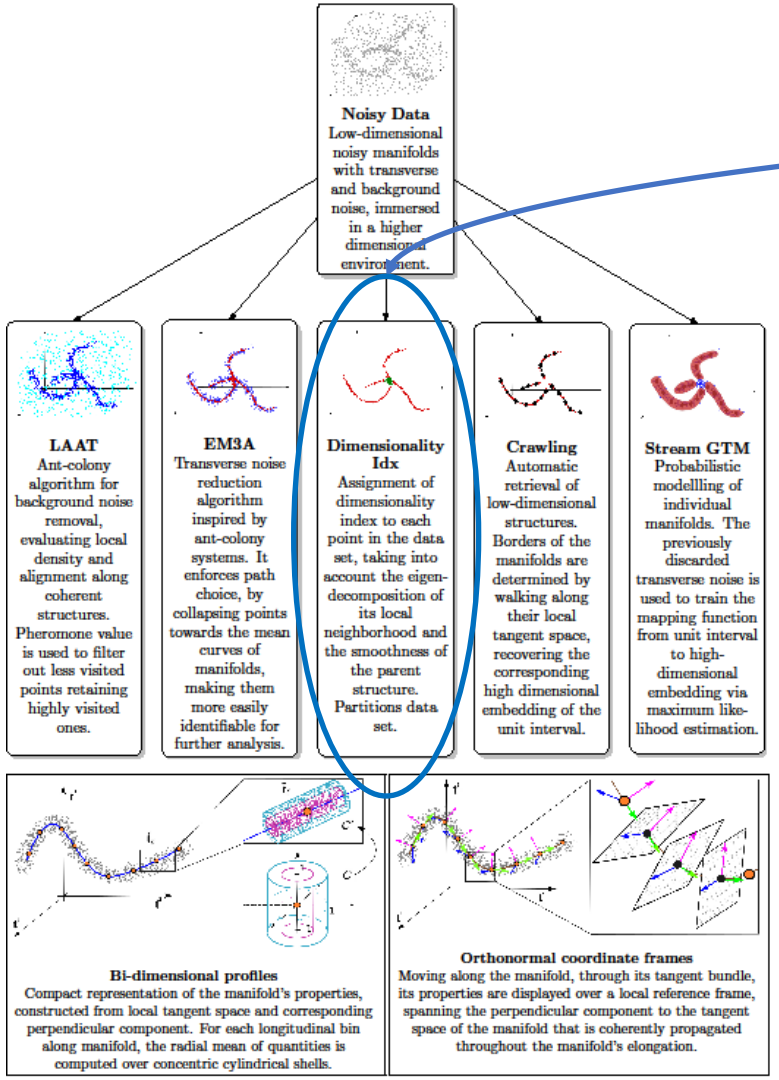

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- normalized eigenspectra (live on a standard simplex)

$$\tilde{\lambda}_{i,j} = \frac{\lambda_{i,j}}{\sum_{k=1}^{d} \lambda_{i,k}}$$

- "ideal" 1D, 2D, 3D etc. normalized eigenspectra:
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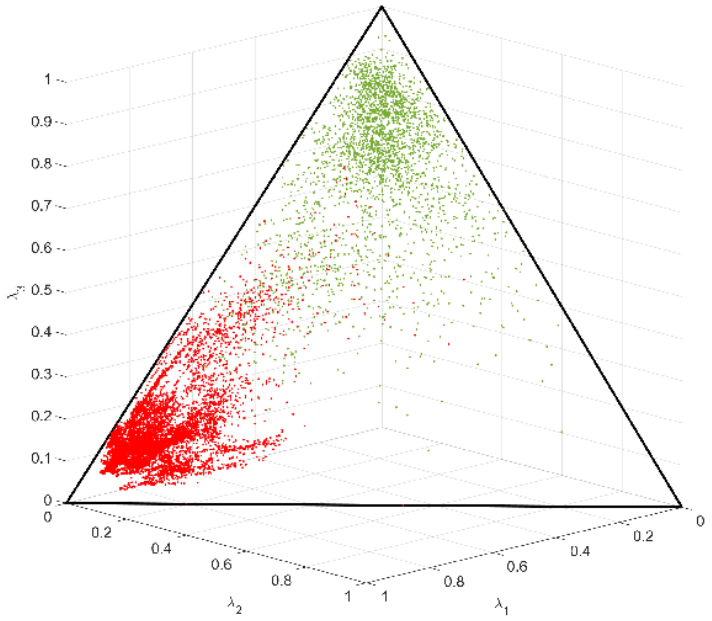

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- cluster normalized spectra w.r.t. to such cluster representatives
Riemannian geodesic Fisher distance:

$$d_J(\tilde{\Lambda}_k, \tilde{\Lambda}_l) = 2 \arccos\left(\sum_{j=1}^{d} \sqrt{(\tilde{\lambda}_{kj} \cdot \tilde{\lambda}_{lj})} \right)$$

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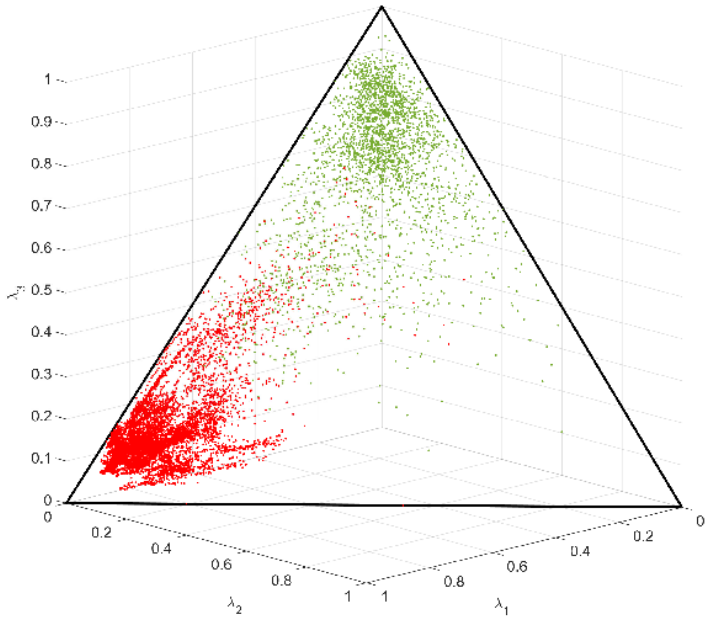

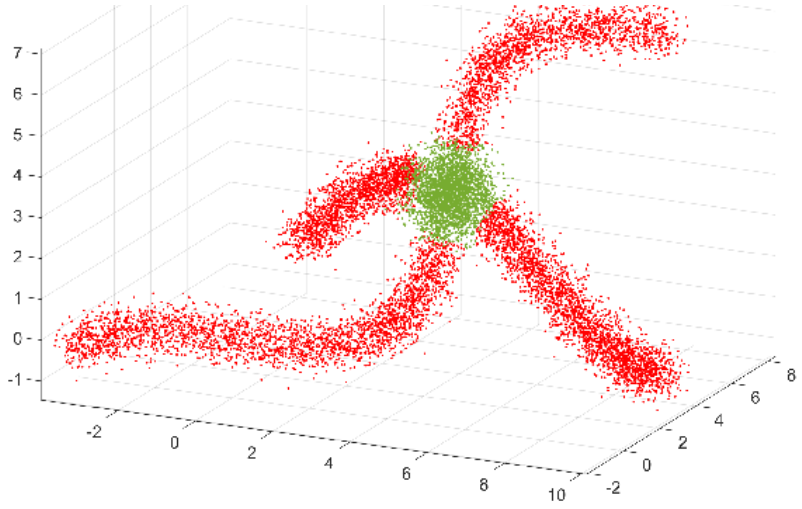

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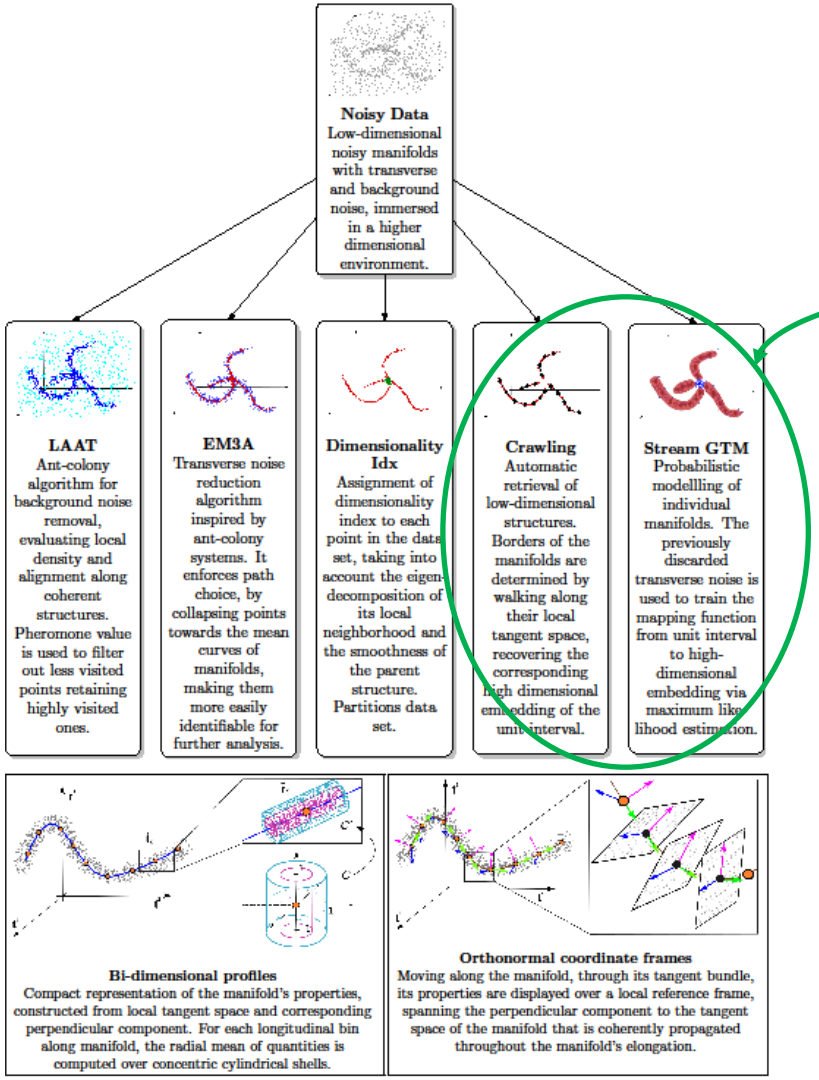

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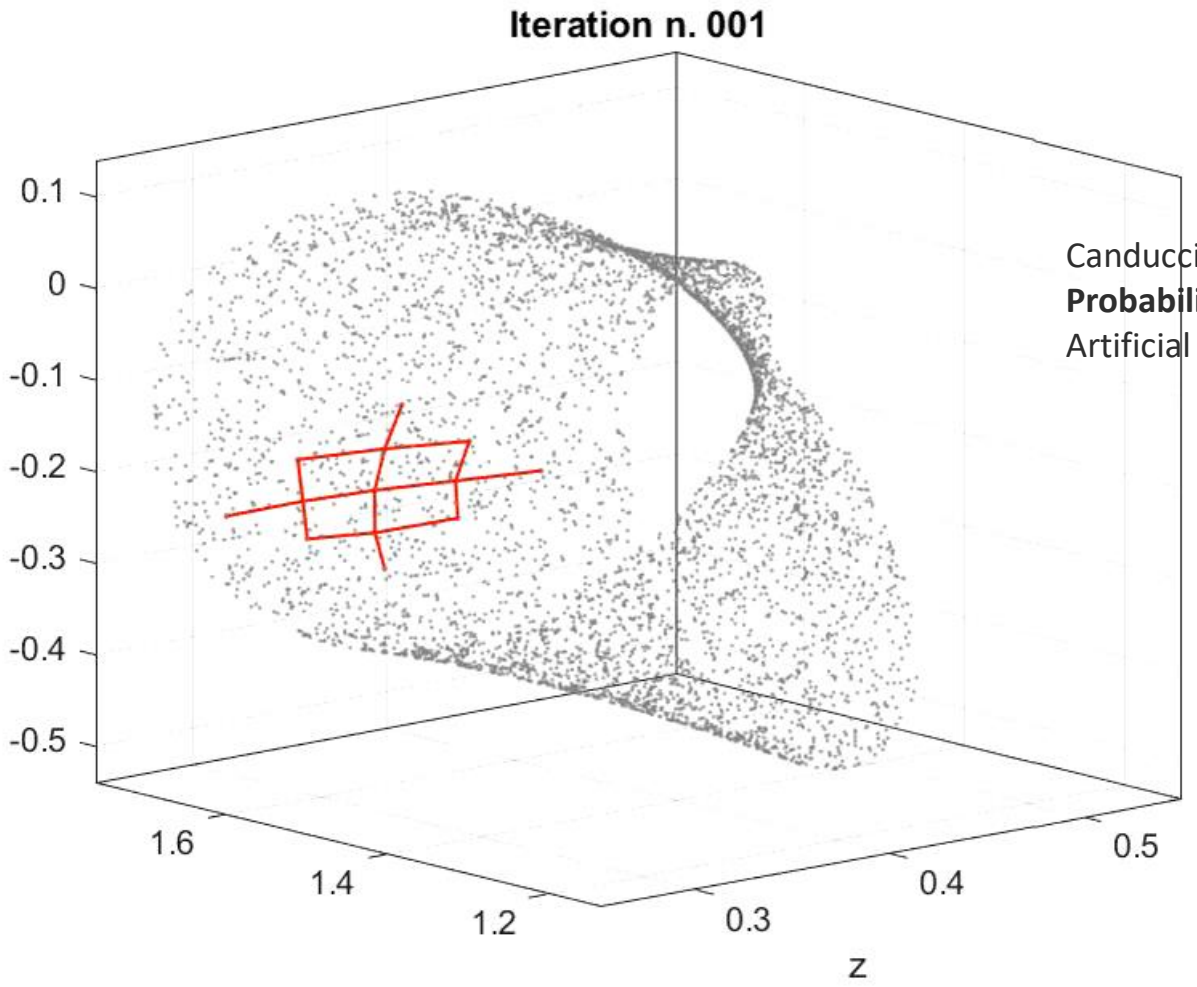
1-DREAM: Crawling



Multi-Manifold Crawling

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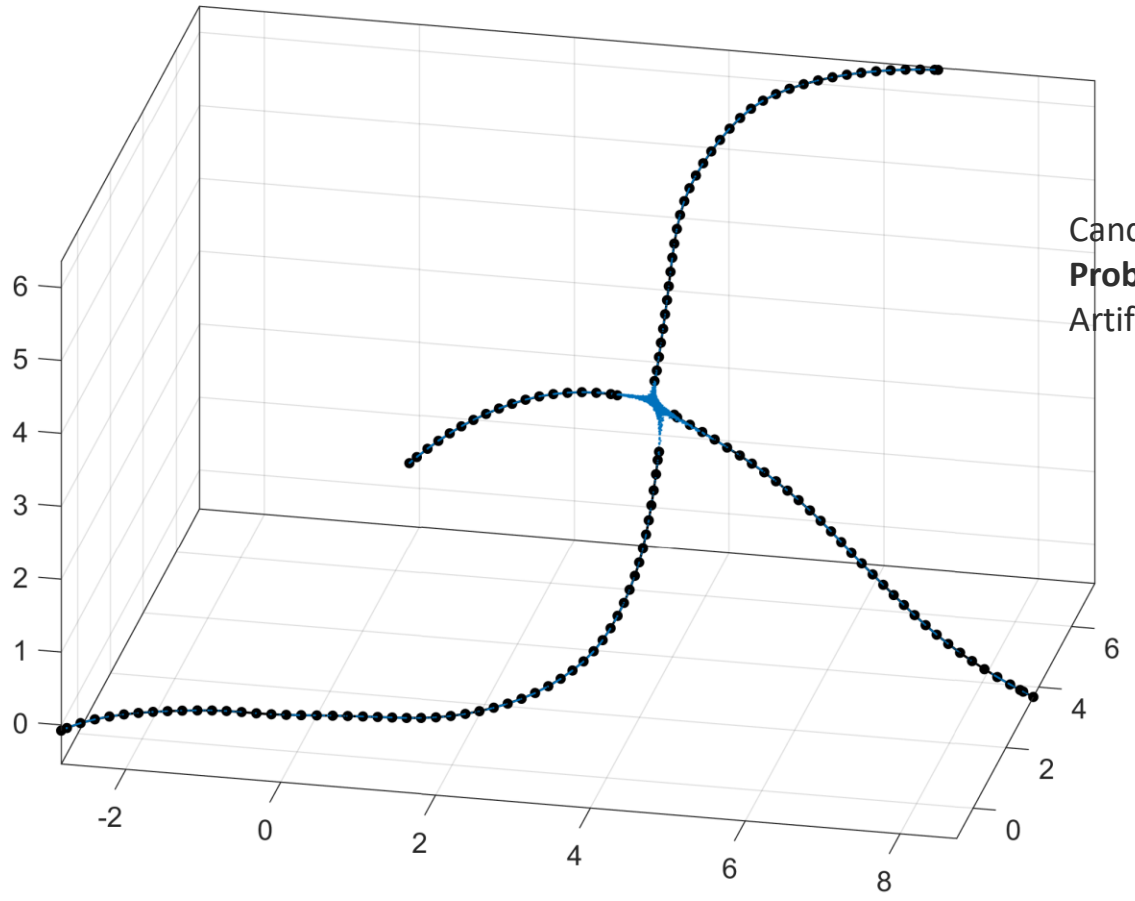

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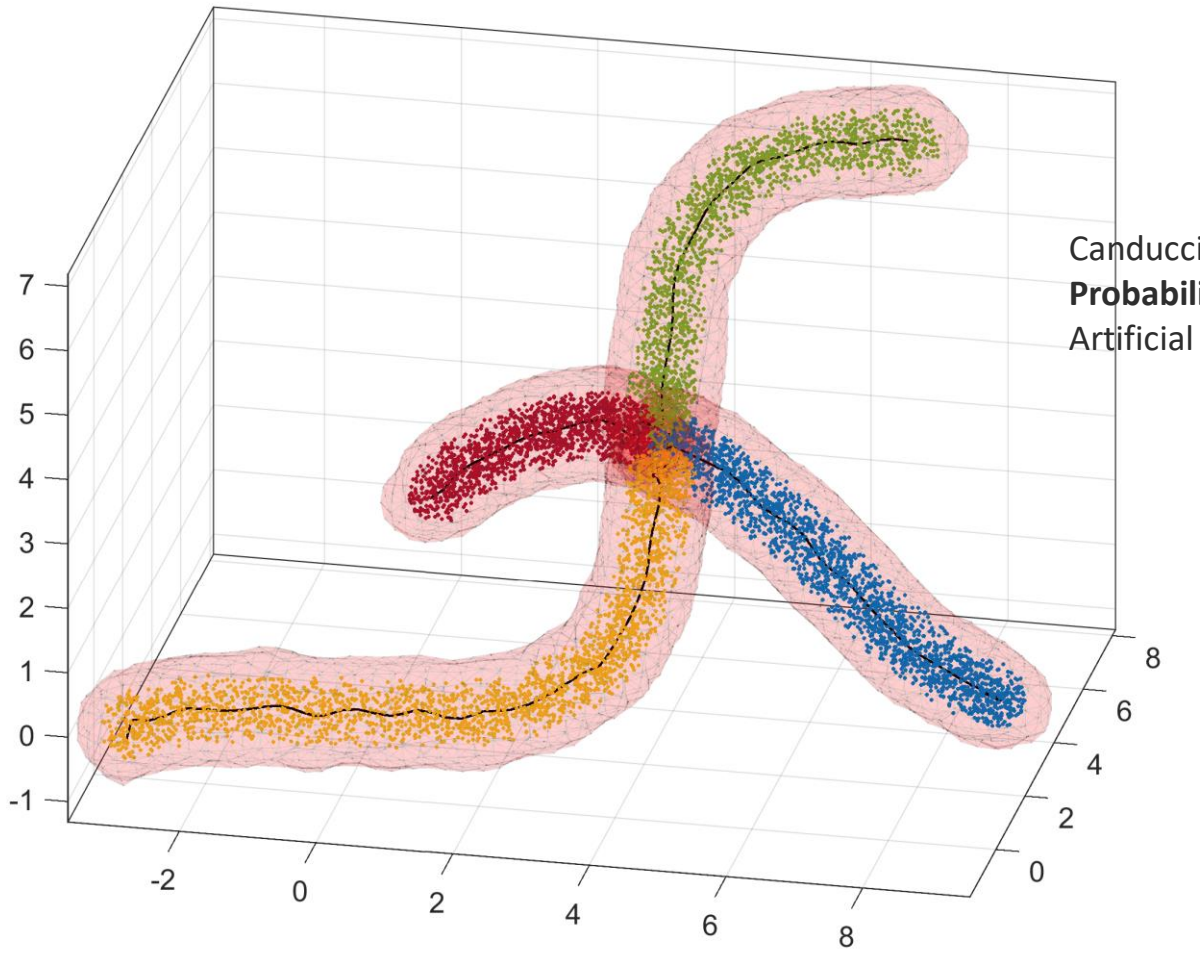
1-DREAM: AGTM



Abstract GTM

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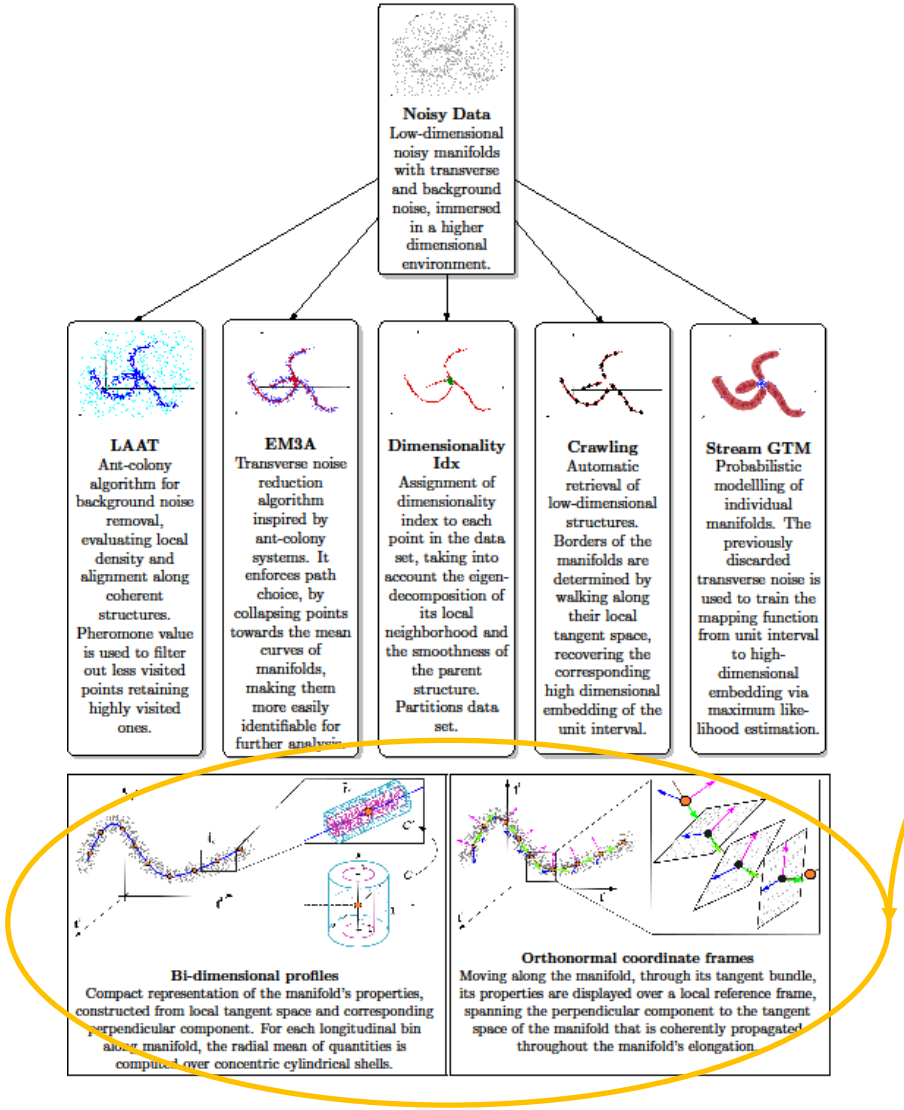
1-DREAM: Visualization



1-DREAM:

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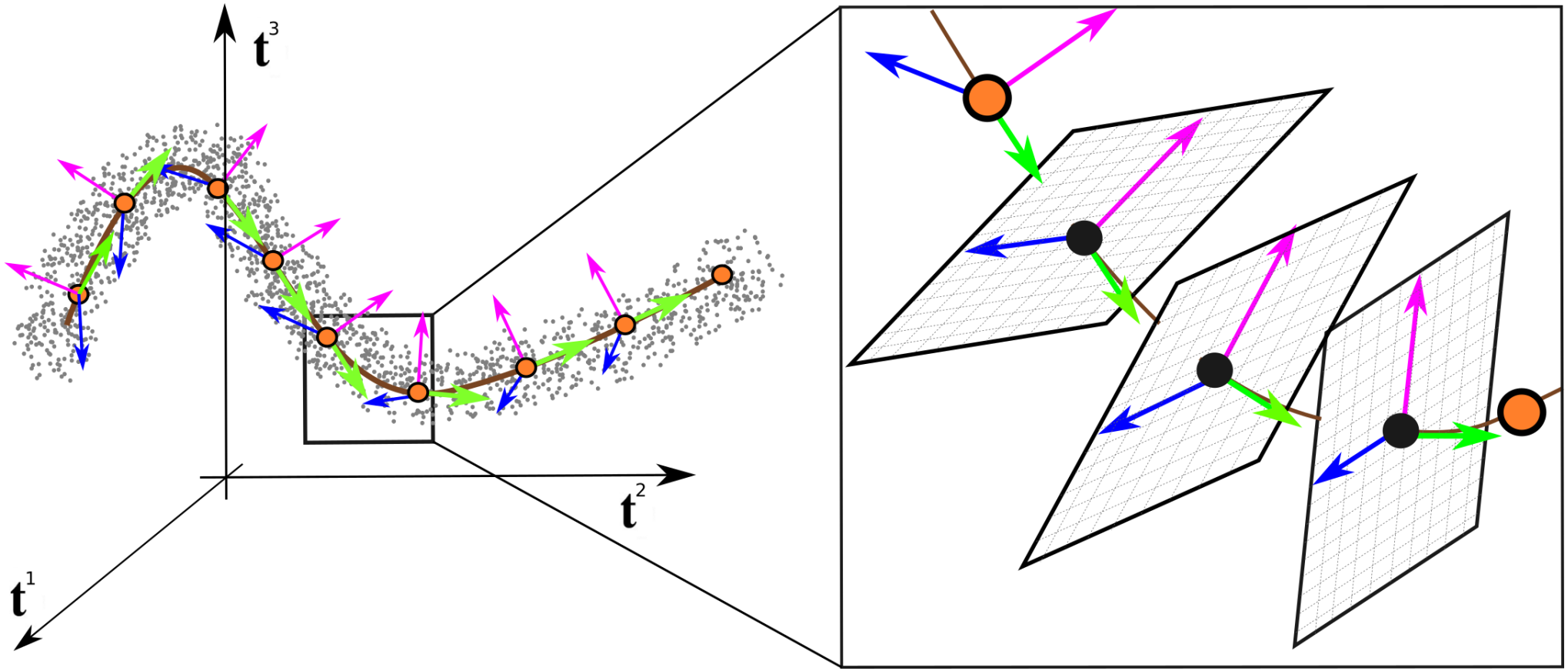
1-DREAM, visualization: Co-moving orthonormal frames



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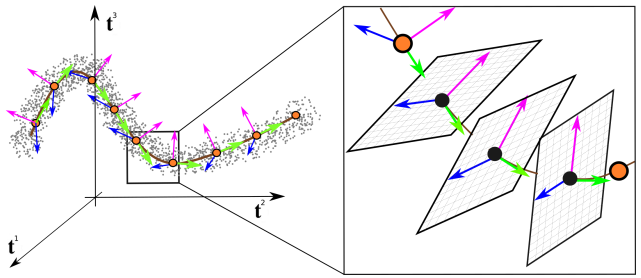
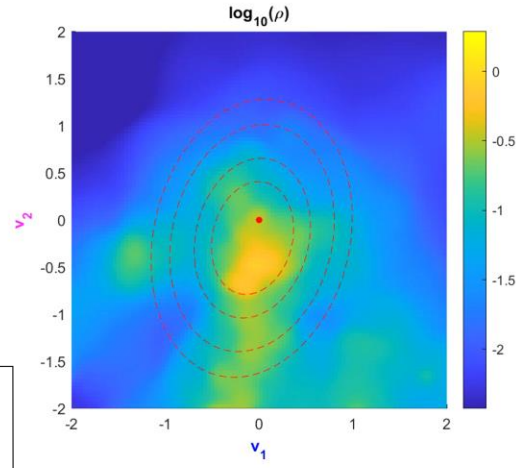
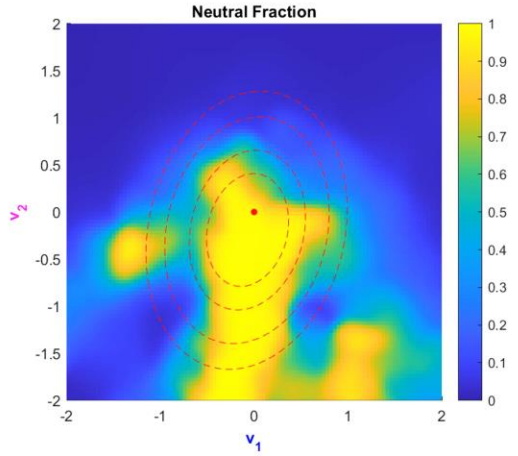
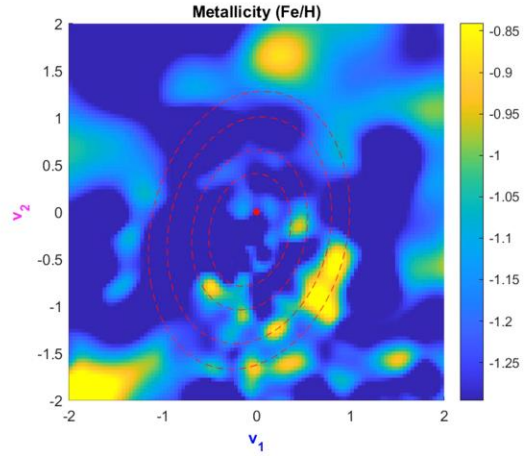
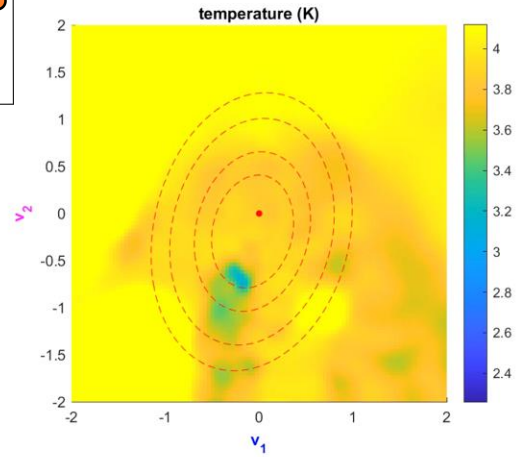
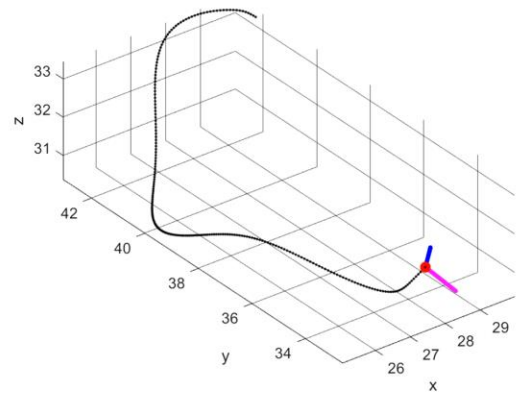


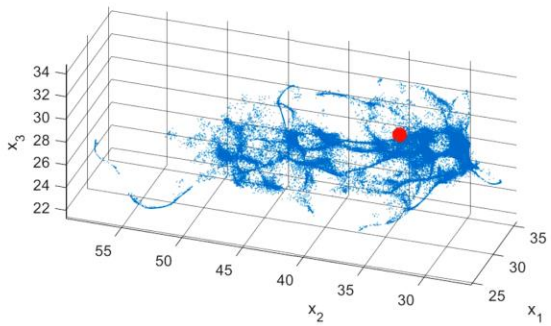




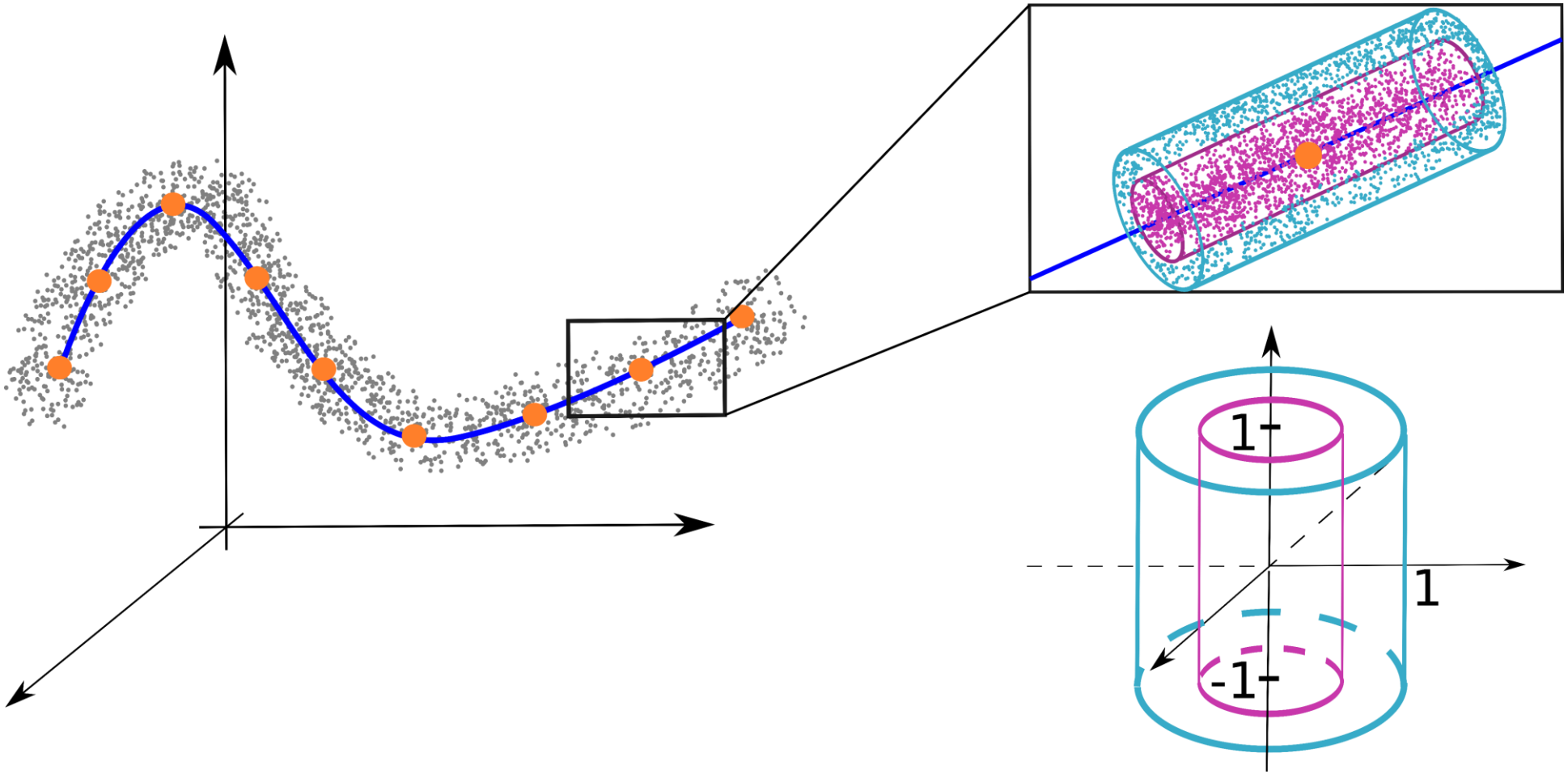








1-DREAM, visualization: Bi-dimensional profiles



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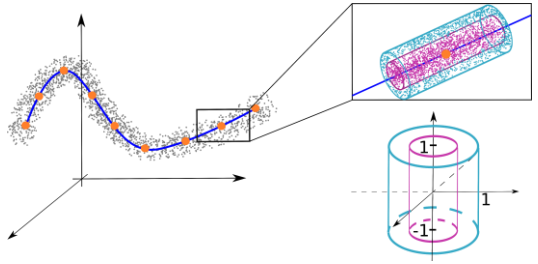
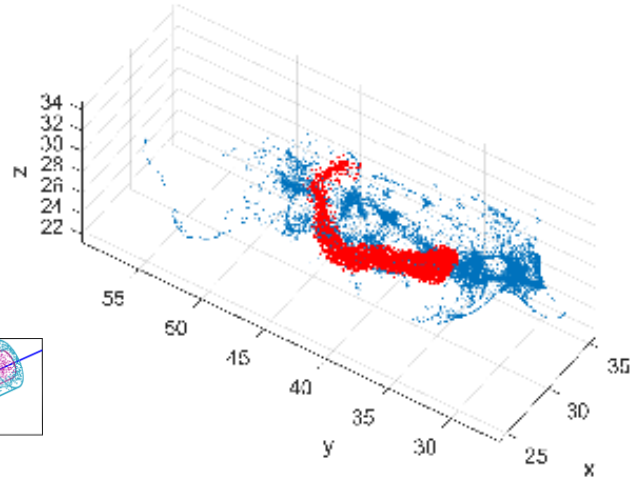
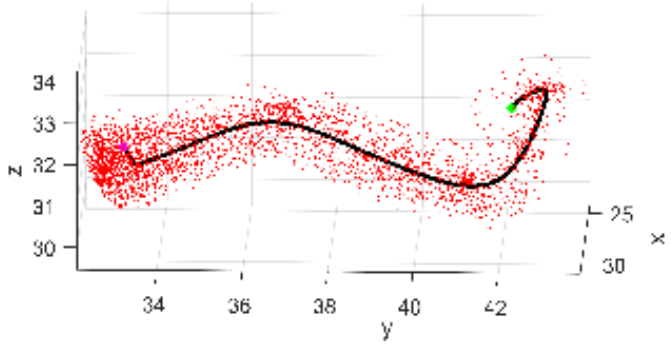
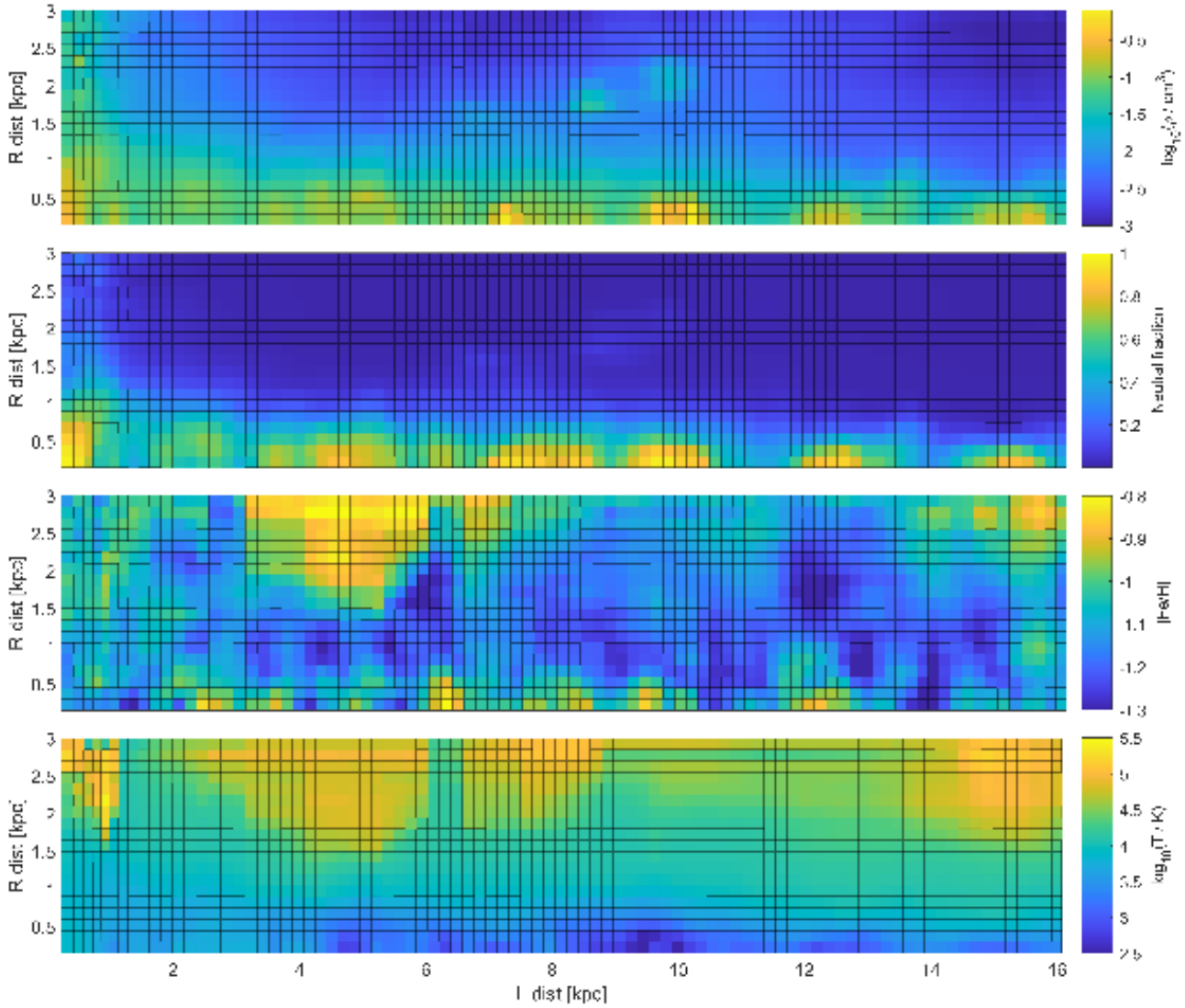
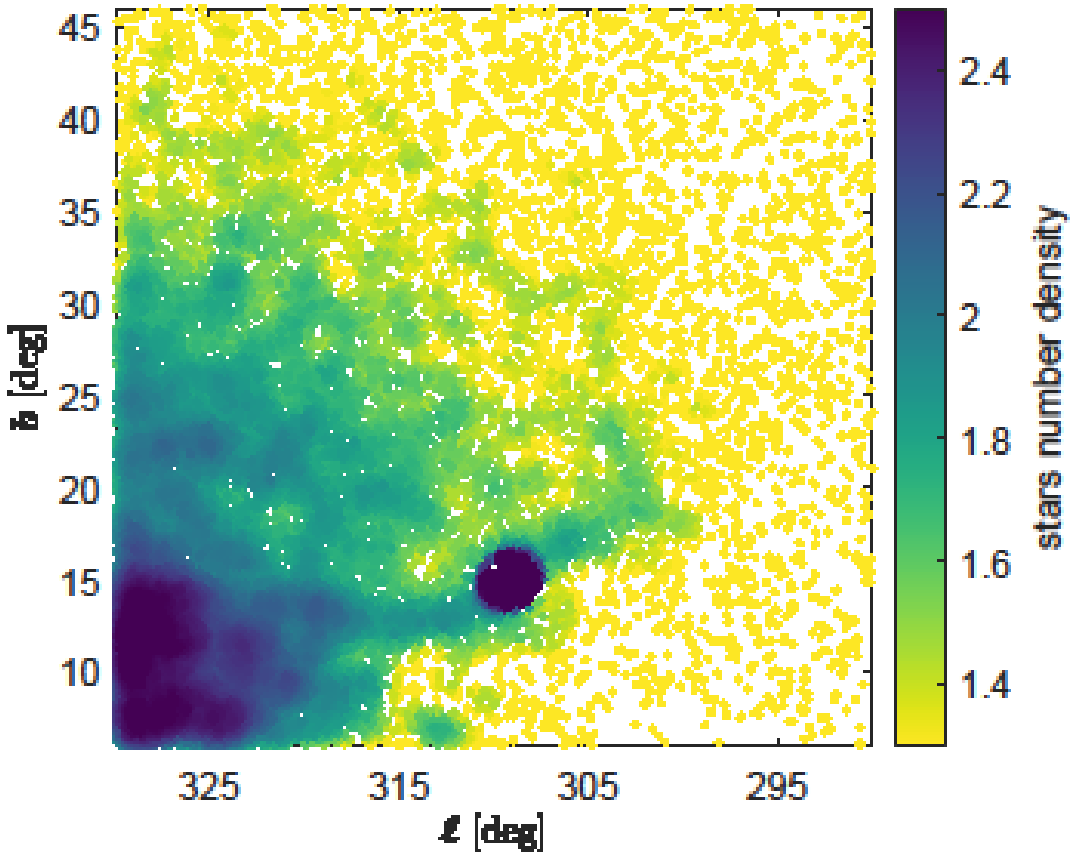








1-DREAM, application 1: GAIA, ω_{Cen} filament



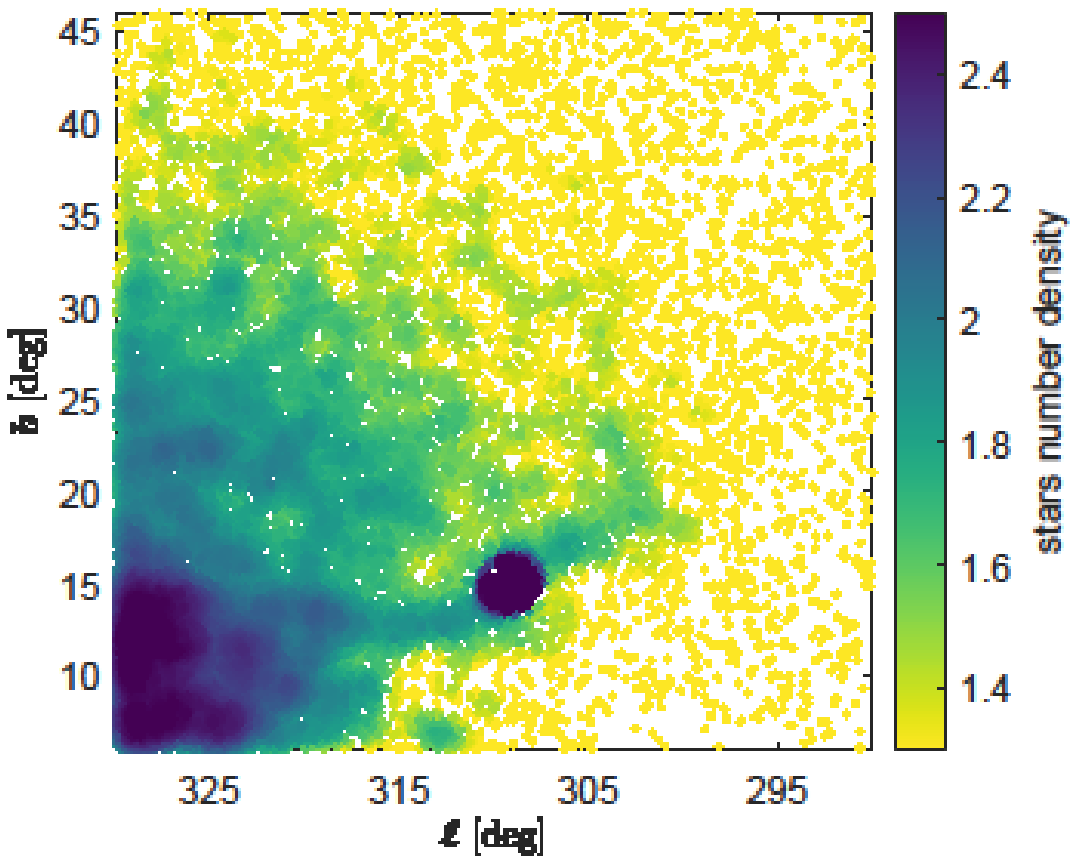
Selection criteria in:

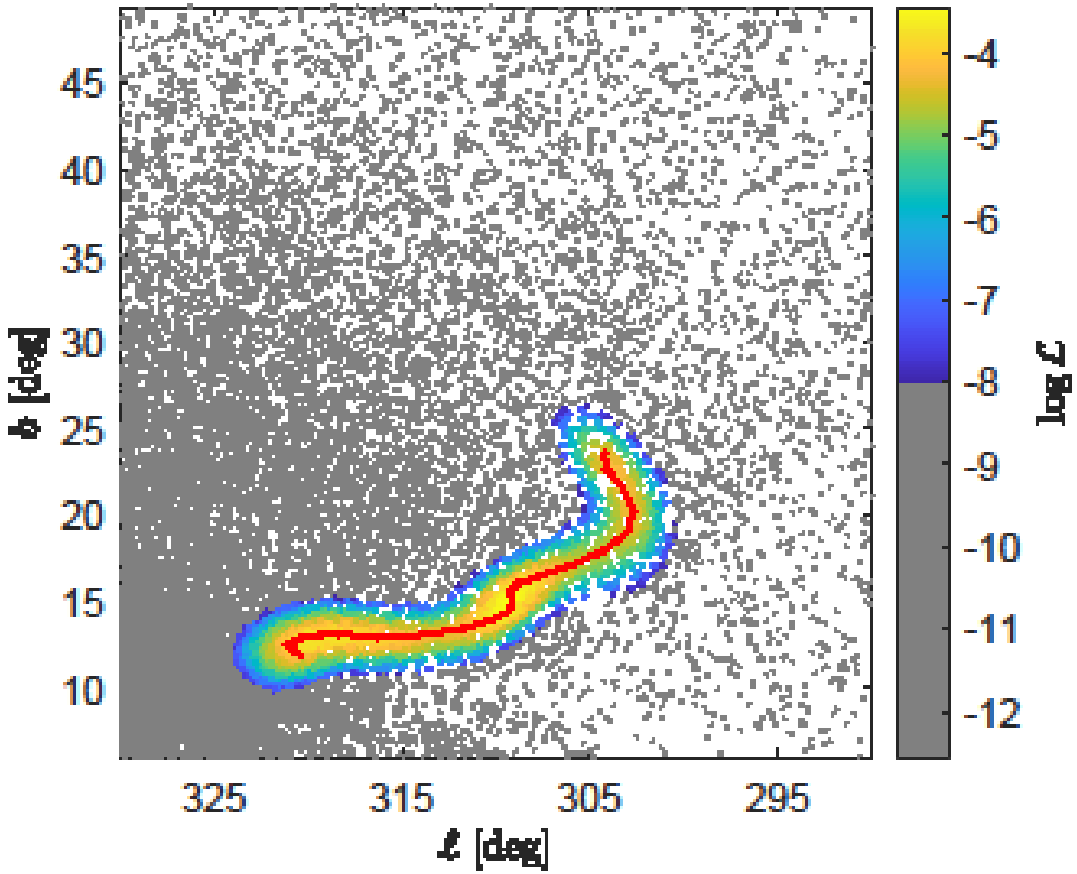
- Coordinates (l and b);
- Proper motion;
- CMD.

Following:

Ibata, R.A., Bellazzini, M., Malhan, K. *et al.* **Identification of the long stellar stream of the prototypical massive globular cluster ω Centauri.** *Nat Astron* **3**, 667–672 (2019). https://doi.org/10.1038/s41550-019-0751-x

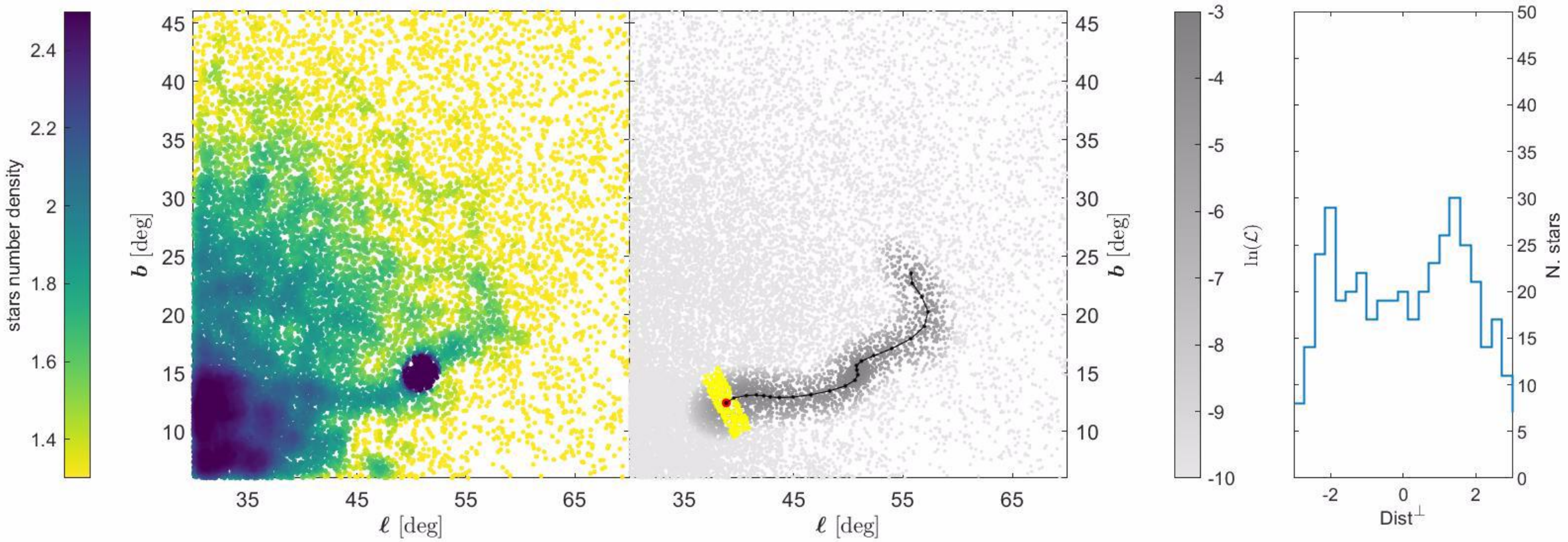
1-DREAM, application 1: GAIA, ω_{Cen} filament





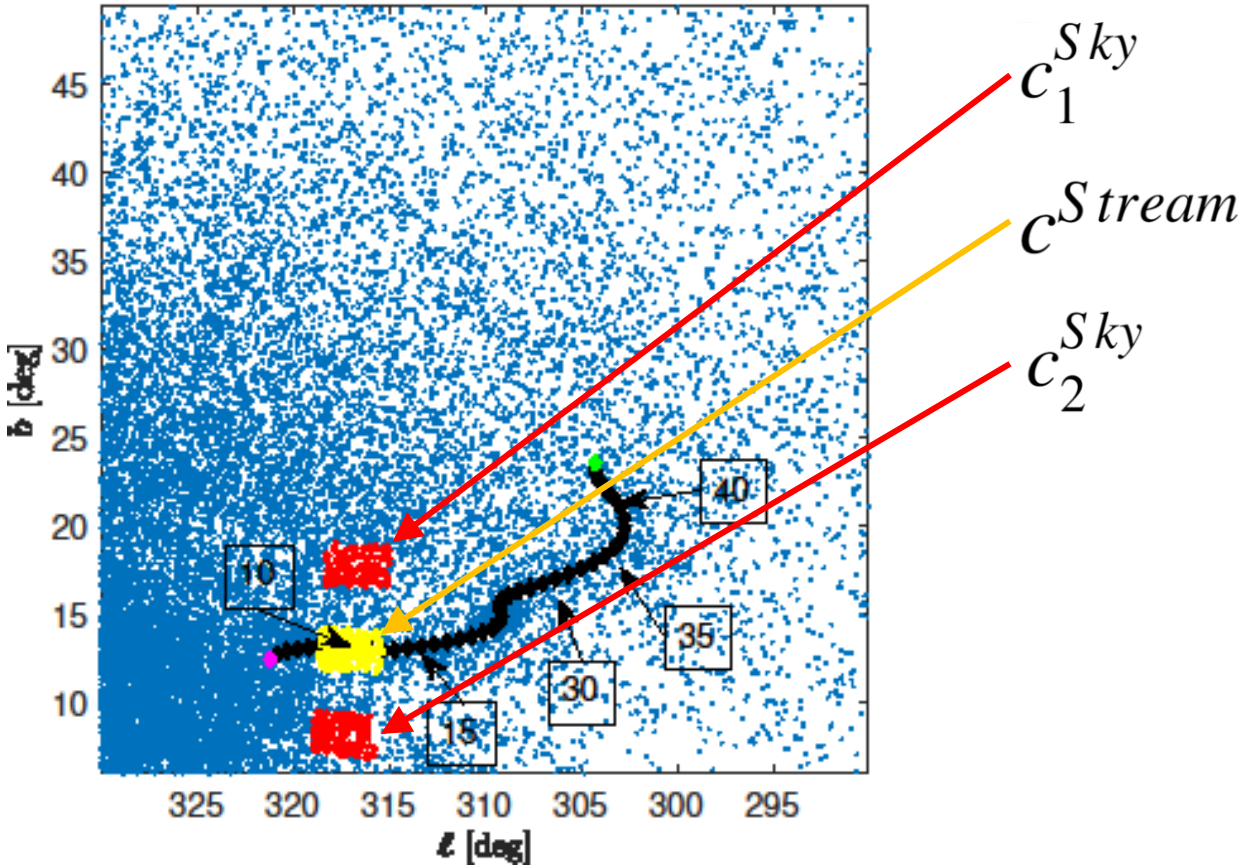
1-DREAM, application 1: GAIA, ω_{Cen} filament

Stars count per bin, along and across filament



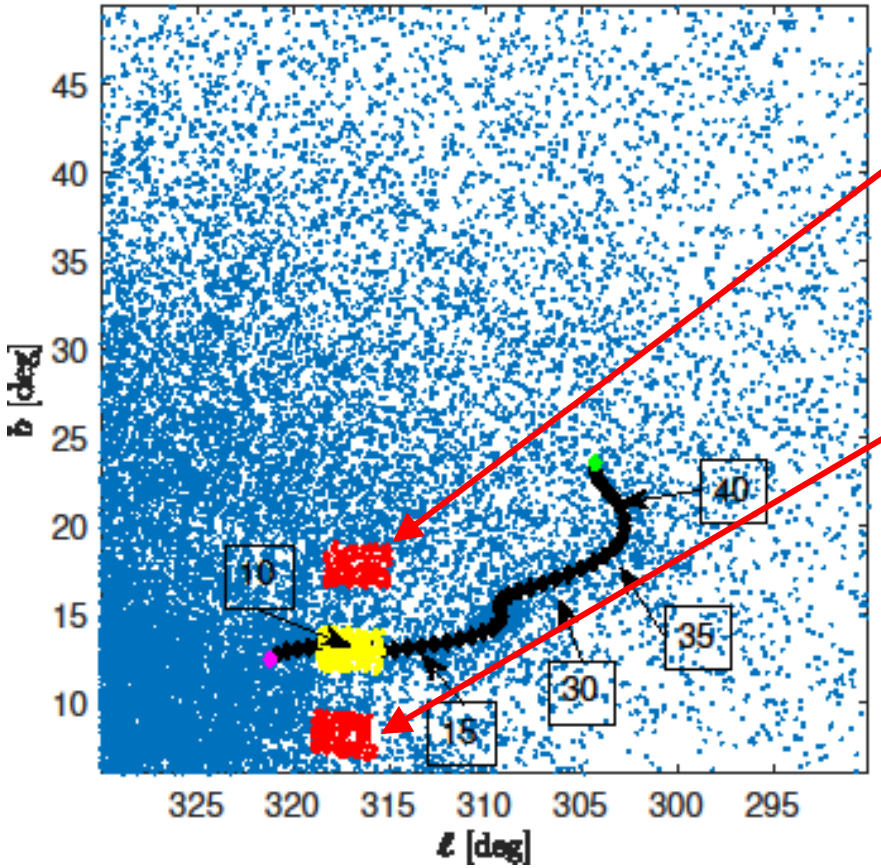
1-DREAM, application 1: GAIA, ω_{Cen} filament

Signal to noise ratio, along filament with comoving background selection



1-DREAM, application 1: GAIA, ω_{Cen} filament

Signal to noise ratio, along filament with comoving background selection



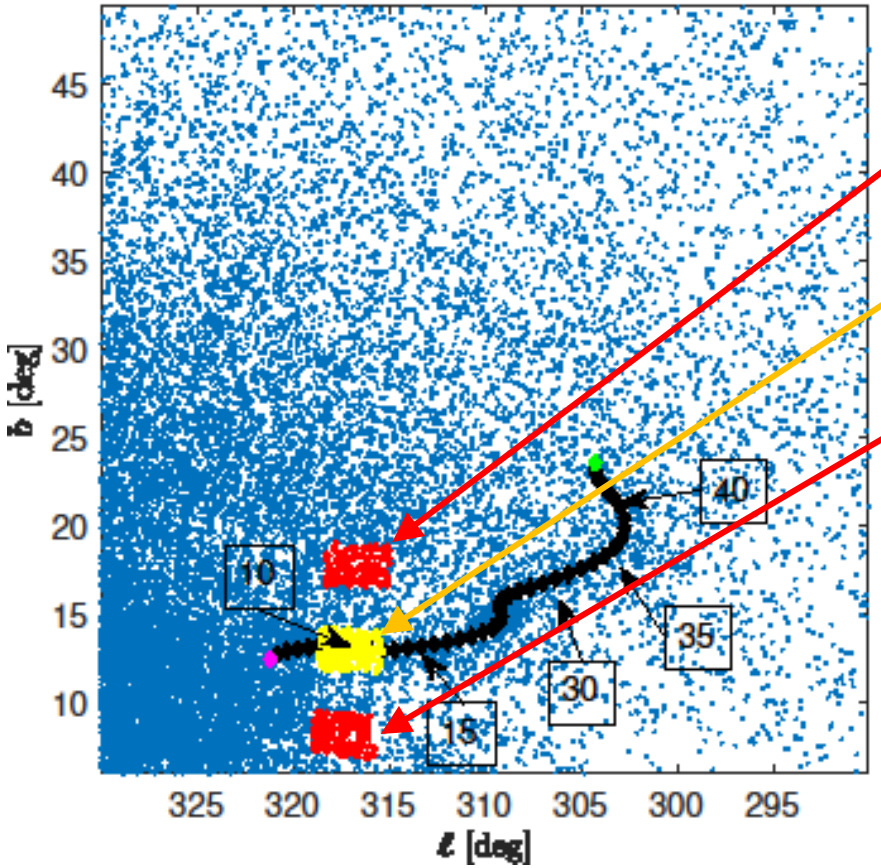
$$c_1^{Sky}$$

$$c_2^{Sky}$$

$$\langle c^{Sky} \rangle = 0.5 \times (c_1^{Sky} + c_2^{Sky})$$

1-DREAM, application 1: GAIA, ω_{Cen} filament

Signal to noise ratio, along filament with comoving background selection



$$c_1^{Sky}$$

$$c^{Stream}$$

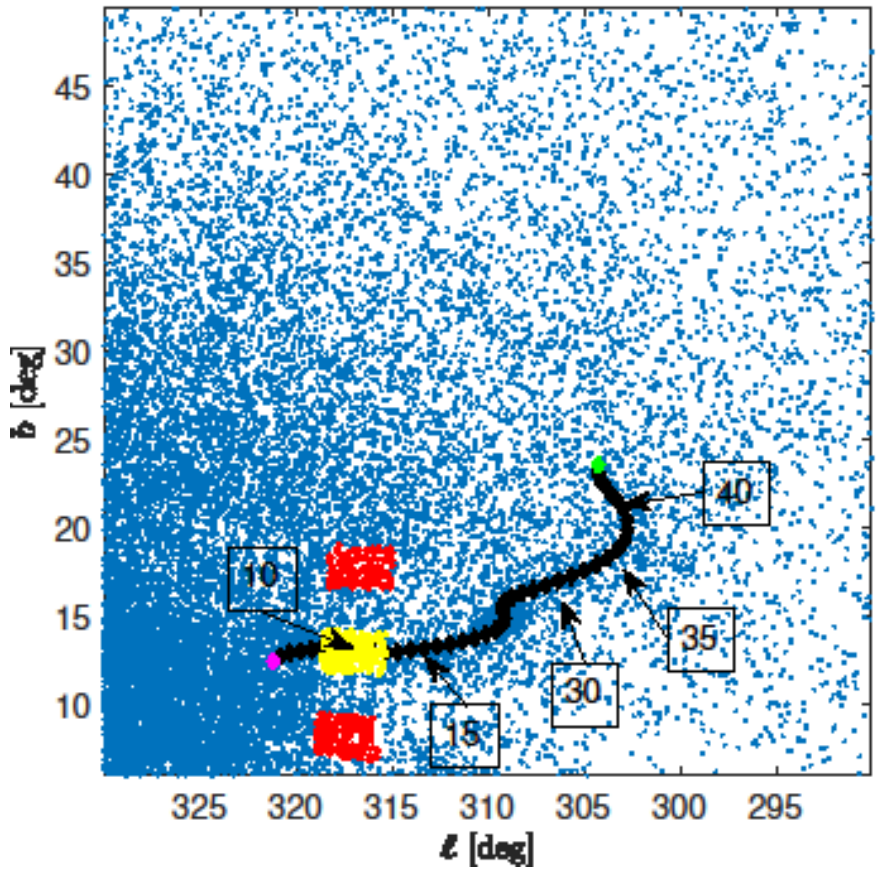
$$c_2^{Sky}$$

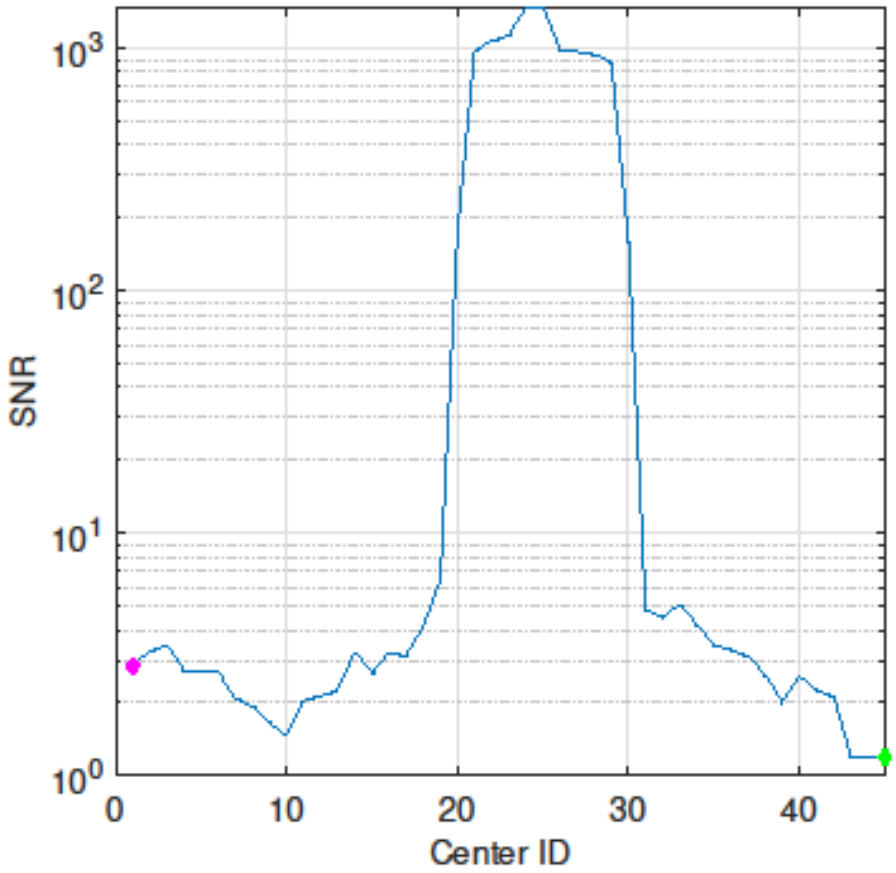
$$\langle c^{Sky} \rangle = 0.5 \times (c_1^{Sky} + c_2^{Sky})$$

$$SNR(\tilde{\boldsymbol{t}}_\ell) = \frac{S(\tilde{\boldsymbol{t}}_\ell)}{N(\tilde{\boldsymbol{t}}_\ell)} = \frac{c^{Stream} - \langle c^{Sky} \rangle}{\sqrt{\langle c^{Sky} \rangle}} \frac{\sqrt{A}}{A}$$

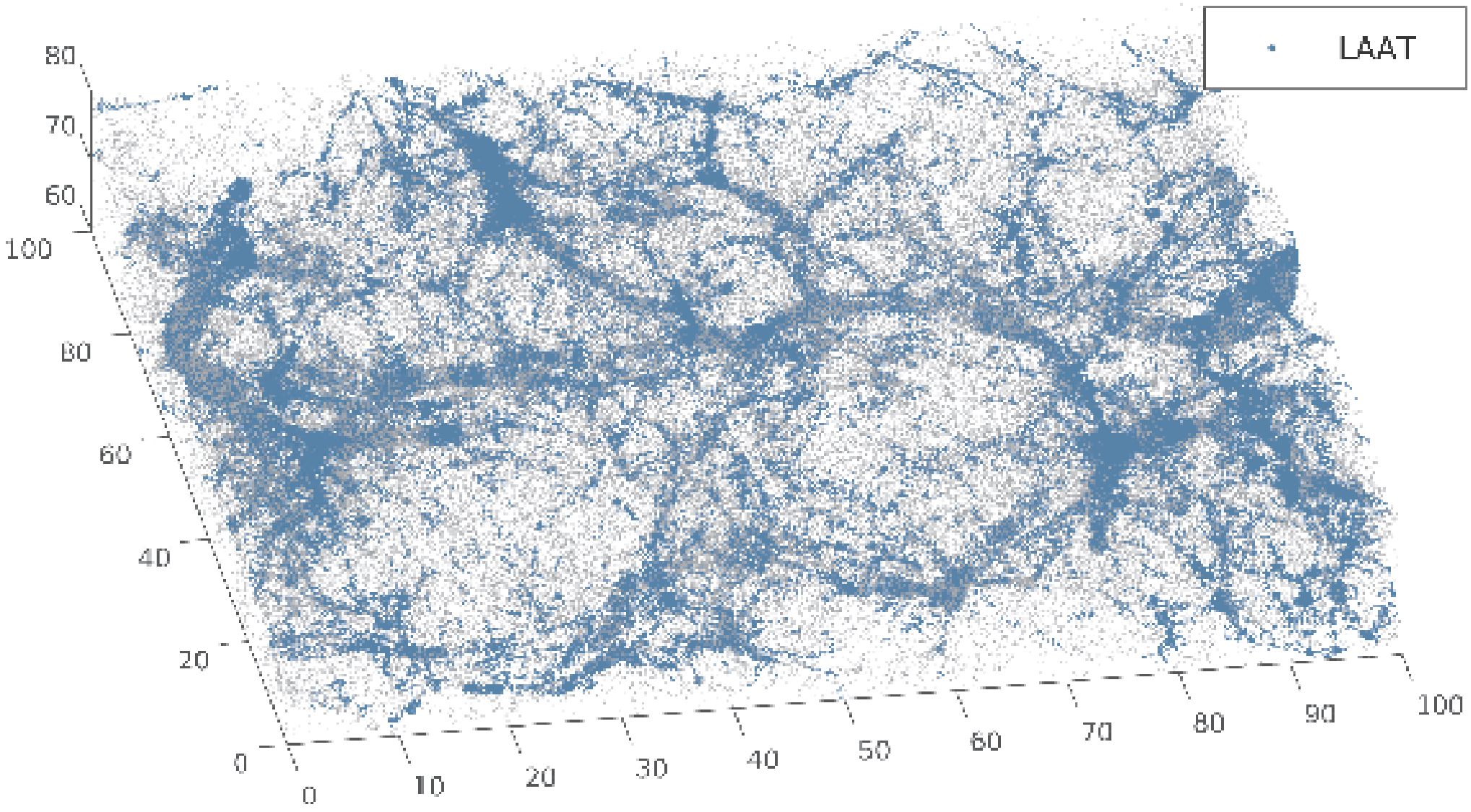
1-DREAM, application 1: GAIA, ω_{Cen} filament

Signal to noise ratio, along filament with comoving background selection

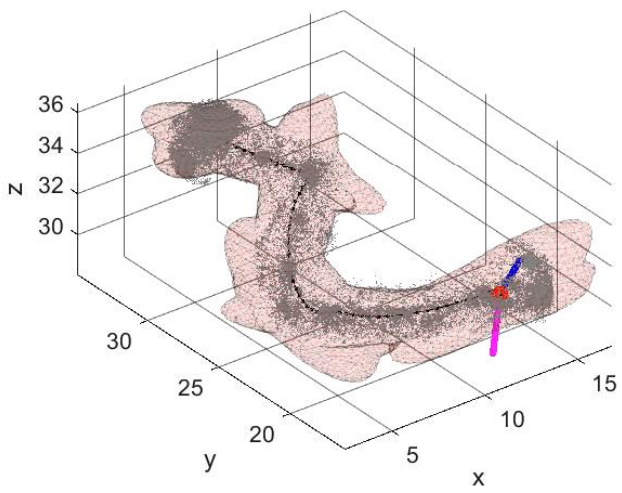


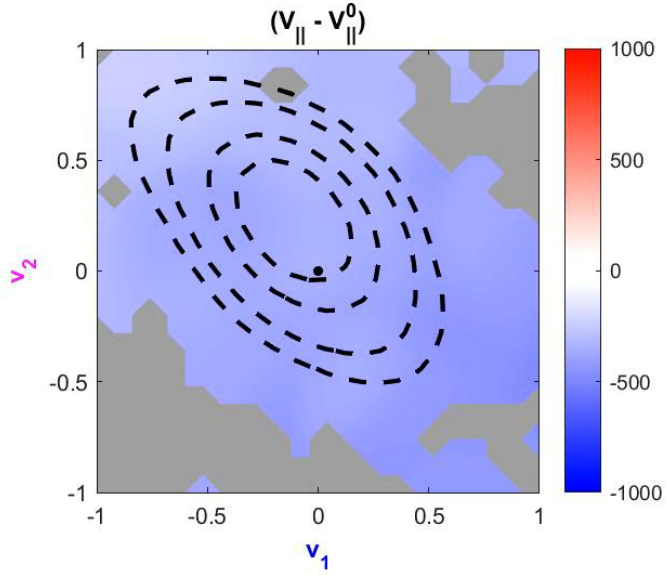


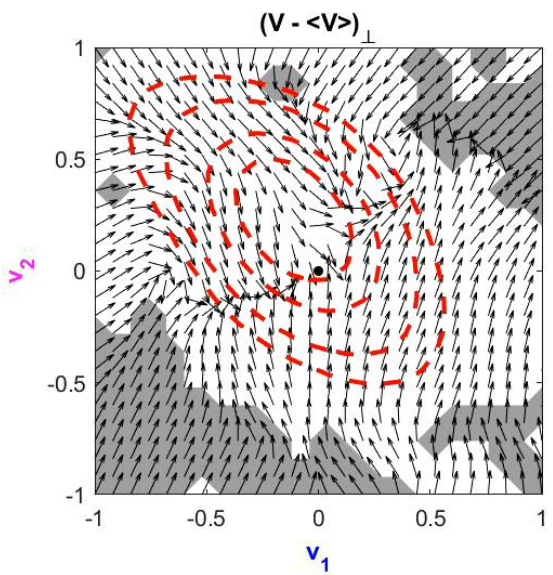
1-DREAM, application 1: Cosmic Web filament

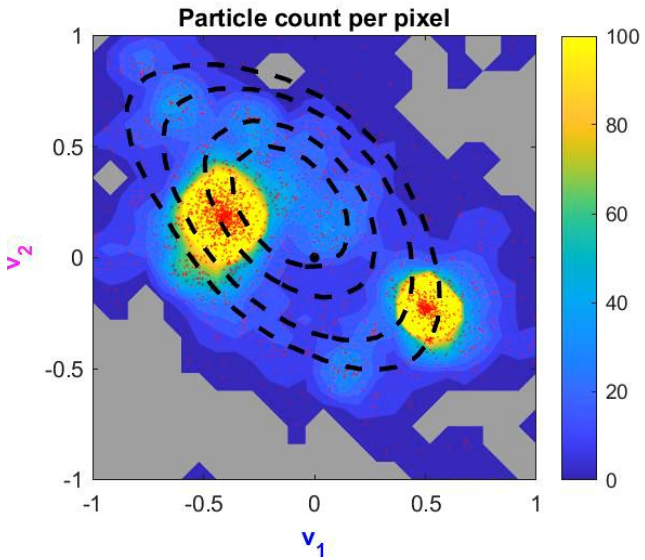


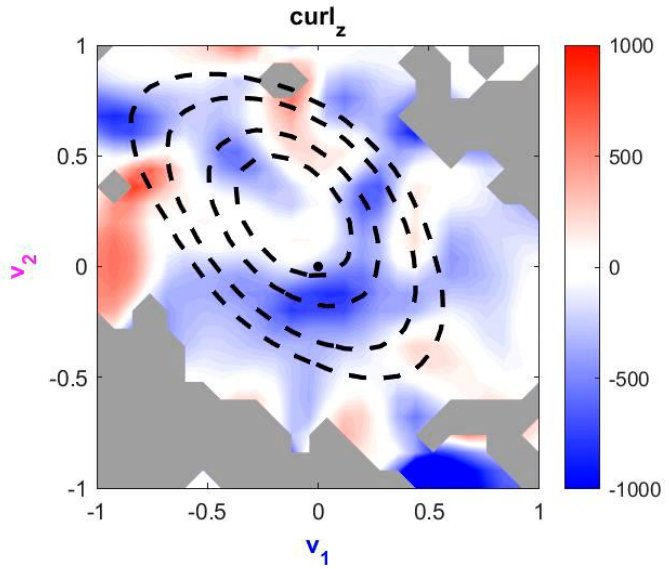
1-DREAM, application 1: Cosmic Web filament – Ex.1

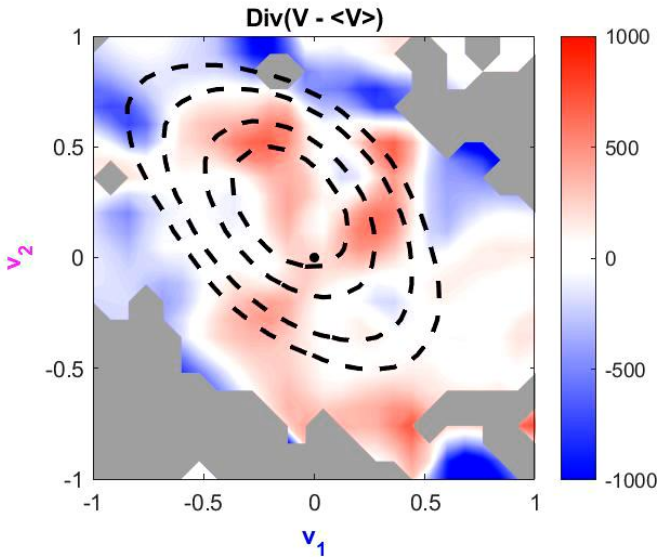




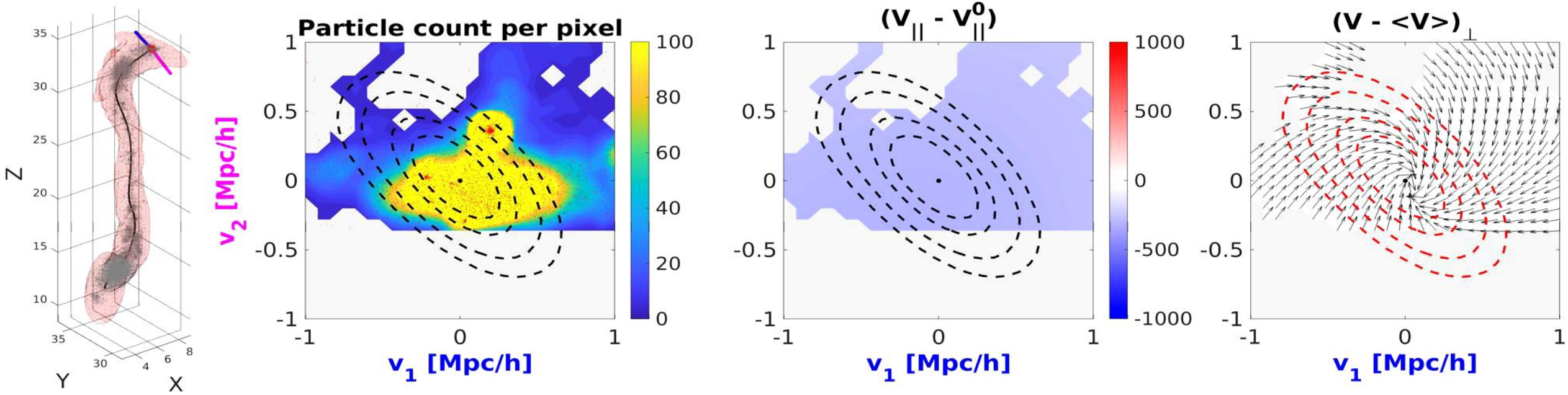






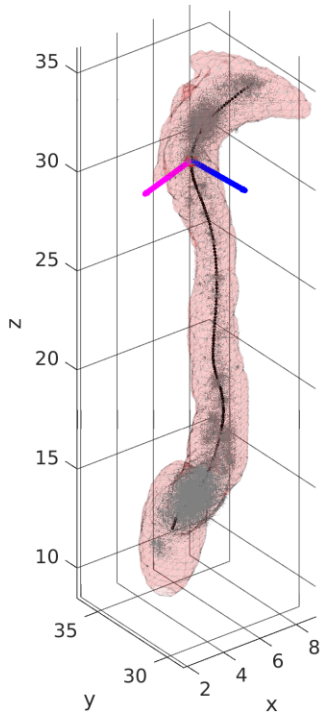


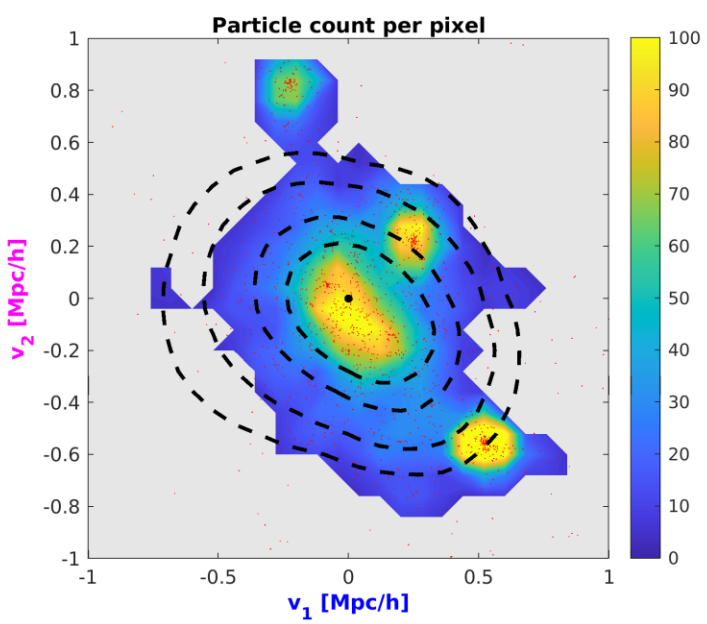
1-DREAM, application 1: Cosmic Web filament – Ex.2

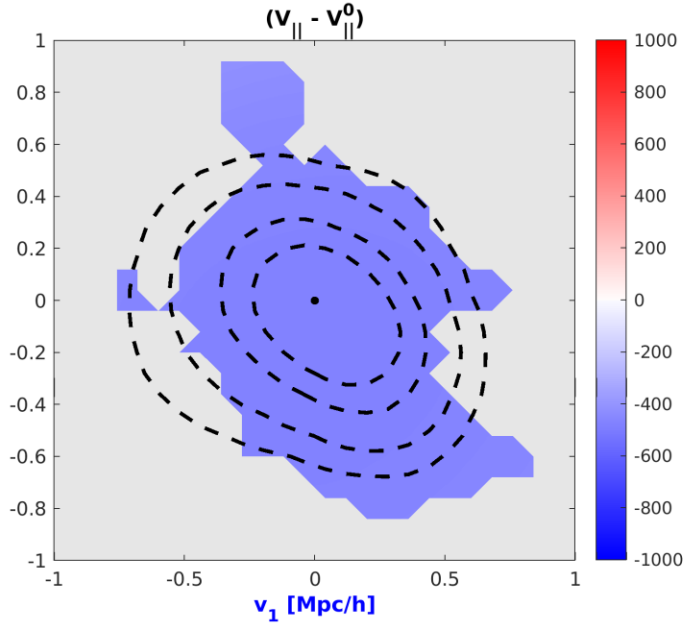


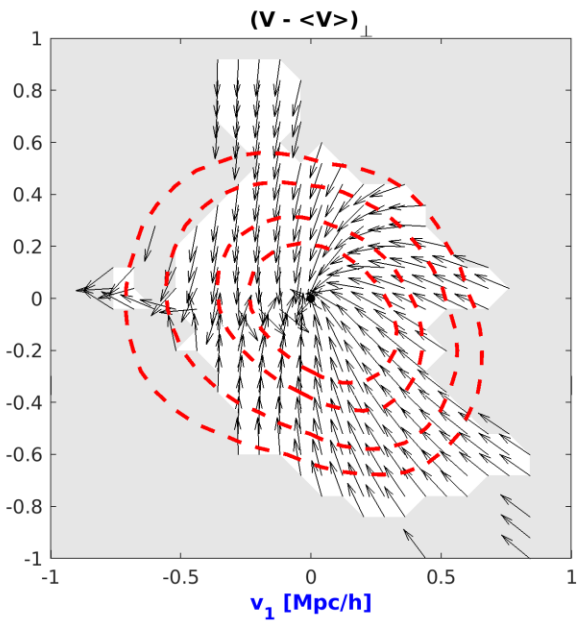
1-DREAM, application 1: Cosmic Web filament – Ex.2

P. Awad, R. Peletier, M. Canducci, R. Smith, A. Taghribi, M. Mohammadi, J. Shin, P. Tiňo, K. Bunte, **Swarm-intelligence-based extraction and manifold crawling along the Large-Scale Structure**, *Monthly Notices of the Royal Astronomical Society*, Volume 520, Issue 3, April 2023, Pages 4517–4539, https://doi.org/10.1093/mnras/stad428



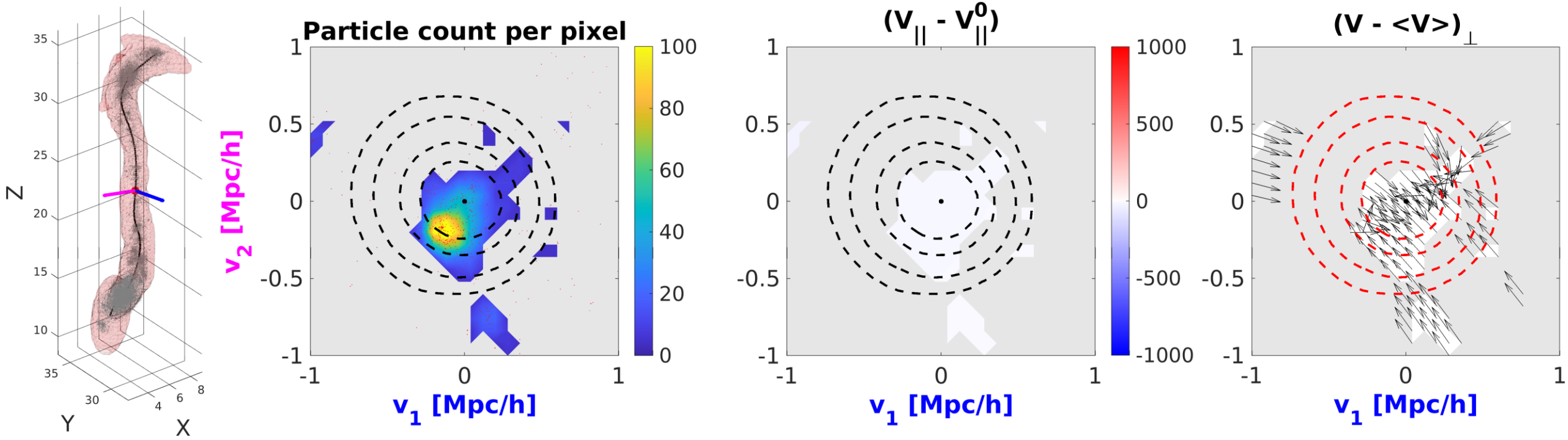






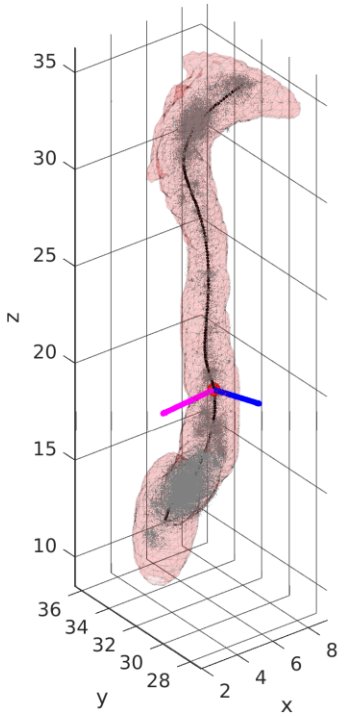
1-DREAM, application 1: Cosmic Web filament – Ex.2

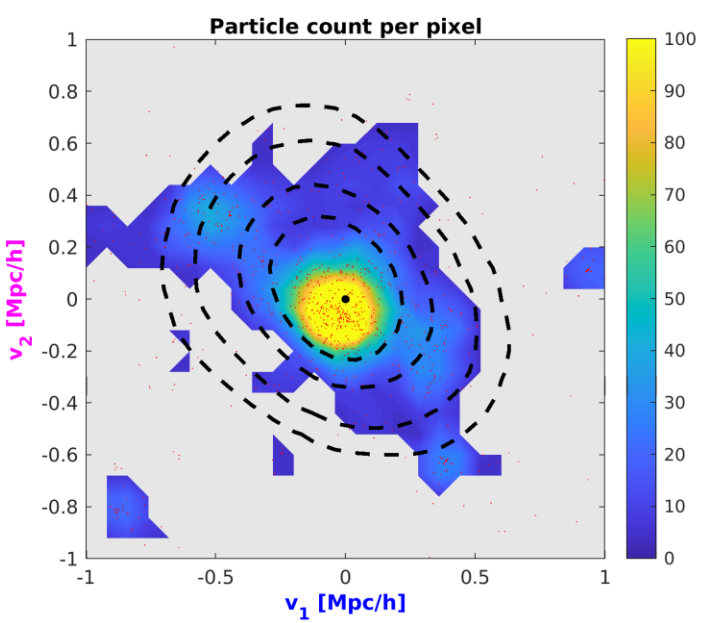
P. Awad, R. Peletier, M. Canducci, R. Smith, A. Taghribi, M. Mohammadi, J. Shin, P. Tiňo, K. Bunte, **Swarm-intelligence-based extraction and manifold crawling along the Large-Scale Structure**, *Monthly Notices of the Royal Astronomical Society*, Volume 520, Issue 3, April 2023, Pages 4517–4539, https://doi.org/10.1093/mnras/stad428

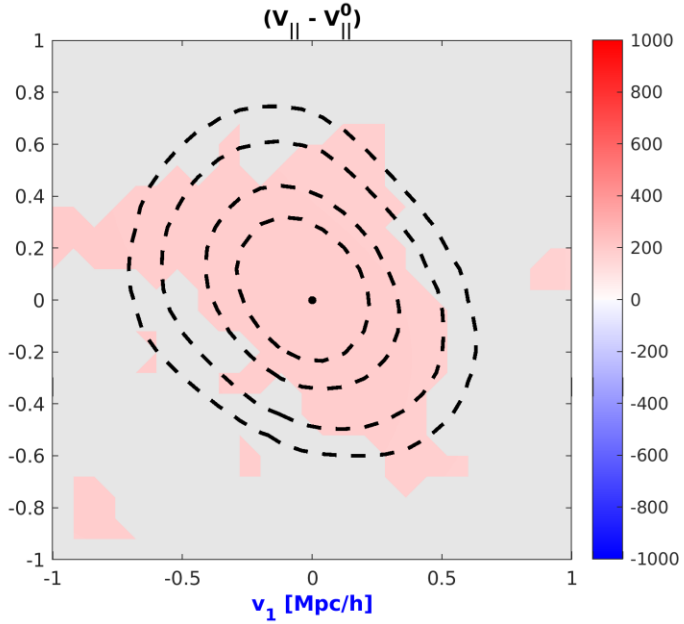


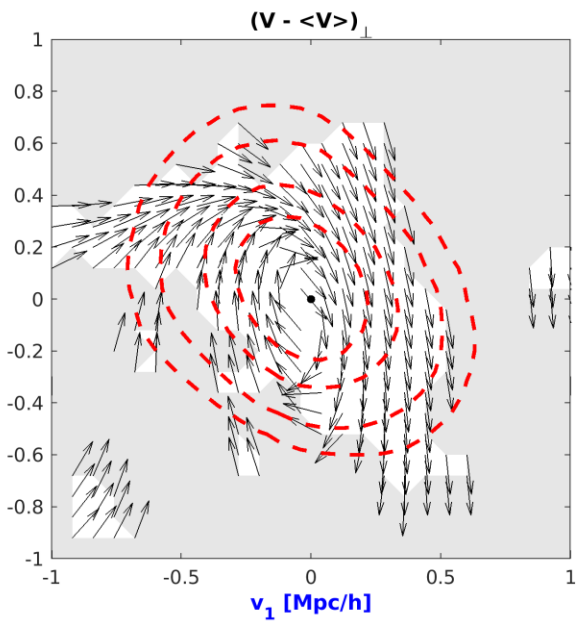
1-DREAM, application 1: Cosmic Web filament – Ex.2

P. Awad, R. Peletier, M. Canducci, R. Smith, A. Taghribi, M. Mohammadi, J. Shin, P. Tiňo, K. Bunte, **Swarm-intelligence-based extraction and manifold crawling along the Large-Scale Structure**, *Monthly Notices of the Royal Astronomical Society*, Volume 520, Issue 3, April 2023, Pages 4517–4539, https://doi.org/10.1093/mnras/stad428



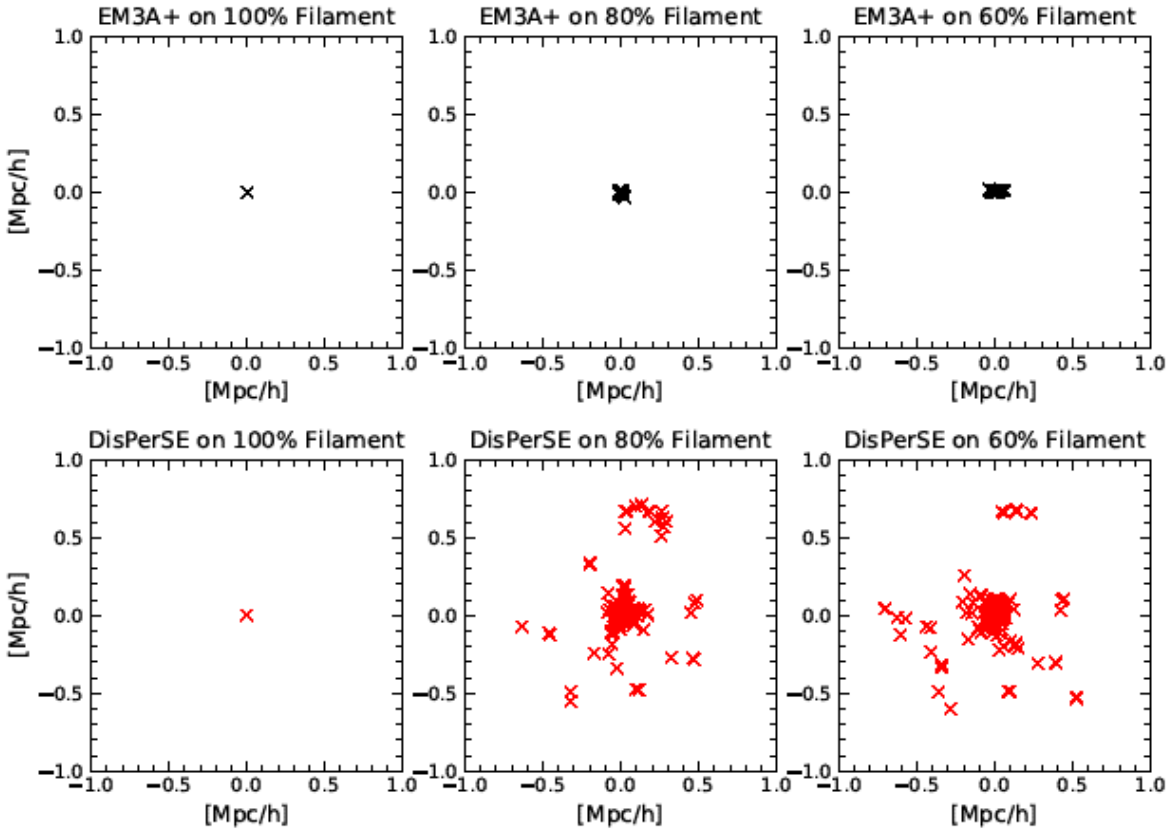


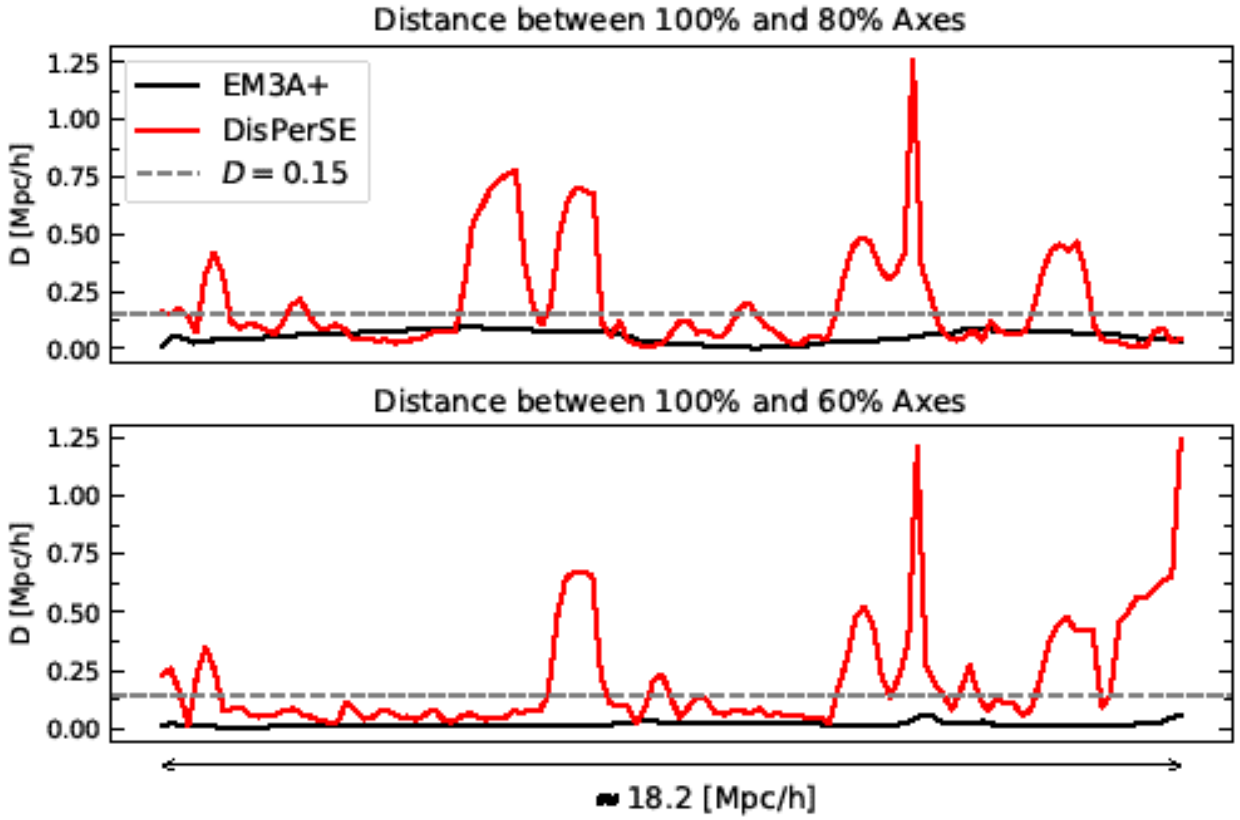




1-DREAM, application 1: Cosmic Web filament - stability

P. Awad, R. Peletier, M. Canducci, R. Smith, A. Taghribi, M. Mohammadi, J. Shin, P. Tiňo, K. Bunte, **Swarm-intelligence-based extraction and manifold crawling along the Large-Scale Structure**, *Monthly Notices of the Royal Astronomical Society*, Volume 520, Issue 3, April 2023, Pages 4517–4539, https://doi.org/10.1093/mnras/stad428





1-DREAM, future directions

Gitlab public repo: https://git.lwp.rug.nl/cs.projects/1DREAM

Upcoming studies (submitted):

- EAS 2023 (submitted): P. Awad – "Substructures within the Jhelum stream proper motion space." University of Groningen
- EAS 2023 (submitted): M.A. Raj – "Unravelling the Fornax-Eridanus supercluster: detection, analysis and visualization of its filaments." University of Groningen

Potential lines of work:

- Temporal analysis of galactic dynamics within cosmic web filaments (how to model temporal evolution of probabilistic models: Canducci, M. *et al.* (2021). **Tracking the Temporal-Evolution of Supernova Bubbles in Numerical Simulations**. In: , *et al.* Intelligent Data Engineering and Automated Learning – IDEAL 2021. IDEAL 2021. Lecture Notes in Computer Science(), vol 13113. Springer, Cham. https://doi.org/10.1007/978-3-030-91608-4_49)
- Filament detection in sparsely populated data sets, the potential of Probabilistic Hough Transform

THANK YOU

Contact:

Marco Canducci, University of Birmingham,
M.Canducci@bham.ac.uk

Gitlab public repo: https://git.lwp.rug.nl/cs.projects/1DREAM

I will be in office **3E3A** the whole afternoon if you are interested in our work and would like to join forces!