Advancing the Visualization Capabilities of ALMA Data Cubes Through Topological Data Analysis

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PART I: TDAV FOR ALMA DATA CUBES

THE NRAO-NSF PILOT GRANT TEAM

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Assistant Professor
U of Utah
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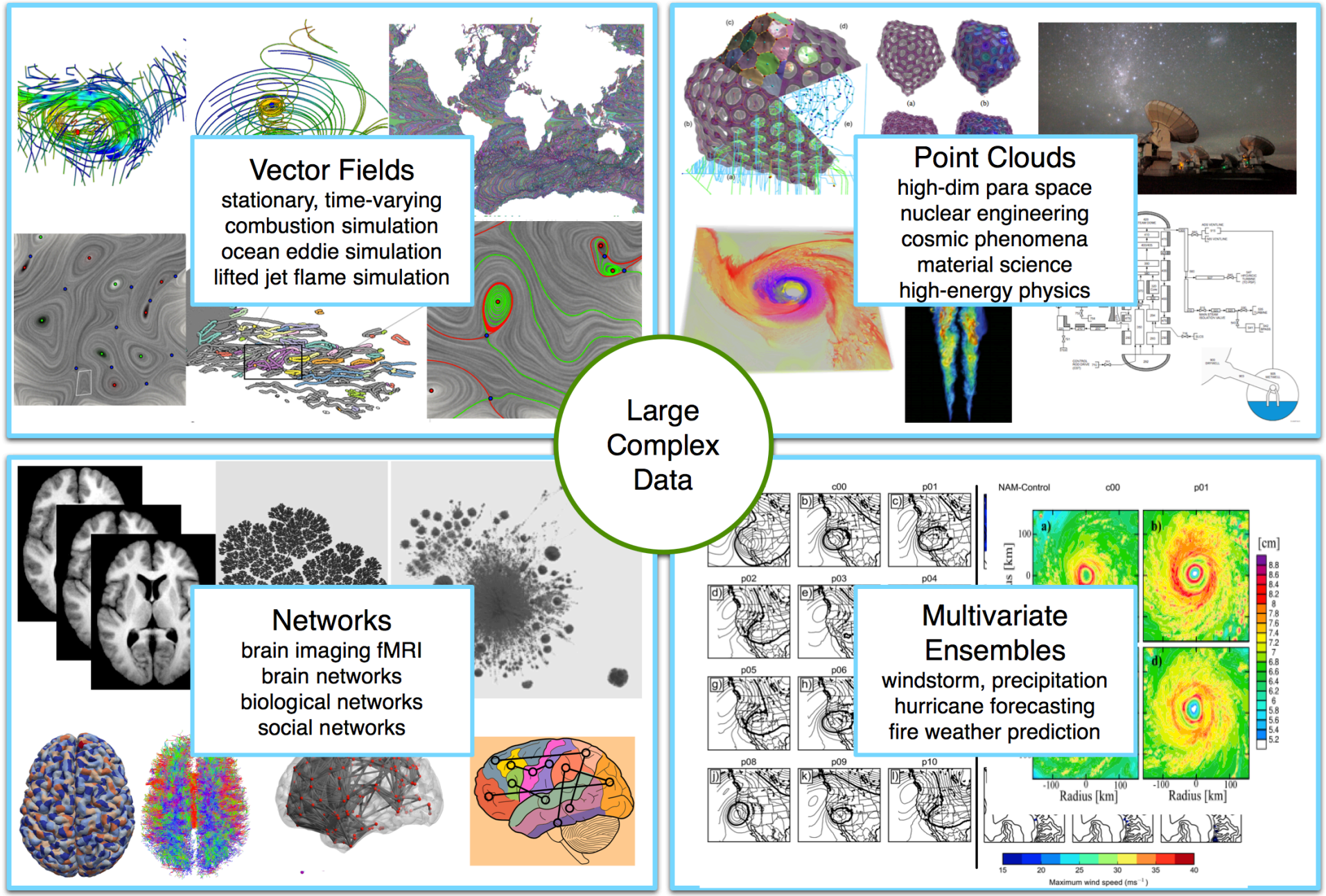

Vector Fields
stationary, time-varying
combustion simulation
ocean eddie simulation
lifted jet flame simulation
Point Clouds
high-dim para space
nuclear engineering
cosmic phenomena
material science
high-energy physics
Large Complex Data
Networks
brain imaging fMRI
brain networks
biological networks
social networks
Multivariate Ensembles
windstorm, precipitation
hurricane forecasting
fire weather prediction
NAM-Control
c00
p01
p02
p03
p04
p05
p06
p08
p09
p10
Radius [km]
[cm]
Maximum wind speed (ms⁻¹)

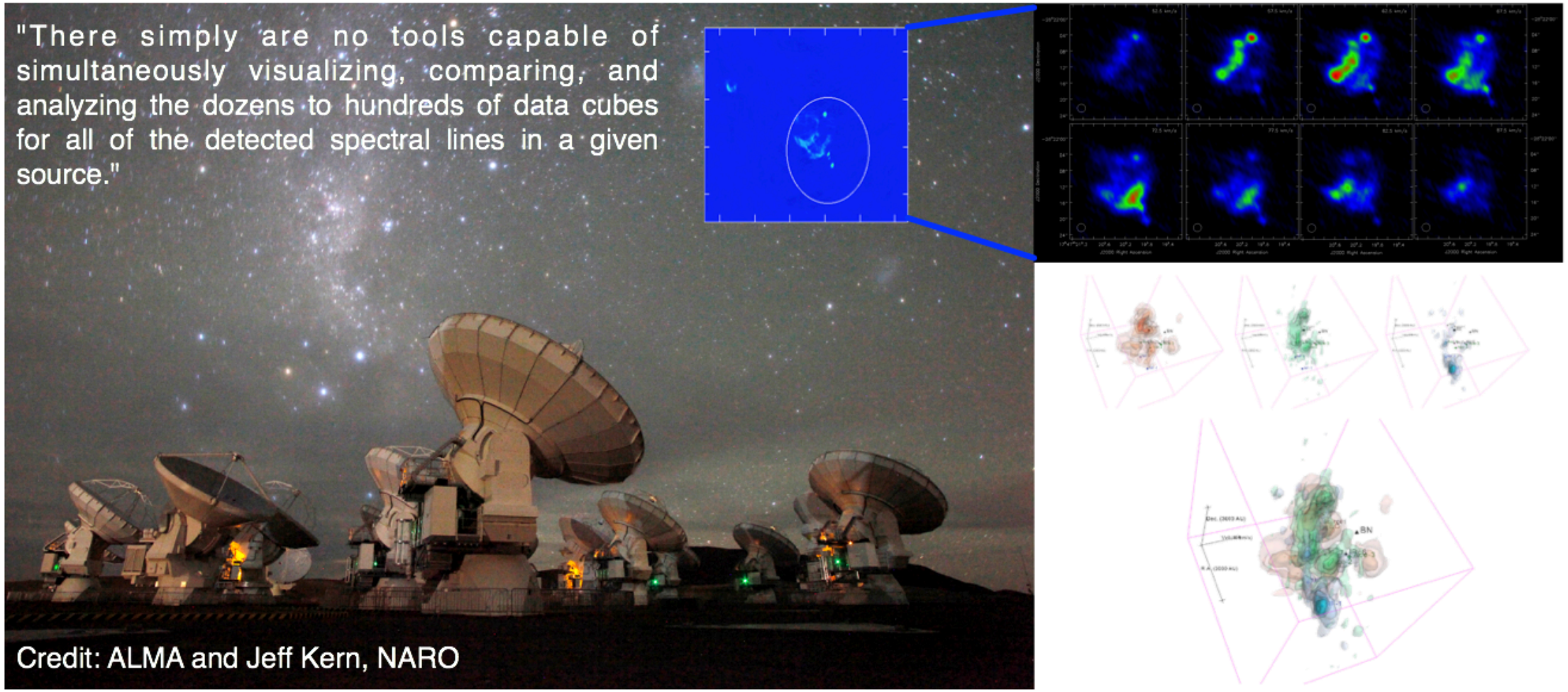
Analysis and Visualization of ALMA Data Cubes

Atacama Large Millimeter/submillimeter Array (ALMA)
One of the world's most powerful telescopes, located in Chile

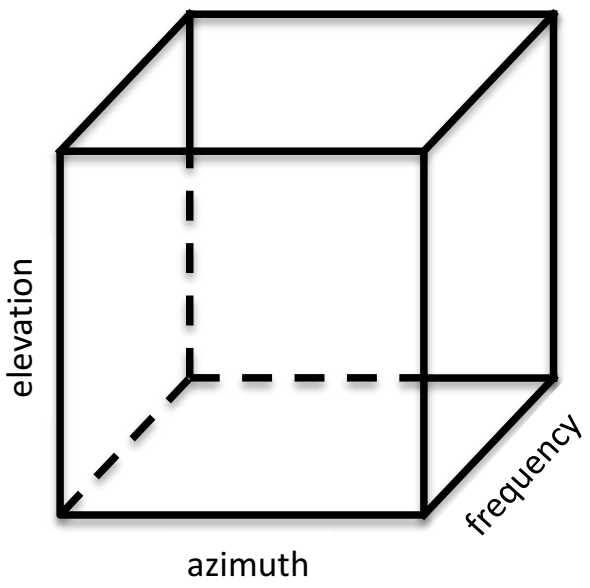
Collaborate with NRAO scientists: analysis and vis of spatial and kinematic structures within ALMA data cubes, e. g. black holes

Develop techniques and software tools for data transformation, feature extraction, feature exploration and feature comparison

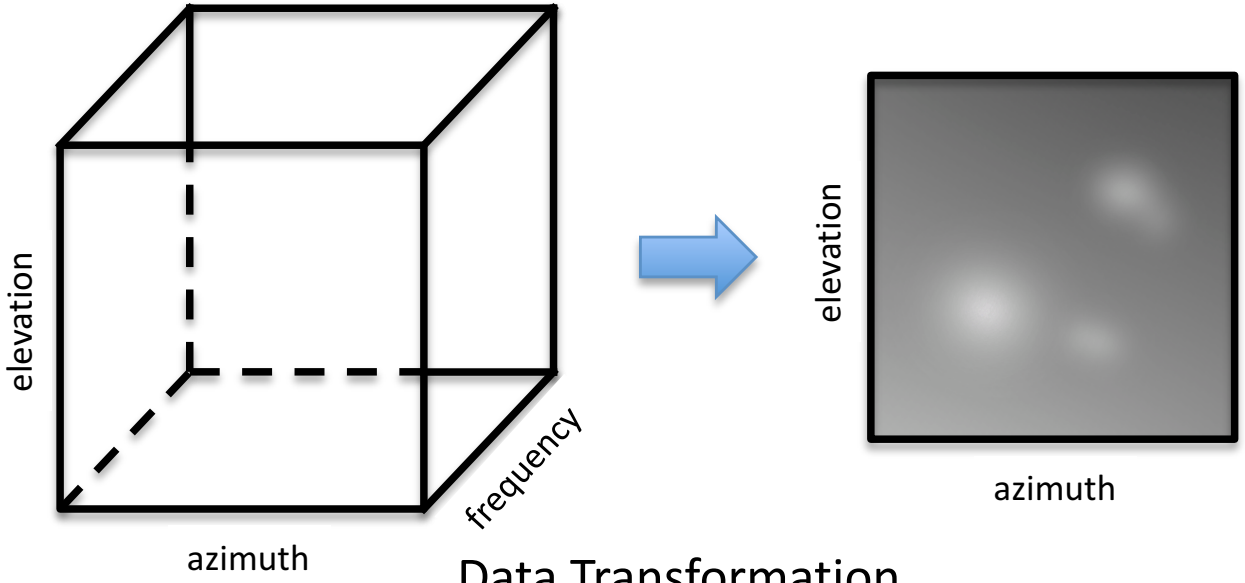
Analysis and Visualization of ALMA Data Cubes



PROCESSING PIPELINE

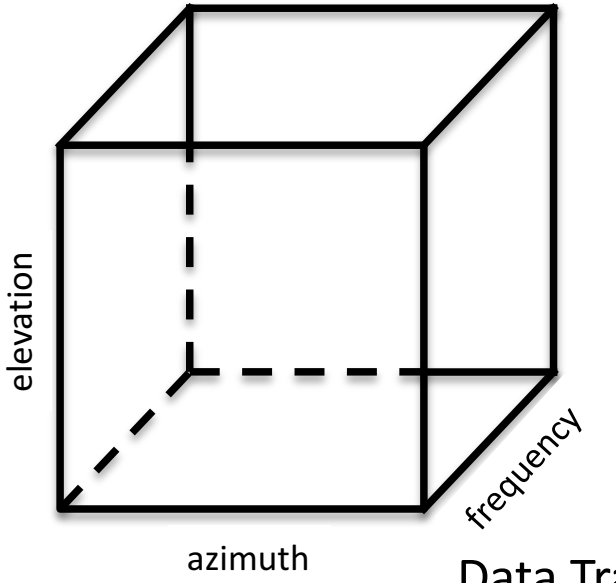


Processing Pipeline



Data Transformation
to Scalar Field

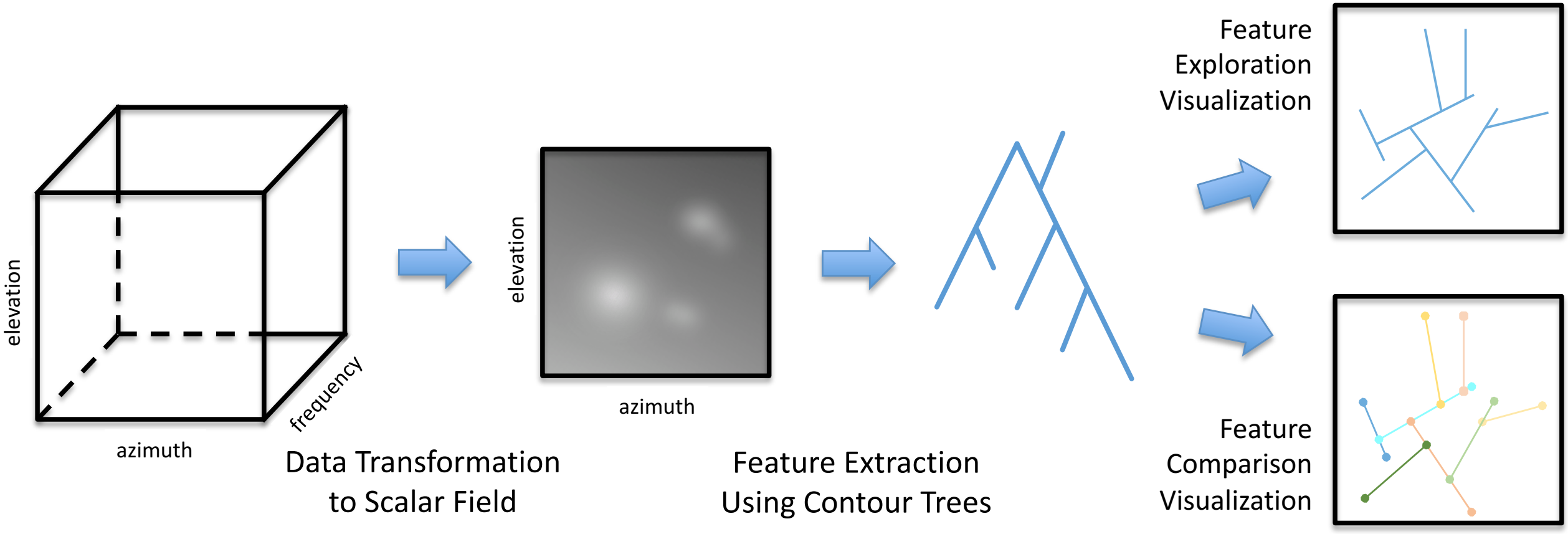
Processing Pipeline



Data Transformation
to Scalar Field

Feature Extraction
Using Contour Trees

Processing Pipeline



Research Questions: Data Transformation

How are the spectral lines represented in a 3D data cube MEANINGFULLY converted to scalar functions for contour tree-based analysis?

Research Questions: Feature Extraction

Once a contour tree is generated, there are many methods for selecting the important features of the tree. Therefore, how do we extract MEANINGFUL features of the data via contour tree simplification to suit the needs of astronomers?

Research Questions: Feature Exploration

What is a MEANINGFUL visualization of contour trees to enable feature exploration of a single data cube by the astronomers?

Research Questions: Feature Comparison

Can contour tree representations be used for MEANINGFUL feature comparisons among multiple data cubes to characterize secular changes with observed properties (for example, transition energy, molecular species and chemical families), or derived properties such as temperature and density?

INTERDISCIPLINARY RESEARCH IS HARD

You

Me

One Case Study:
Black hole with in the ghost of Mirach Galaxy

- Stellar and gas kinematics (movement of stars/gas w/o needing to understand how they acquired their motion)
- Contours: light distribution of the galaxy, or the luminosity in the gas emission lines.

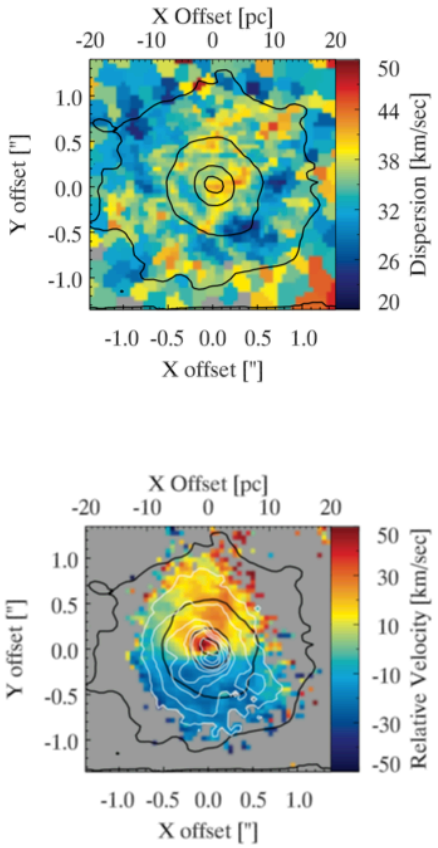
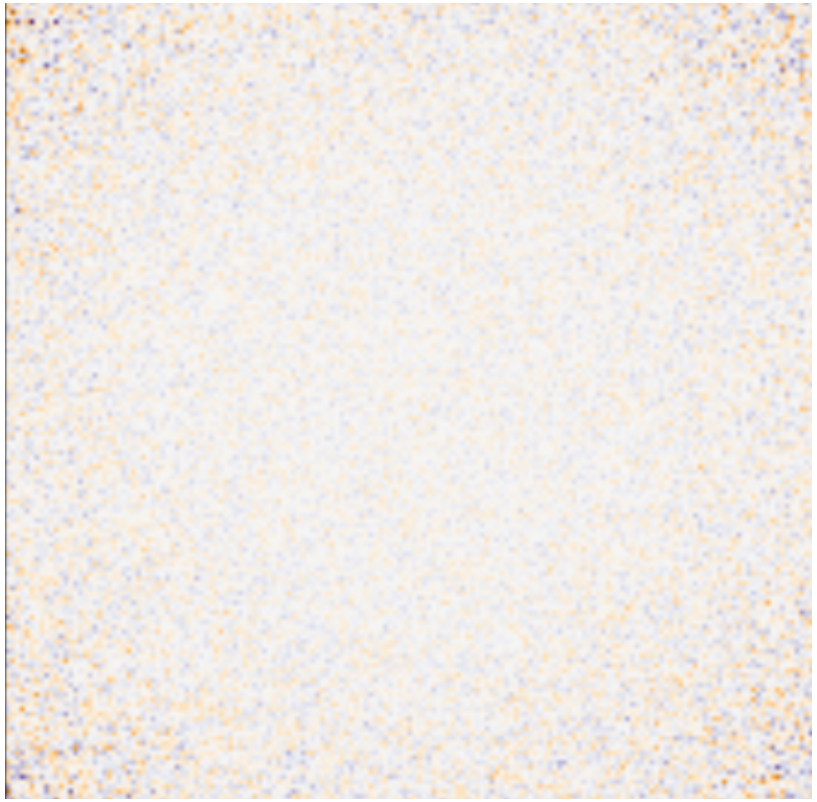


Image courtesy: Anil Seth

Mo' Data Mo' Problem



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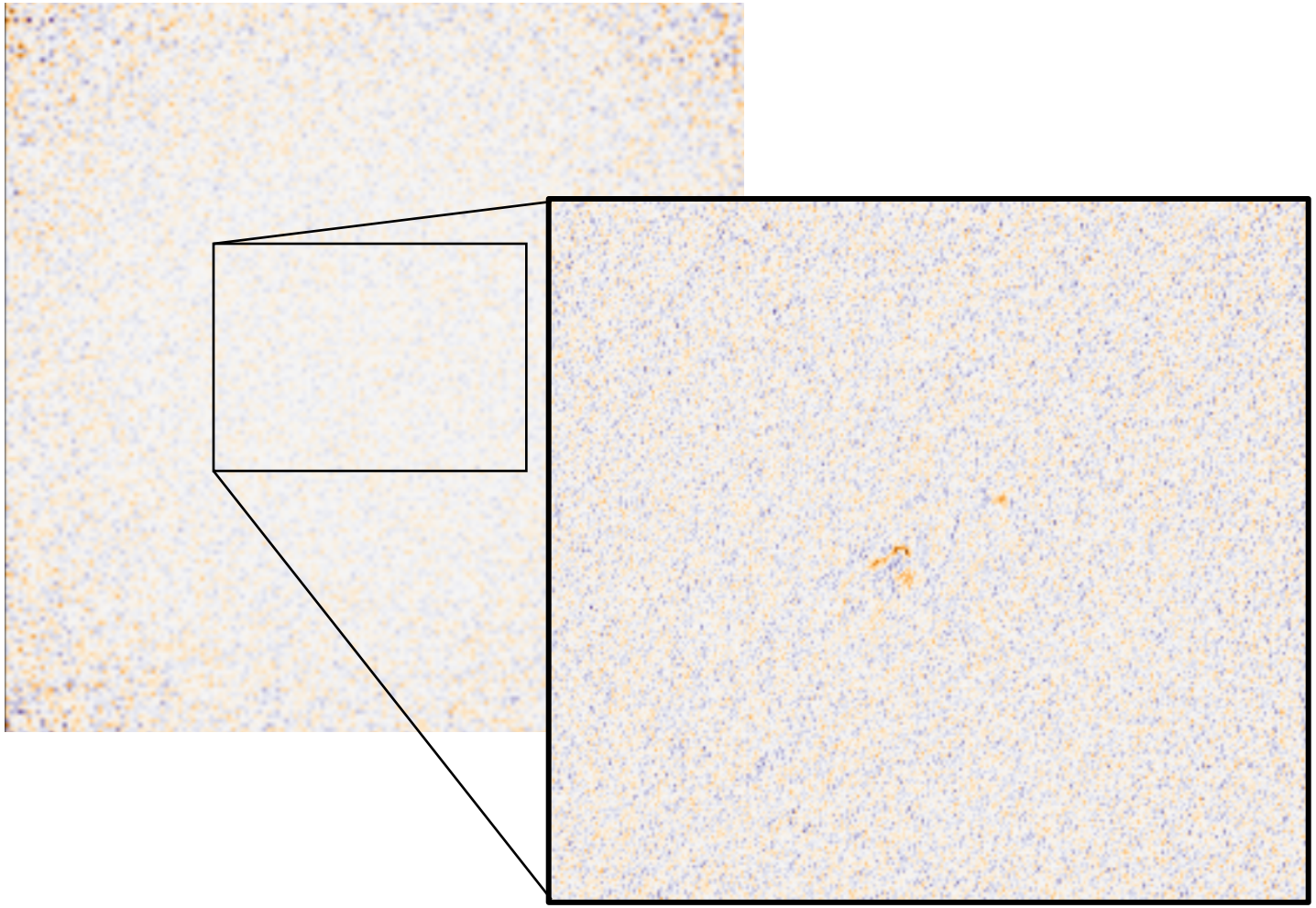

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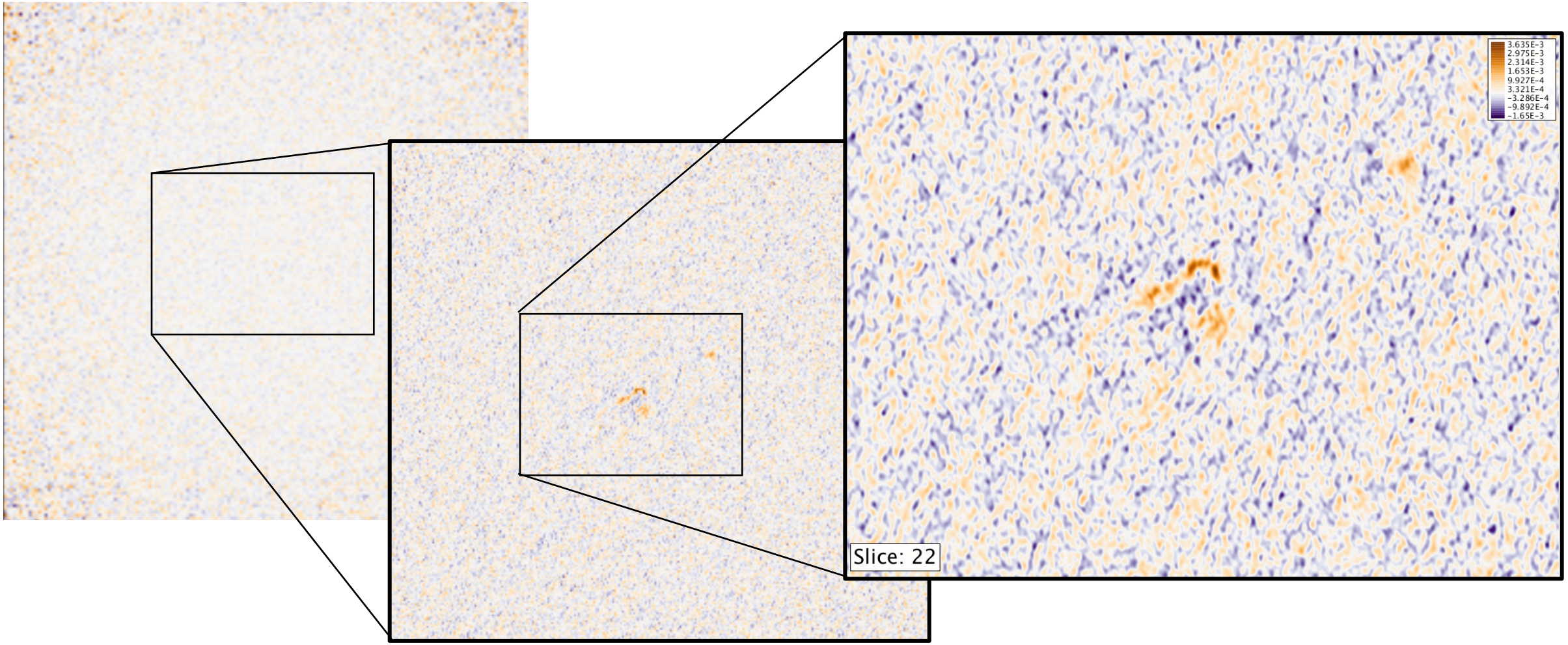

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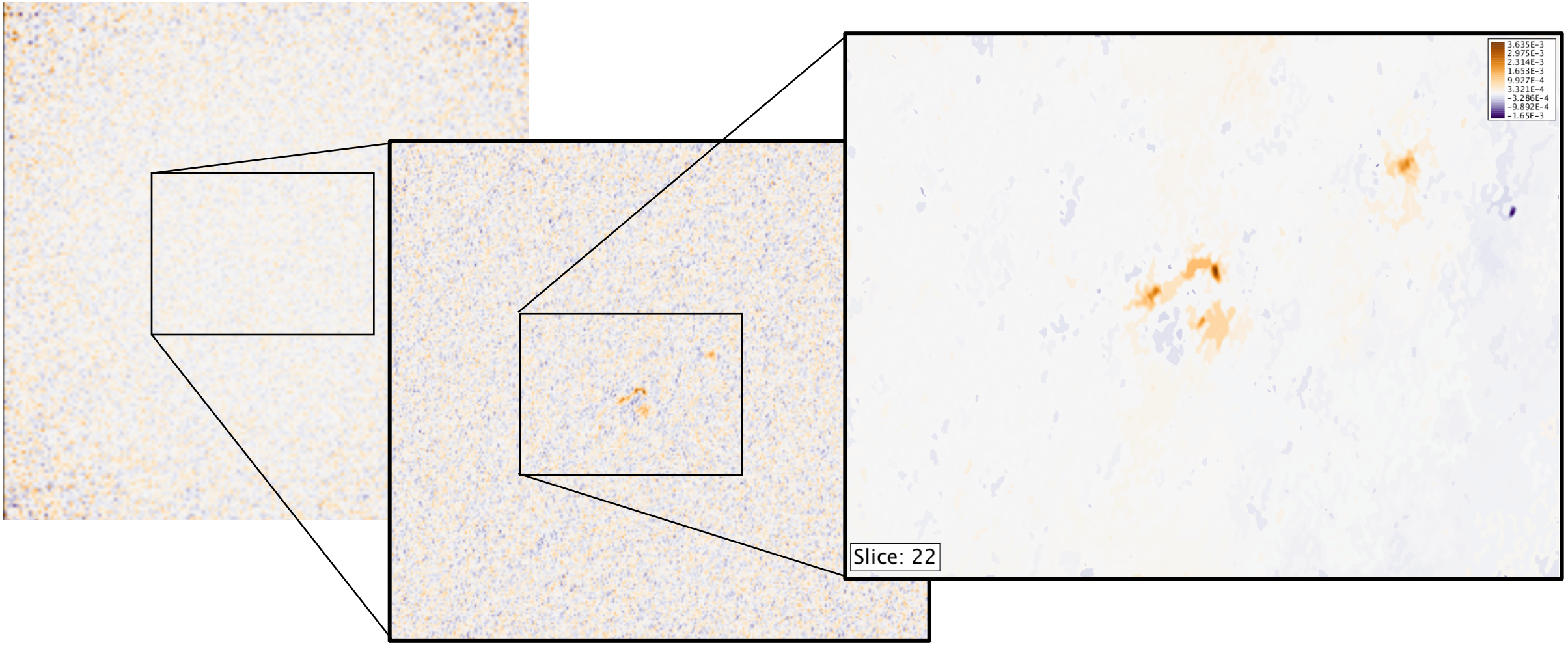


Topological Data Analysis and Visualization (TDAV)

study of approaches to EXTRACT structure from NOISY or COMPLEX data and REPRESENT that data in an actionable form

PERSISTENT HOMOLOGY

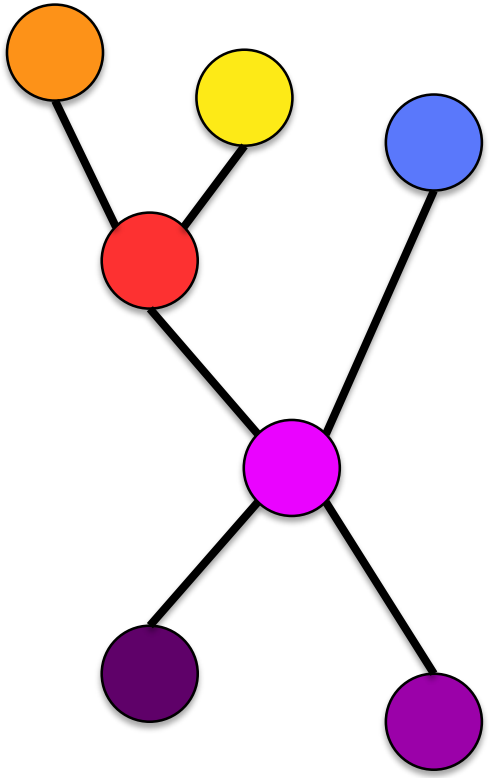
a method for computing topological FEATURES of a space at DIFFERENT spatial RESOLUTIONS

How Does This Relate to Radio Astronomy?

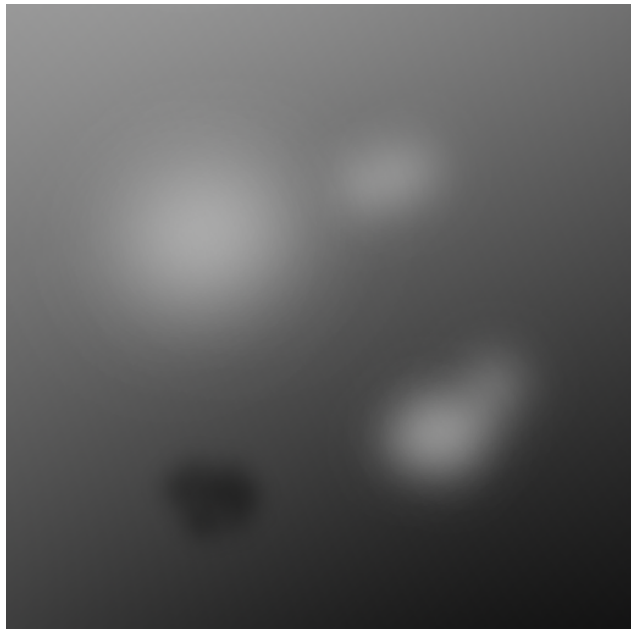
TDAV represents a DIVERSE toolbox capable of addressing analysis NEEDS in many contexts

Our development study addresses these needs specifically via the CONTOUR TREE

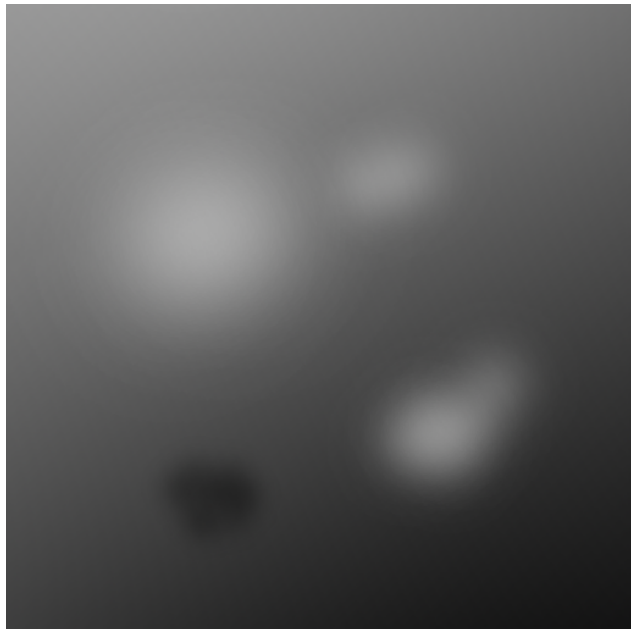
Topological Skeleton: Contour tree

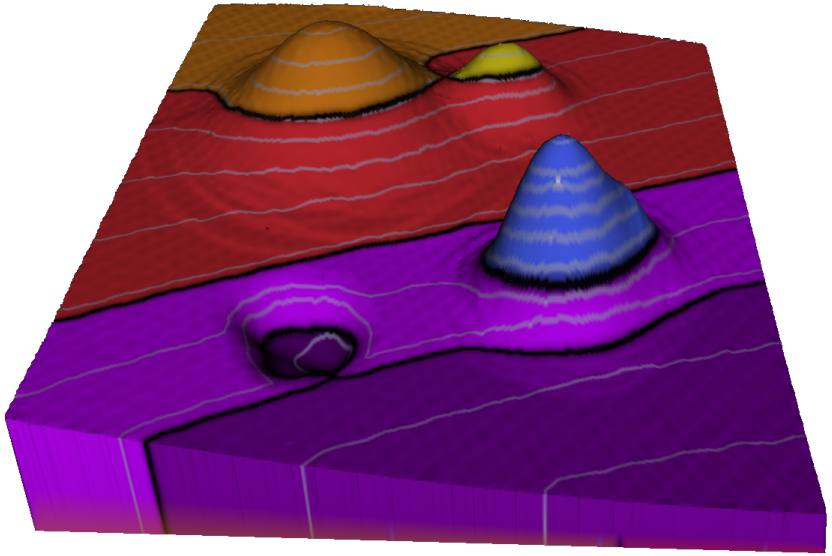


Contour trees

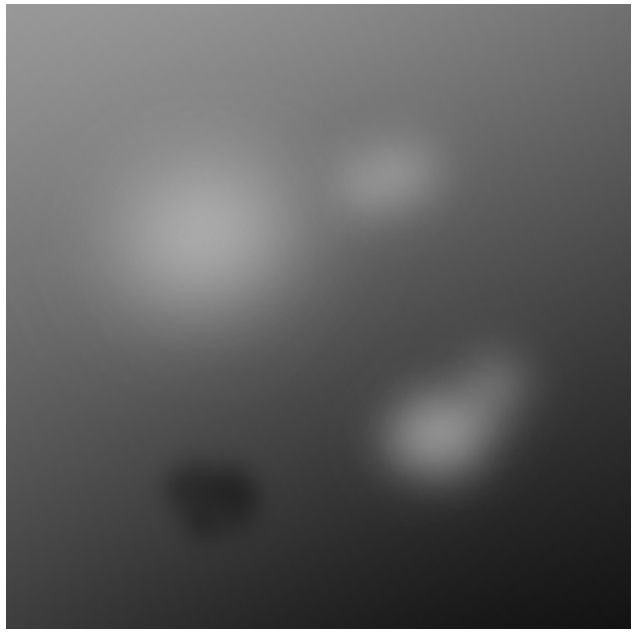


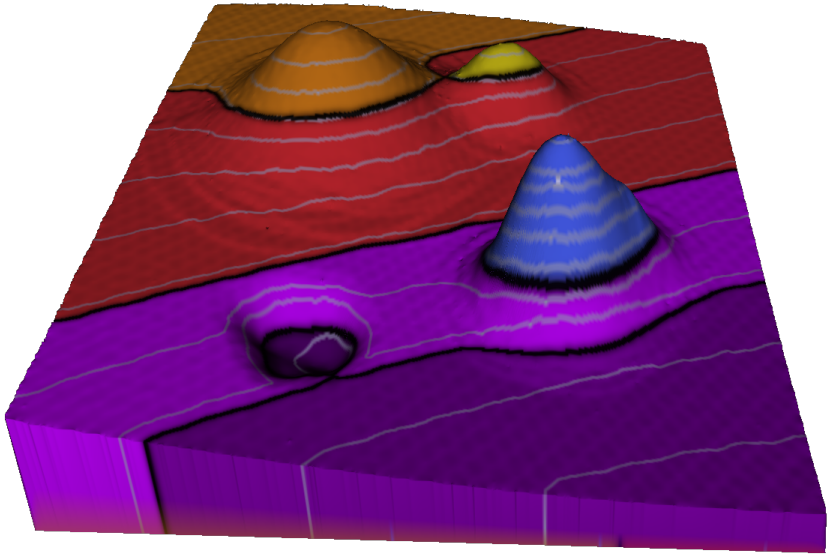
Contour trees

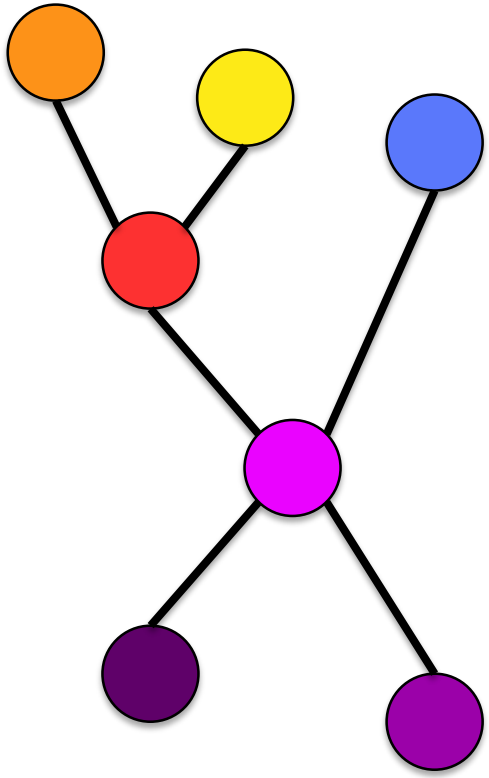




Contour trees







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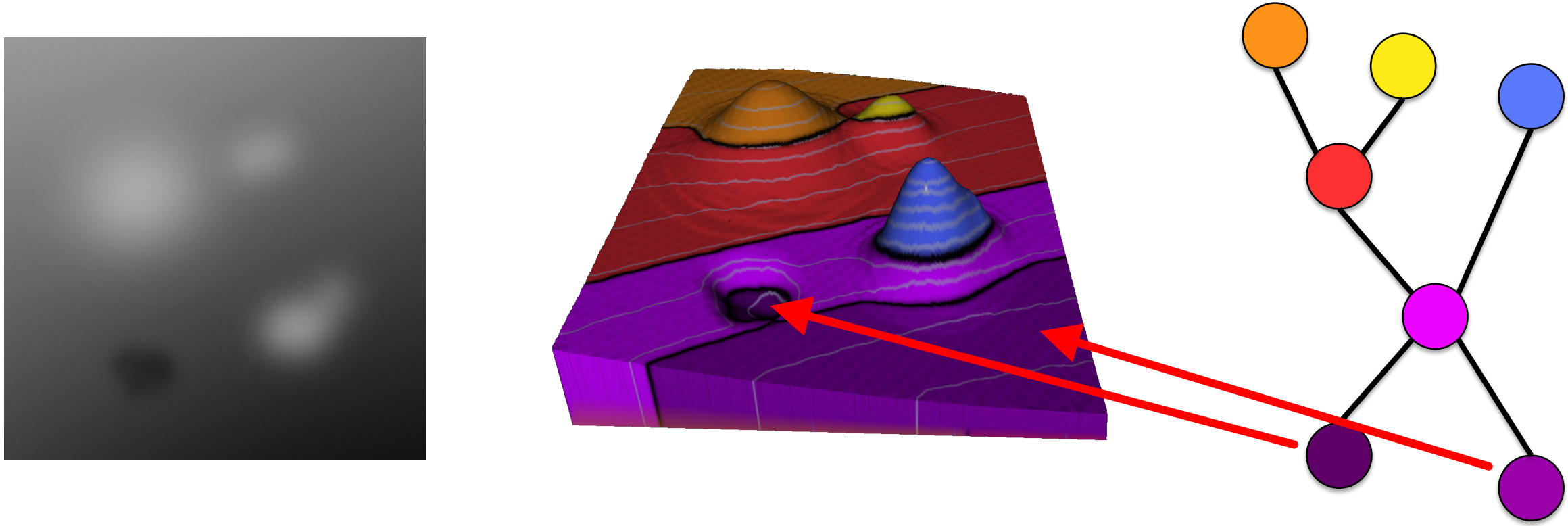

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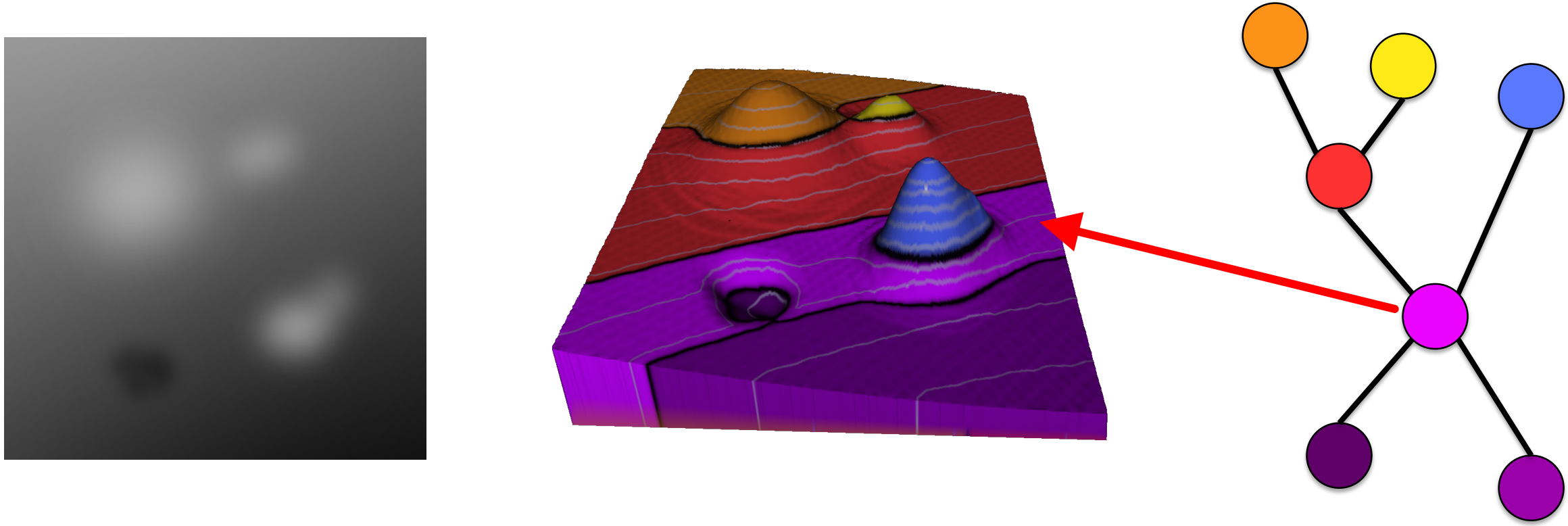

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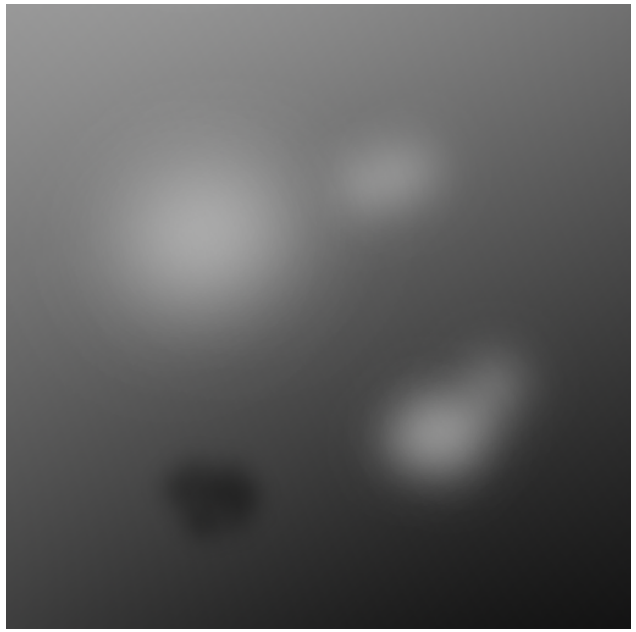

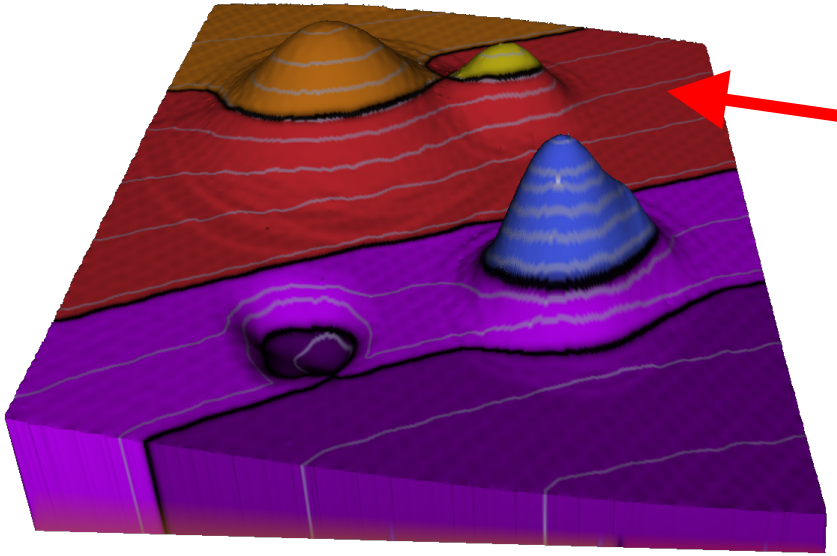

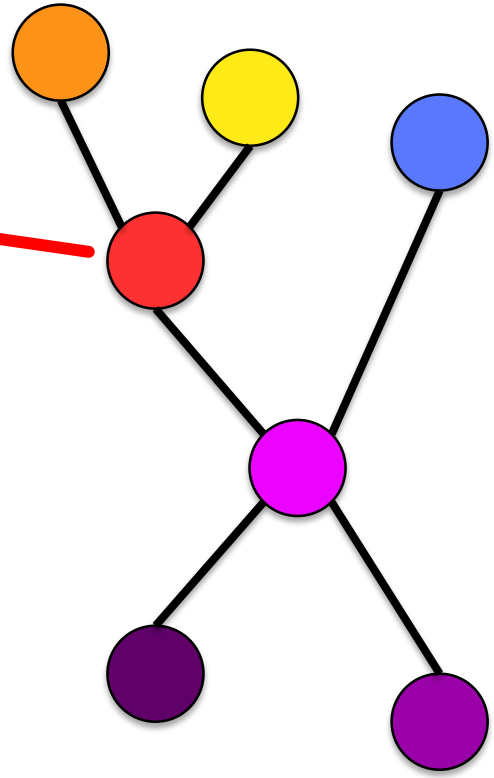

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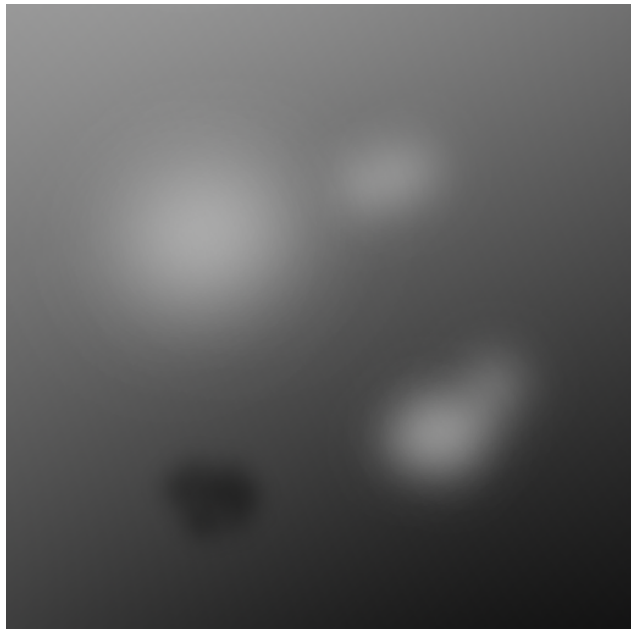

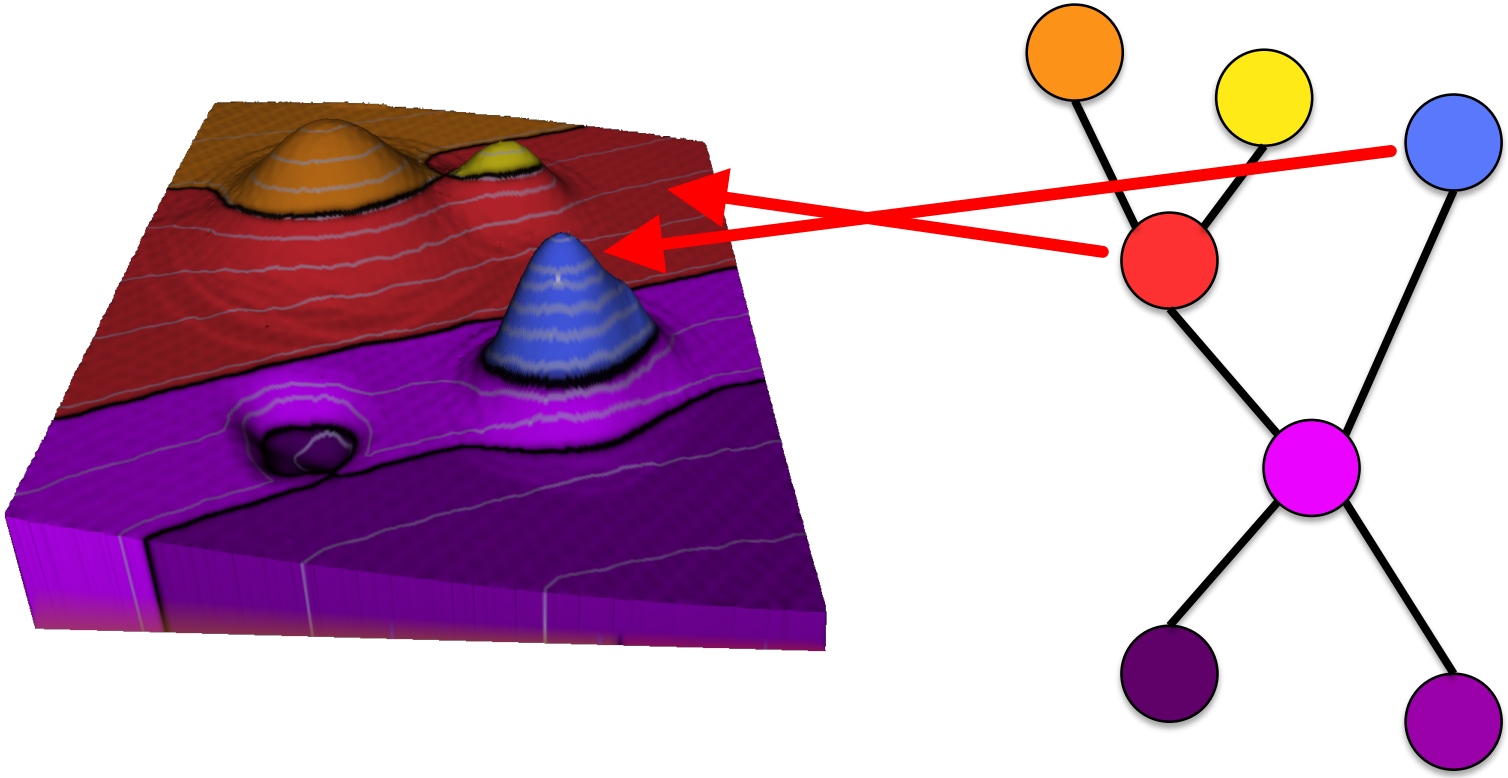

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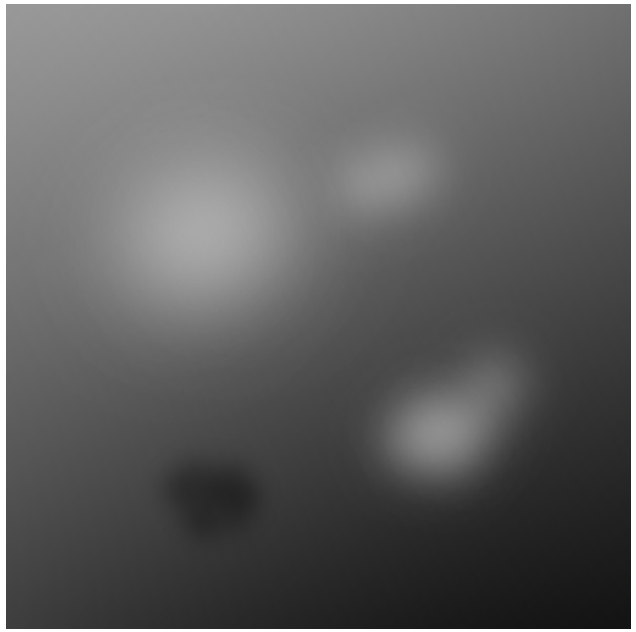
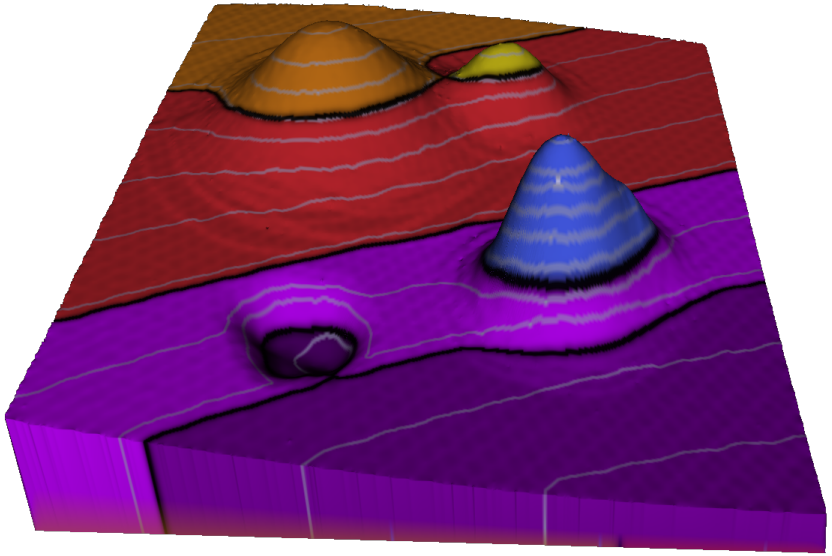
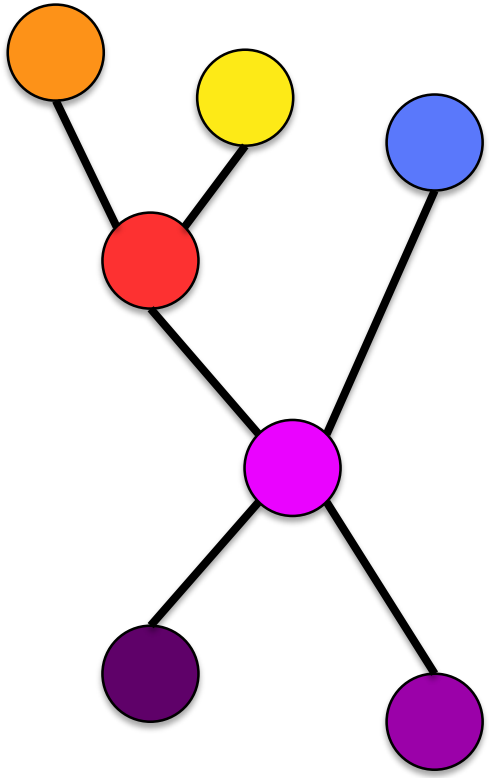
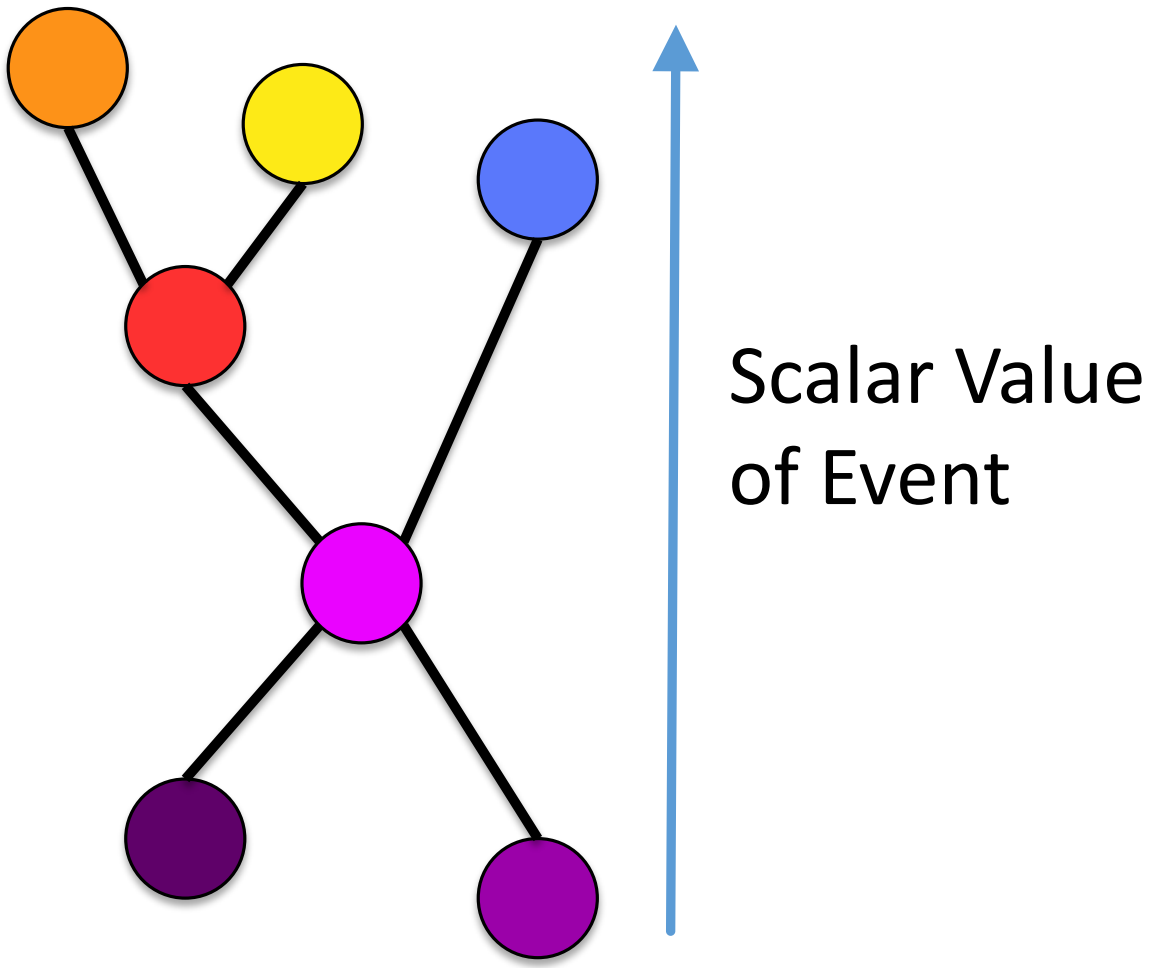






A Closer Look at the Contour Tree



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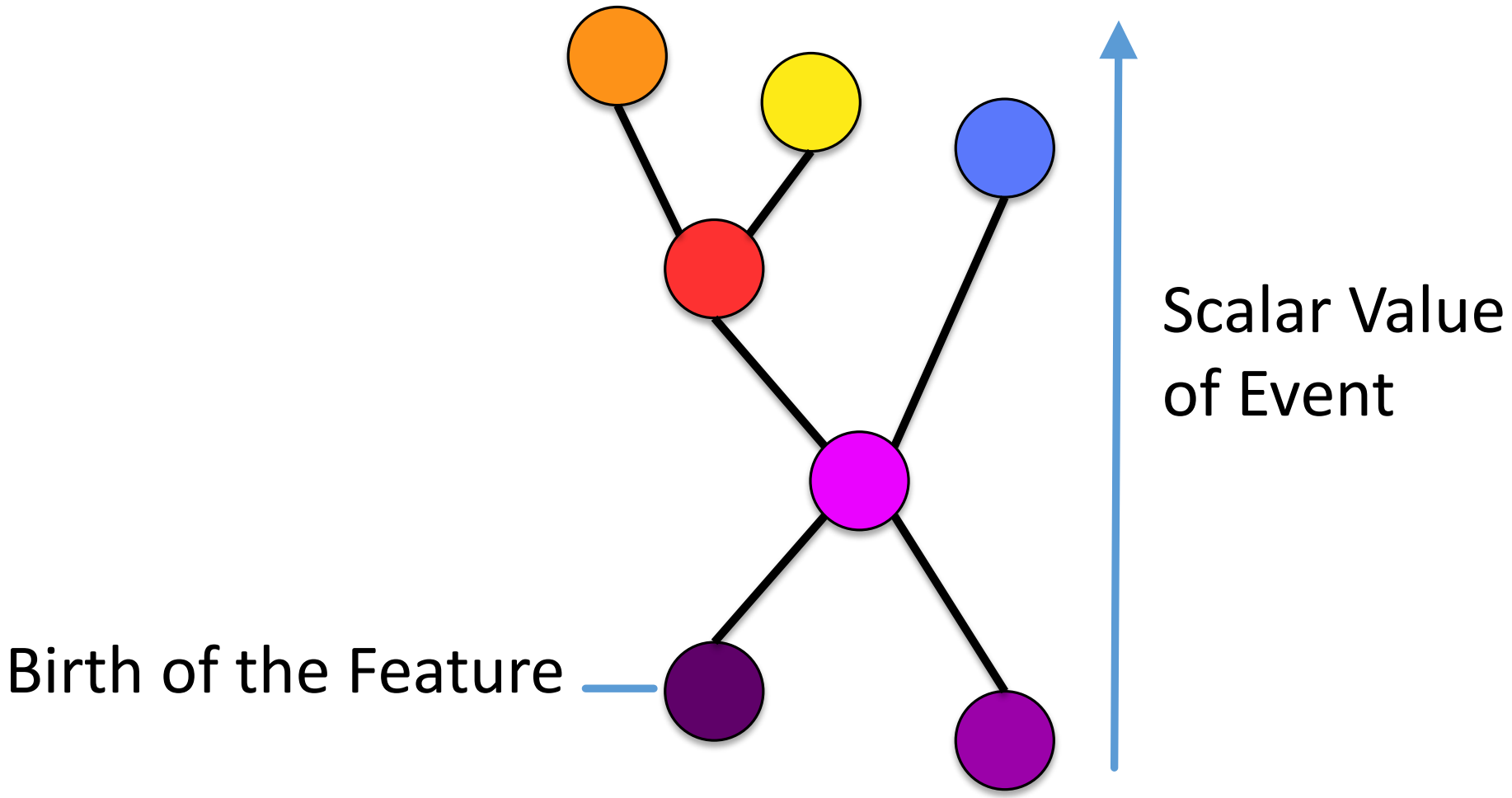

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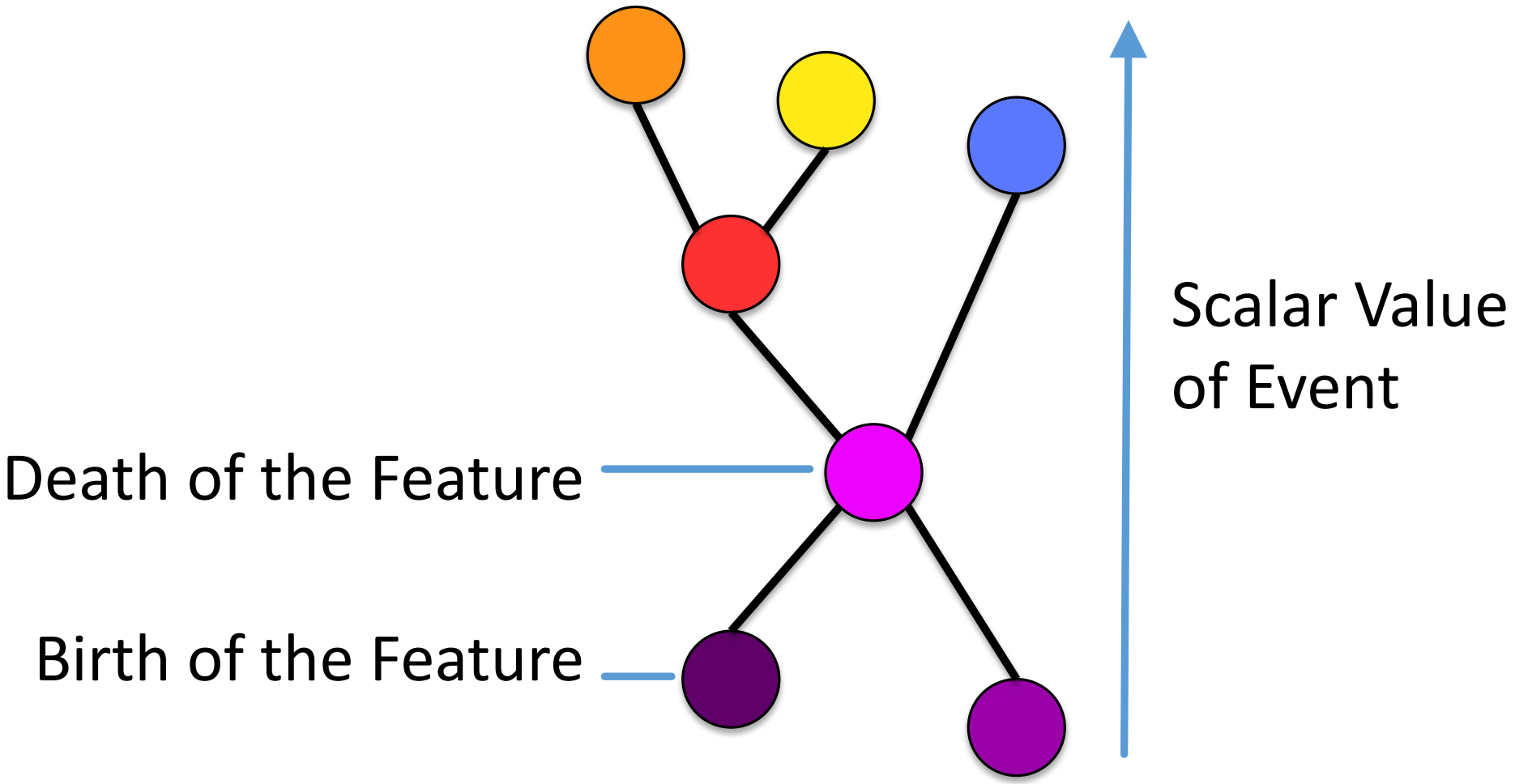

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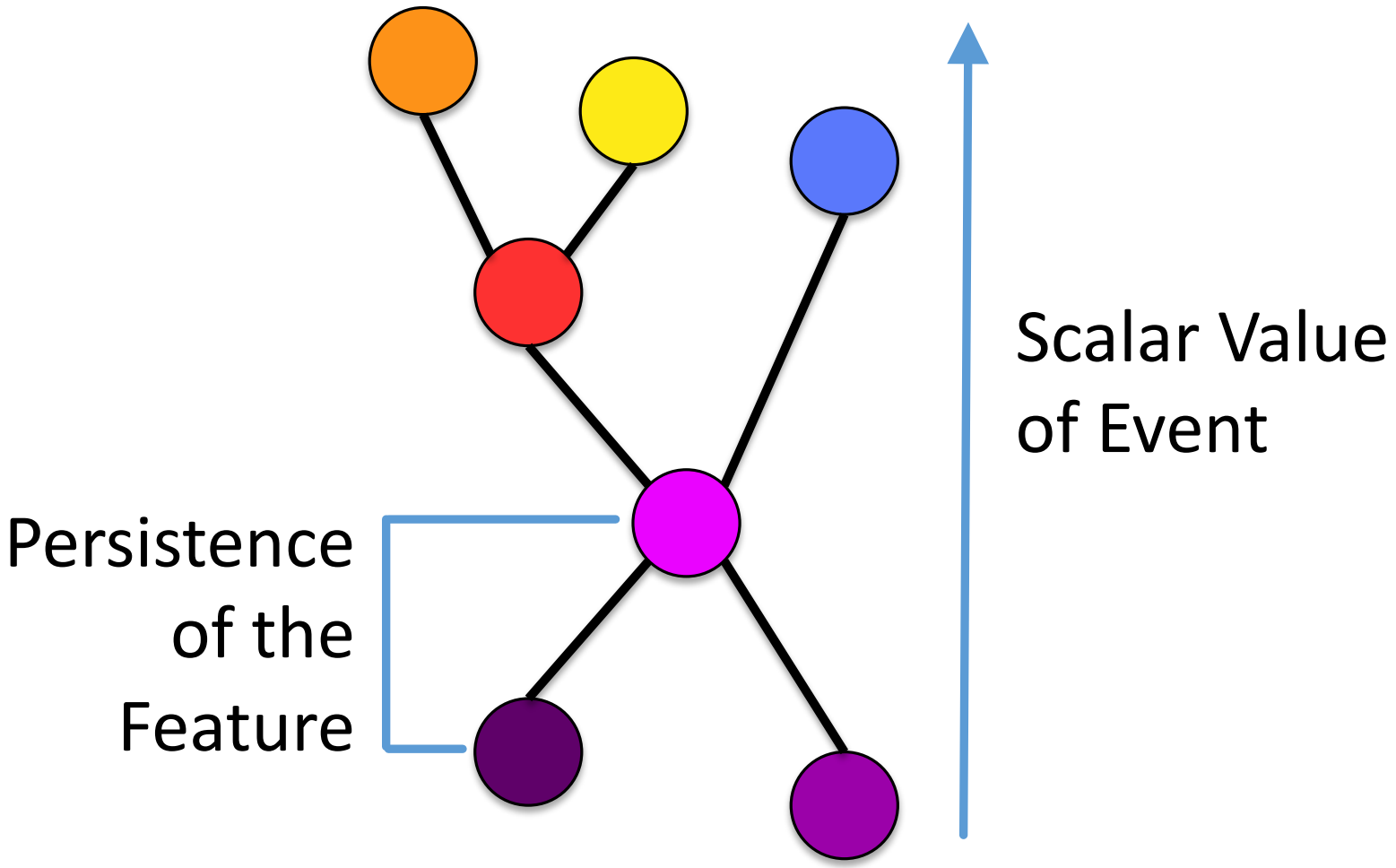
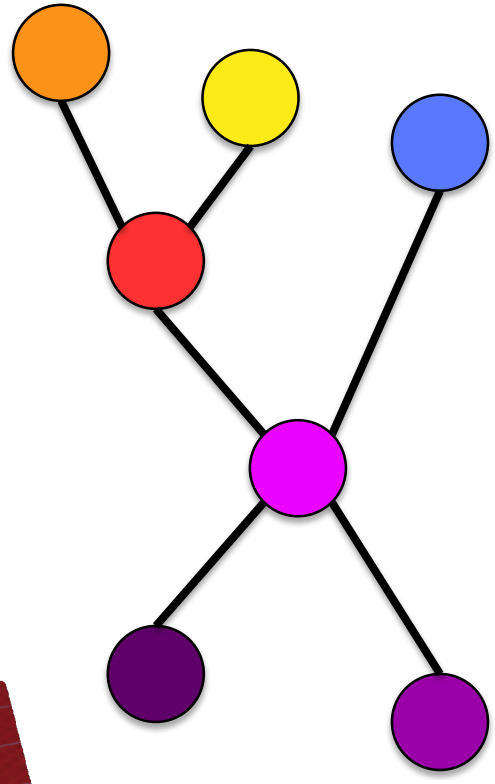
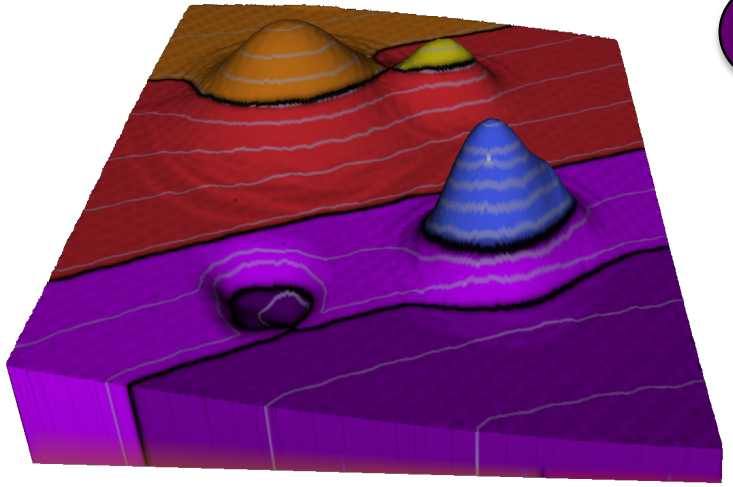


Feature Removal





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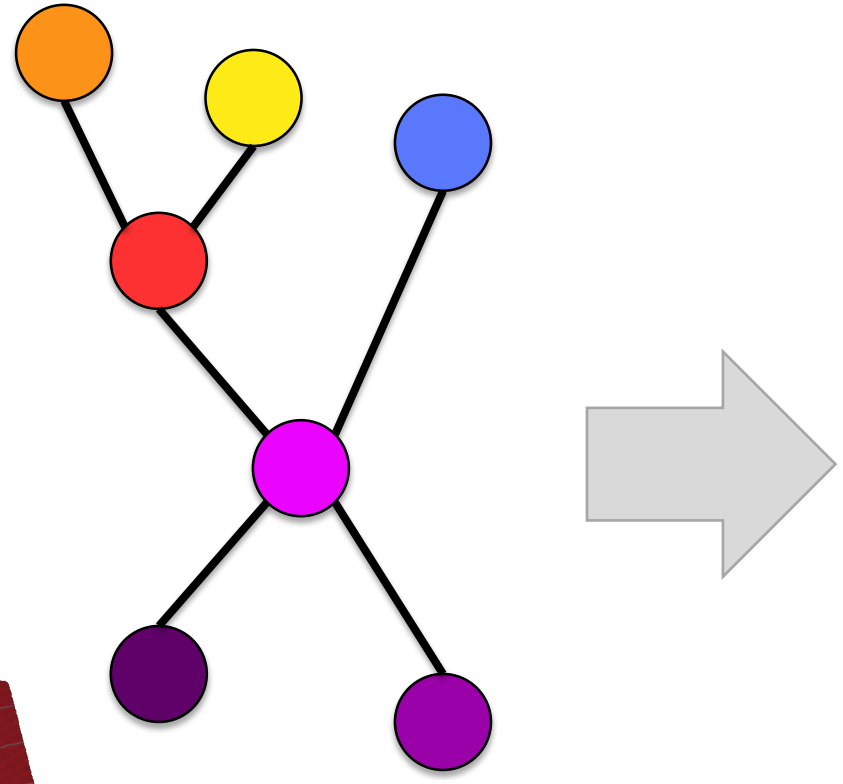
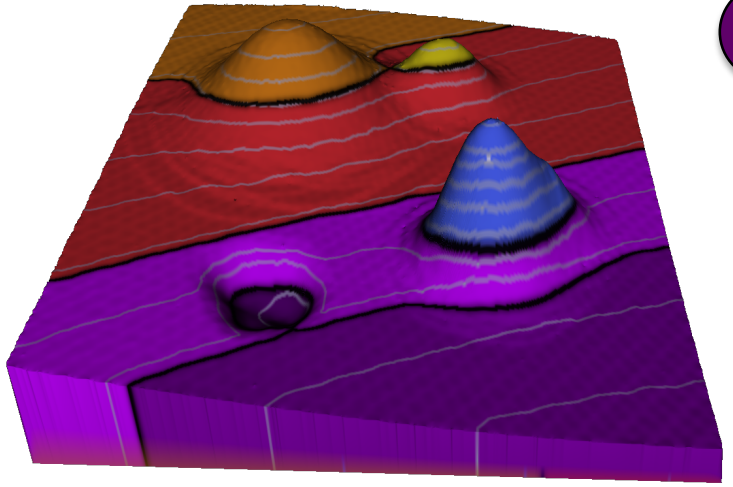
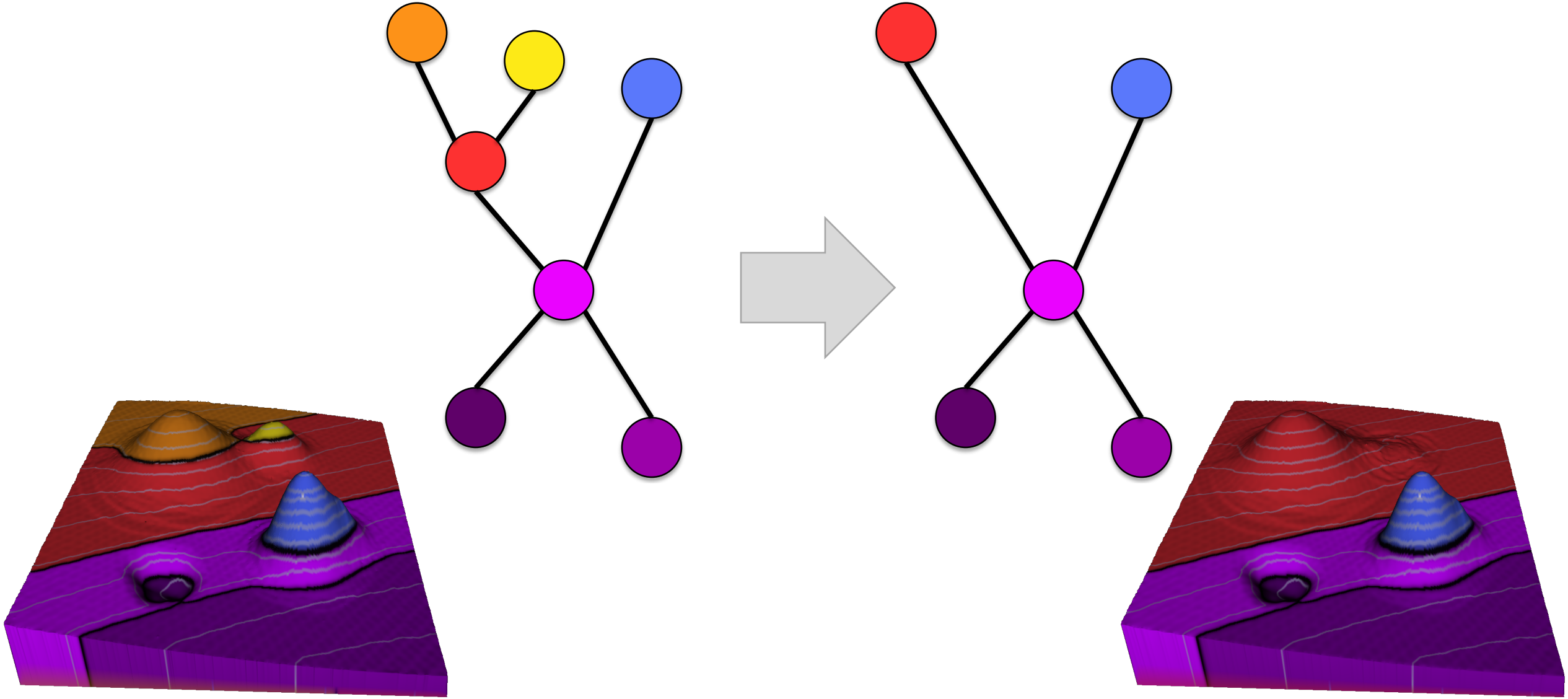
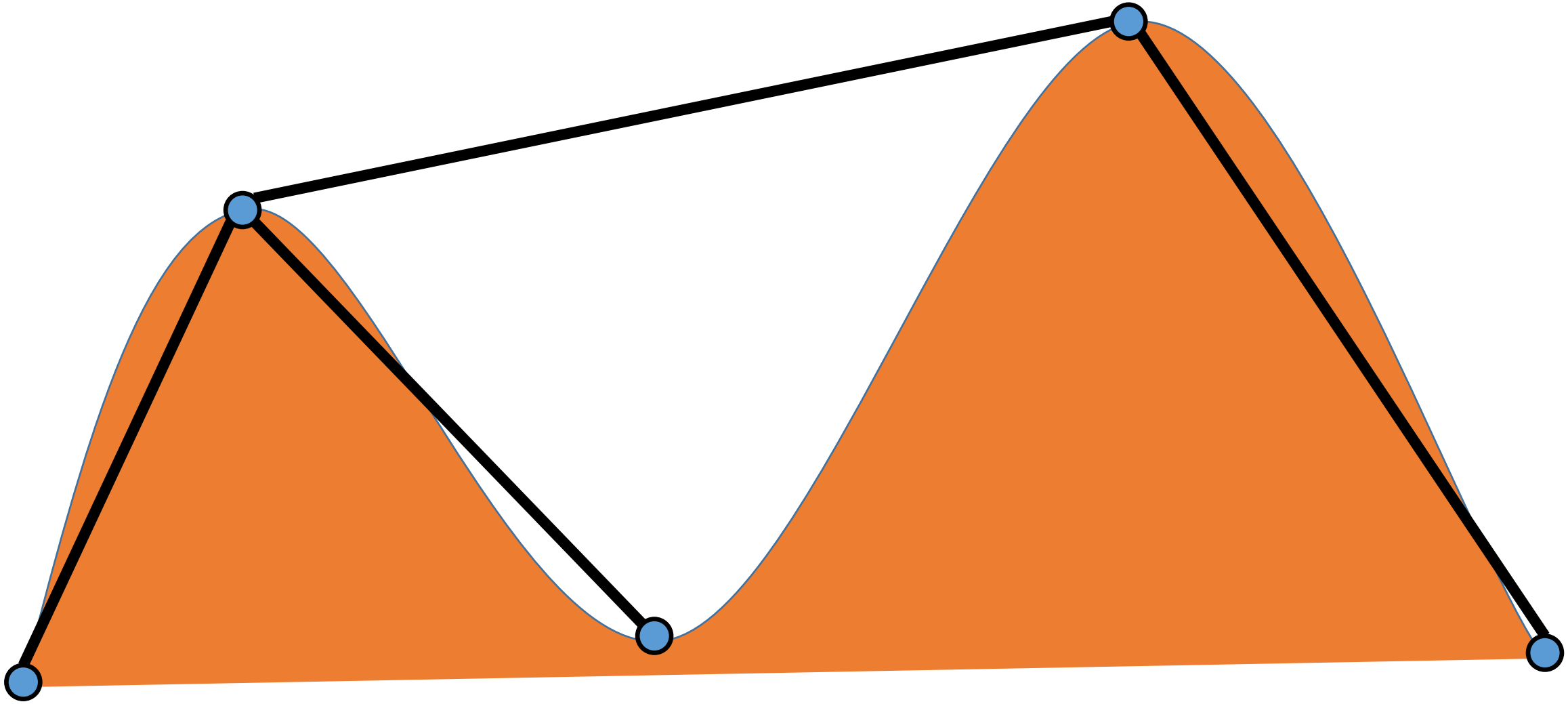




Feature Removal



Scalar field Simplification



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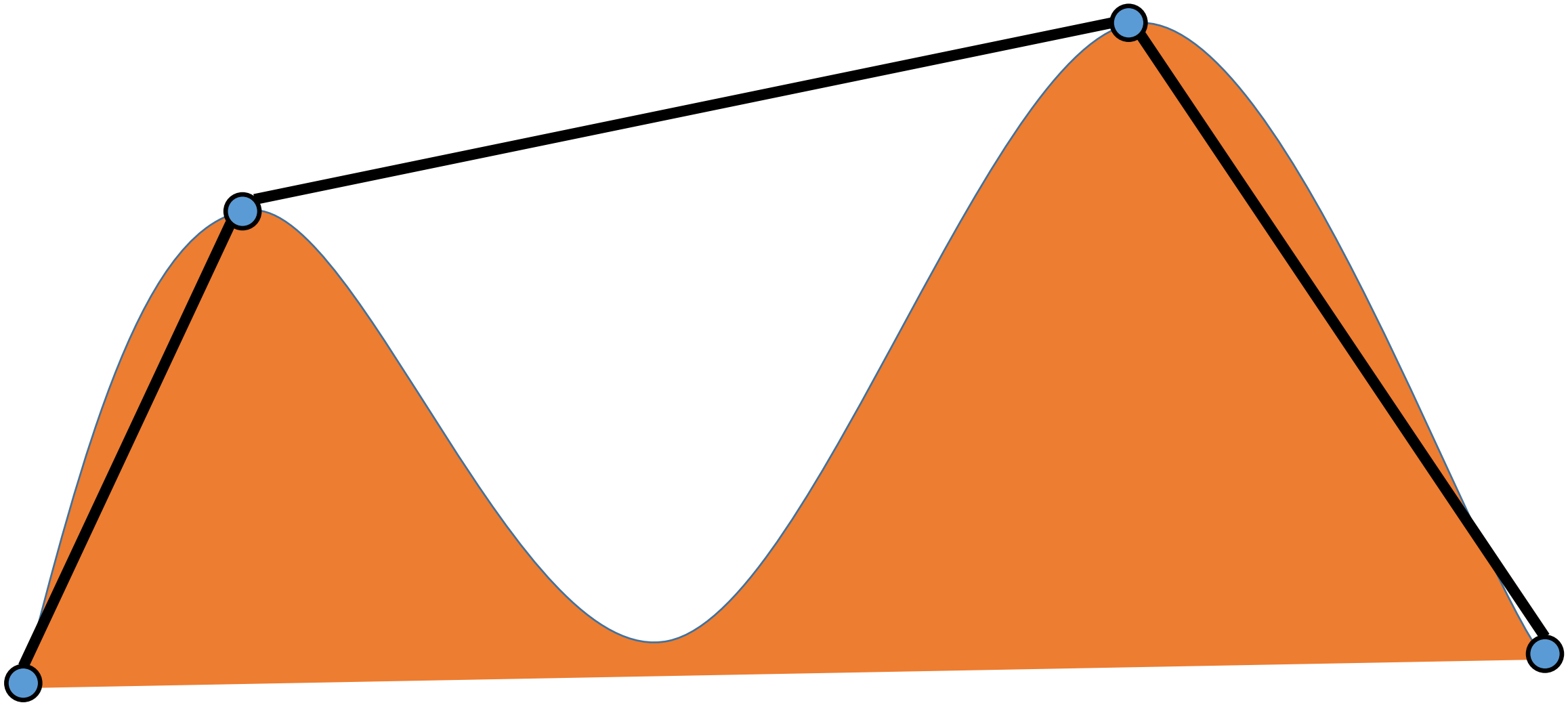

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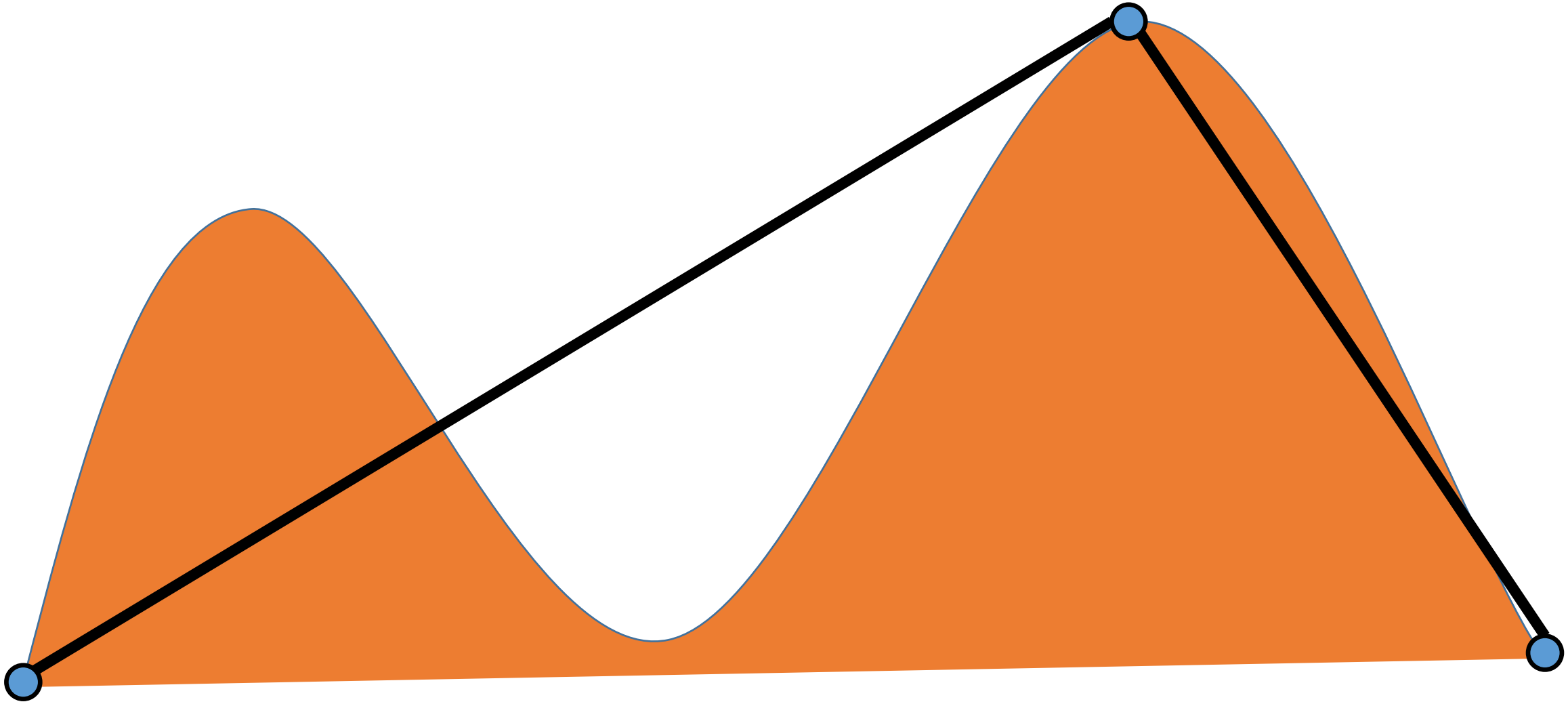

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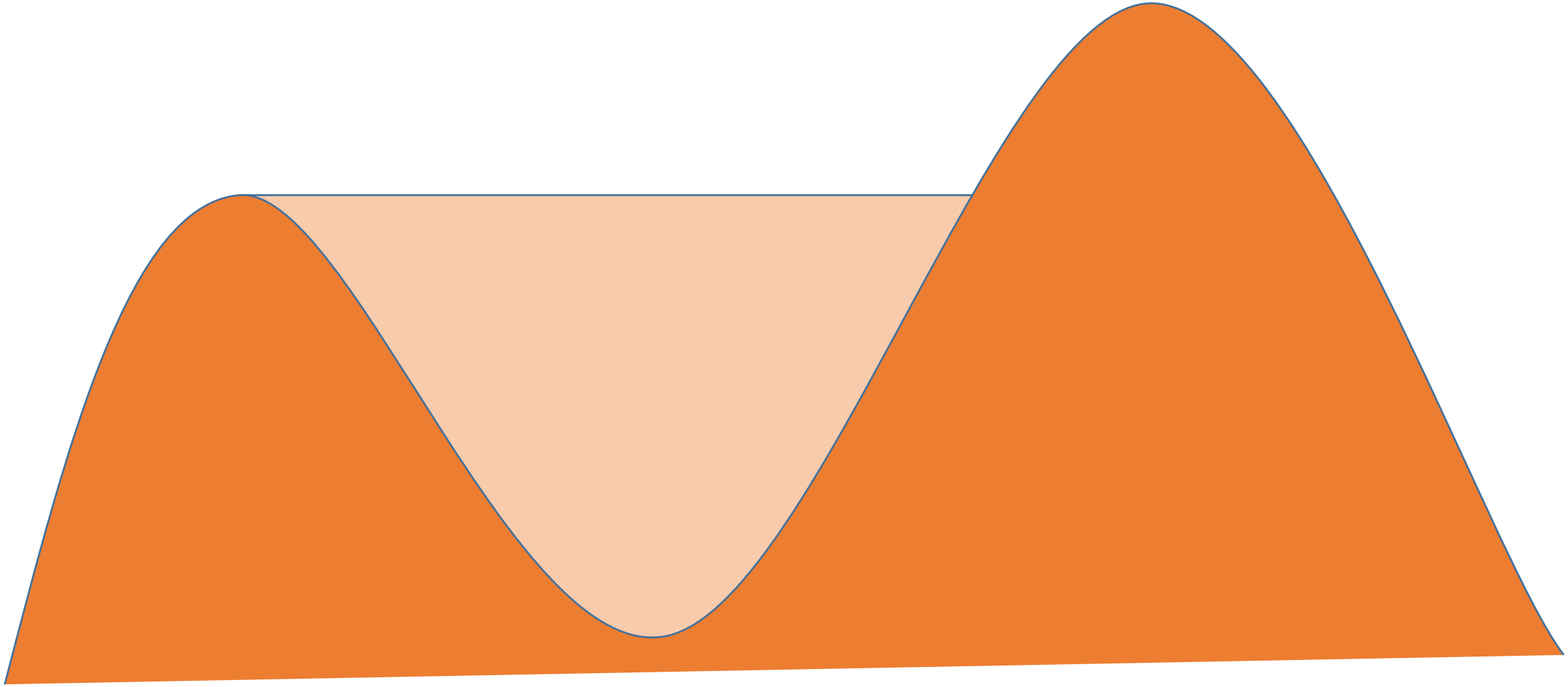

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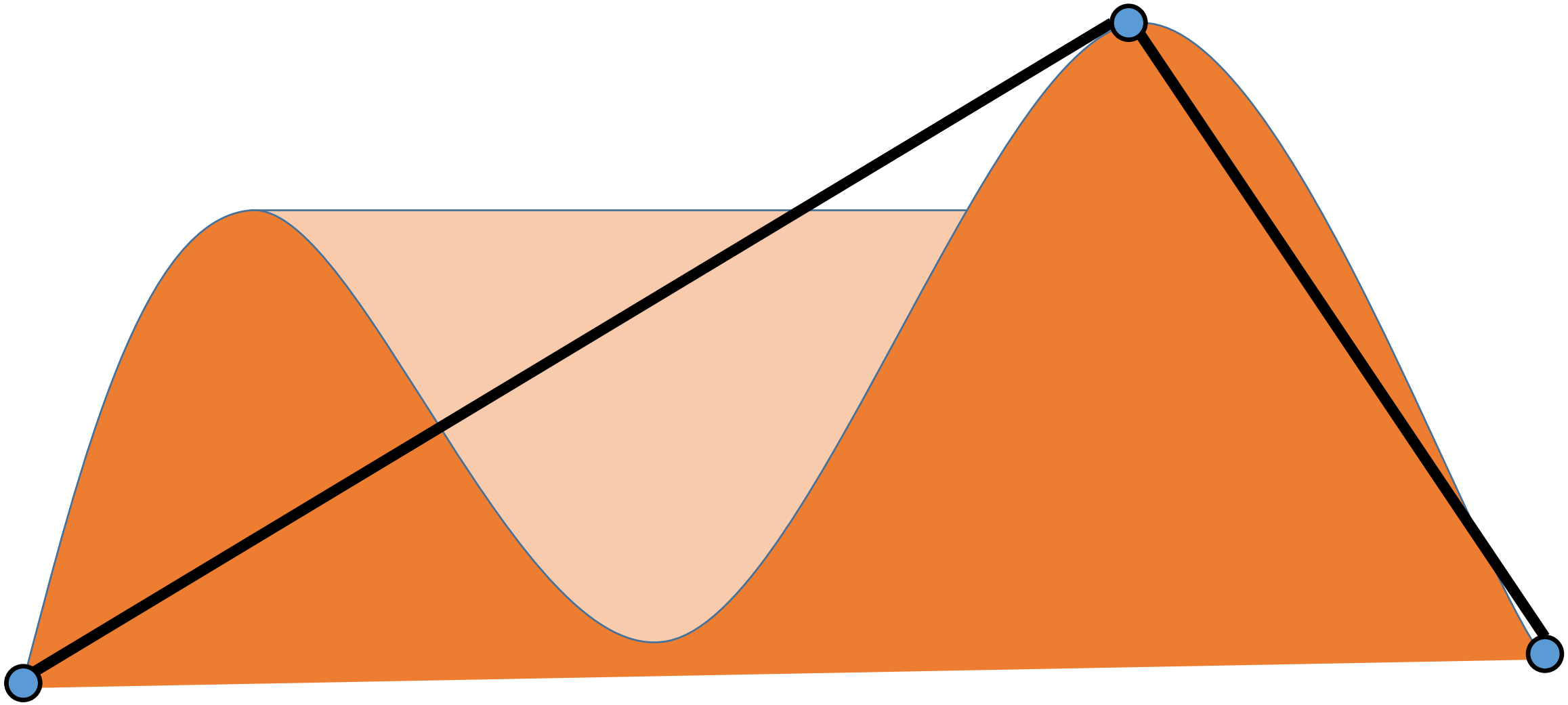


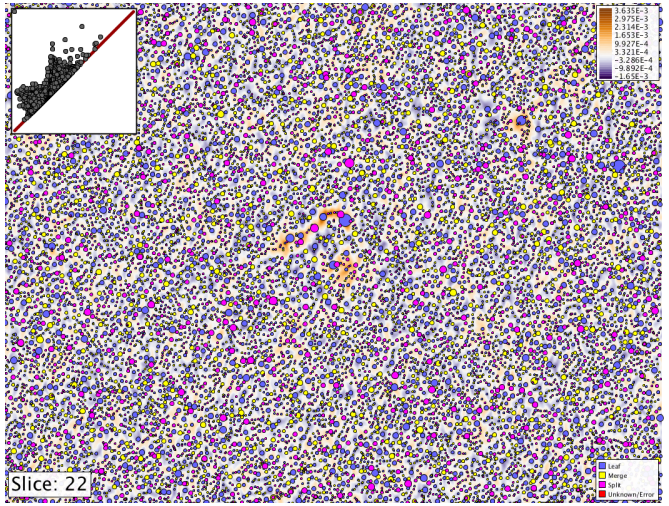
RESULTS

Simple Spinning Disk

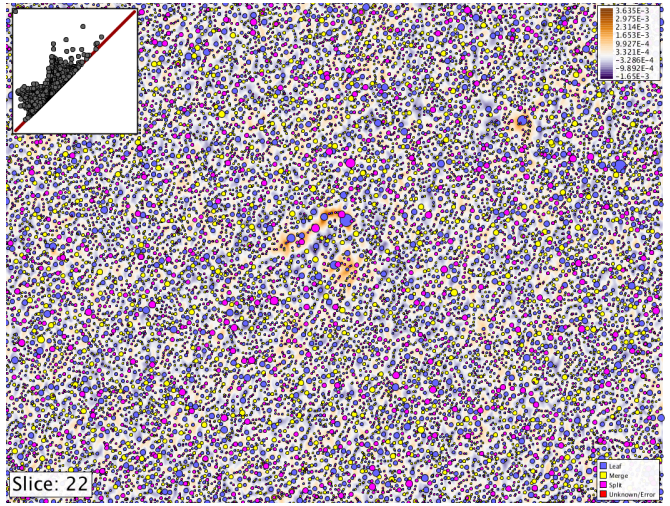
from Anil Seth
Phys. & Astro.
University of Utah

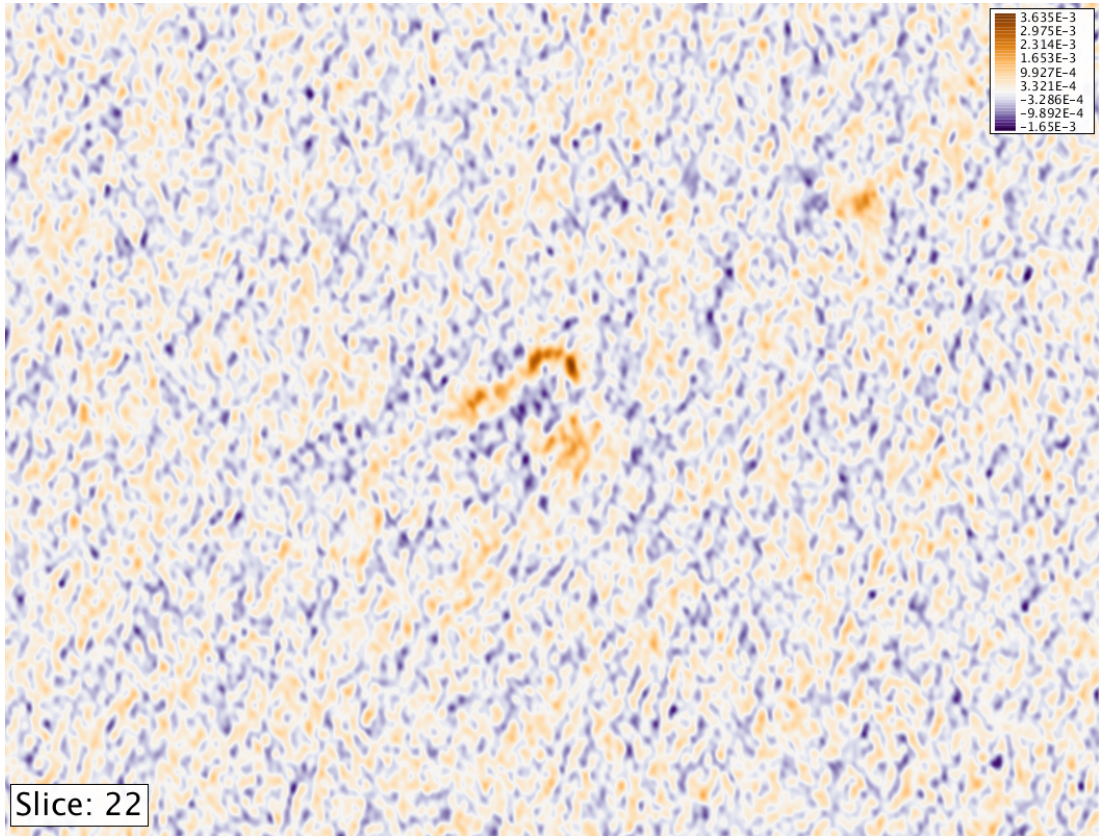
Varying Persistent Simplification

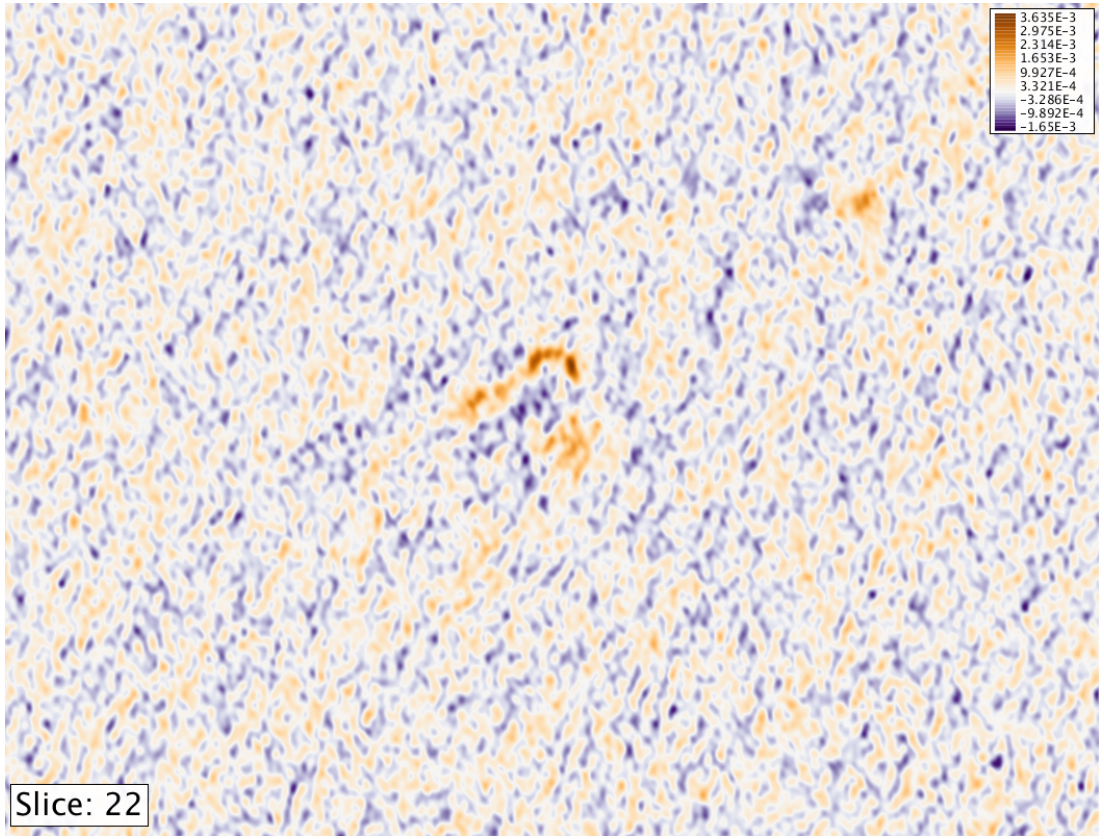
original



simplified







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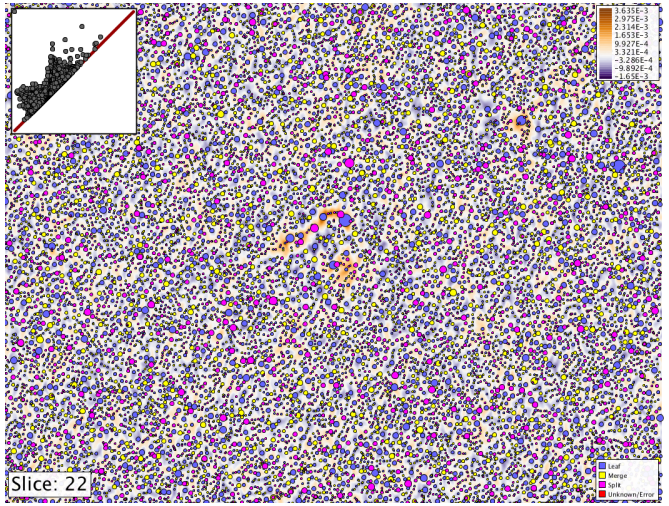

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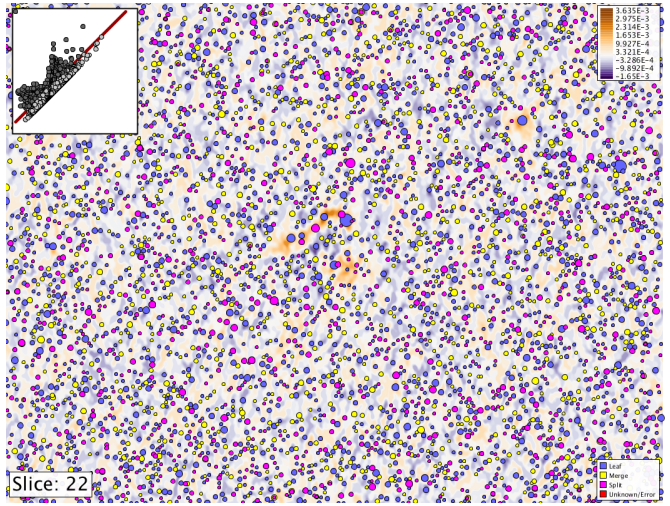

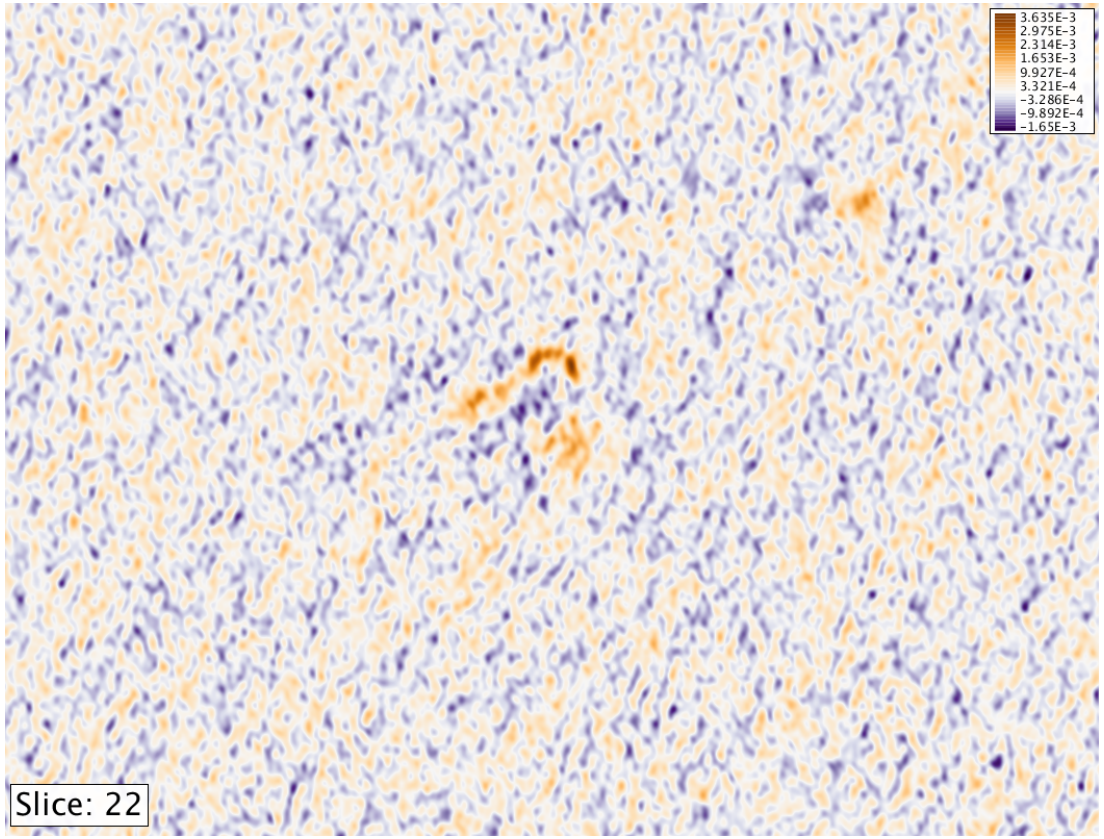

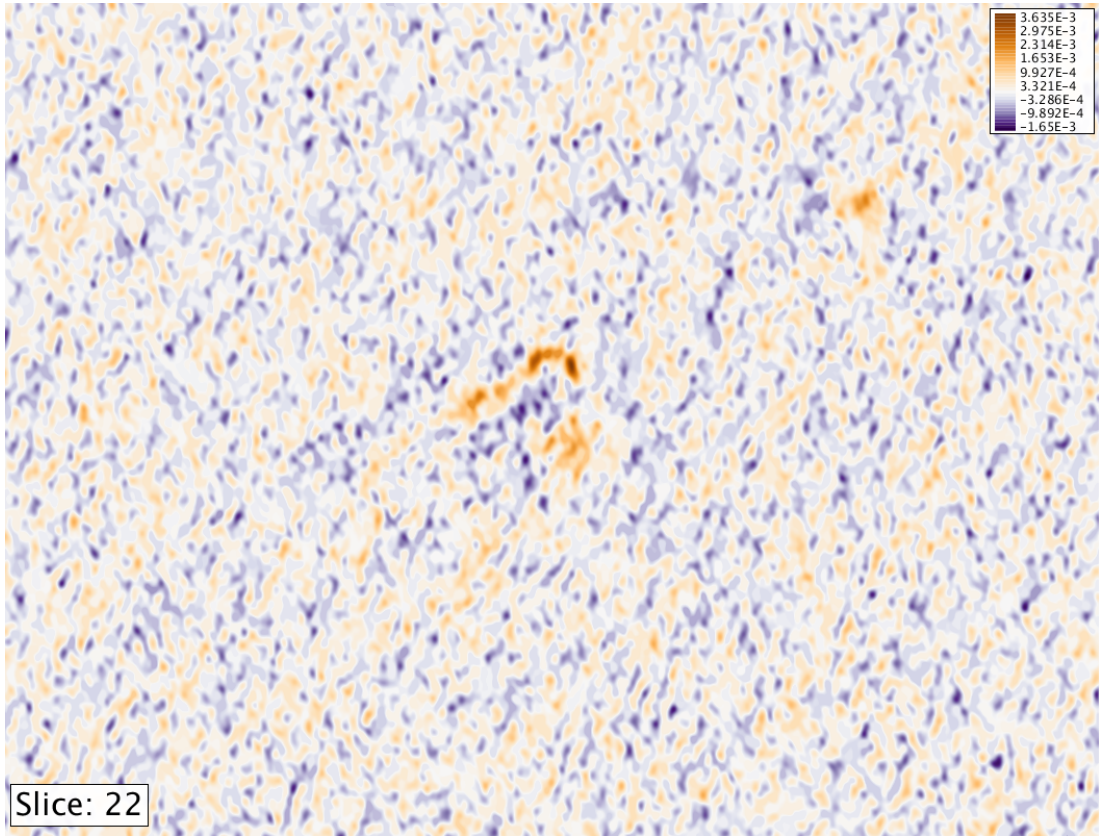

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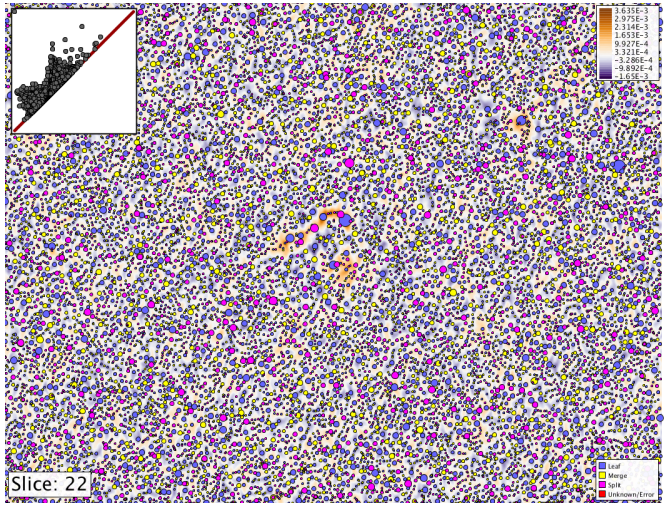

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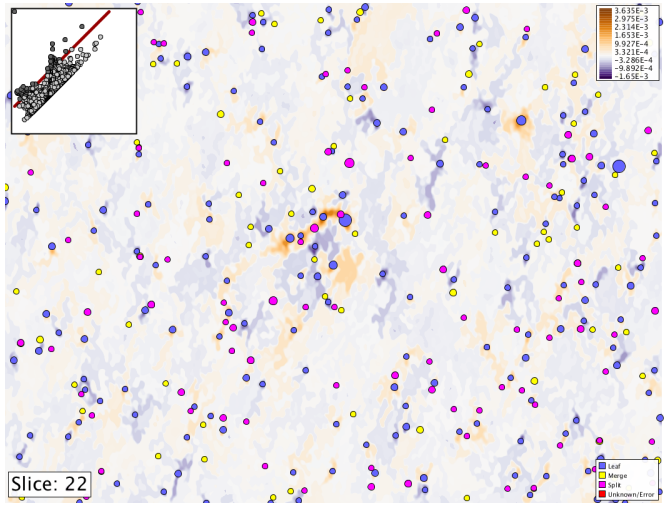

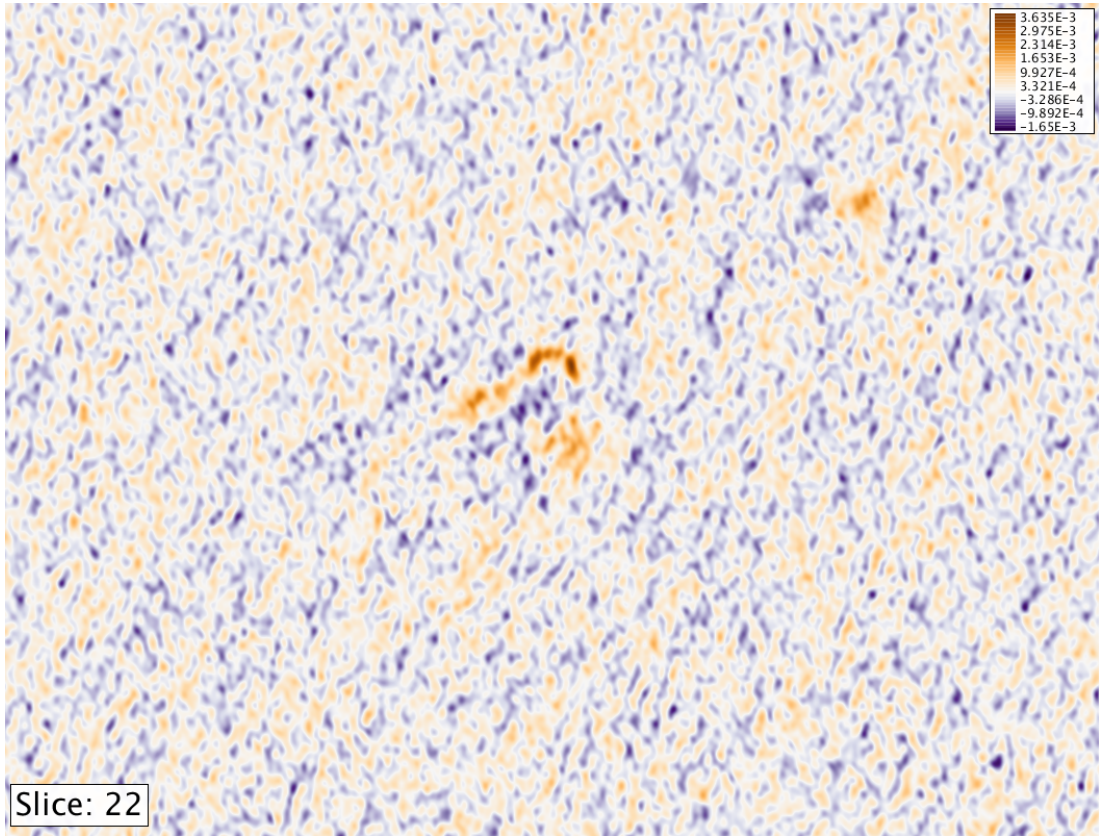

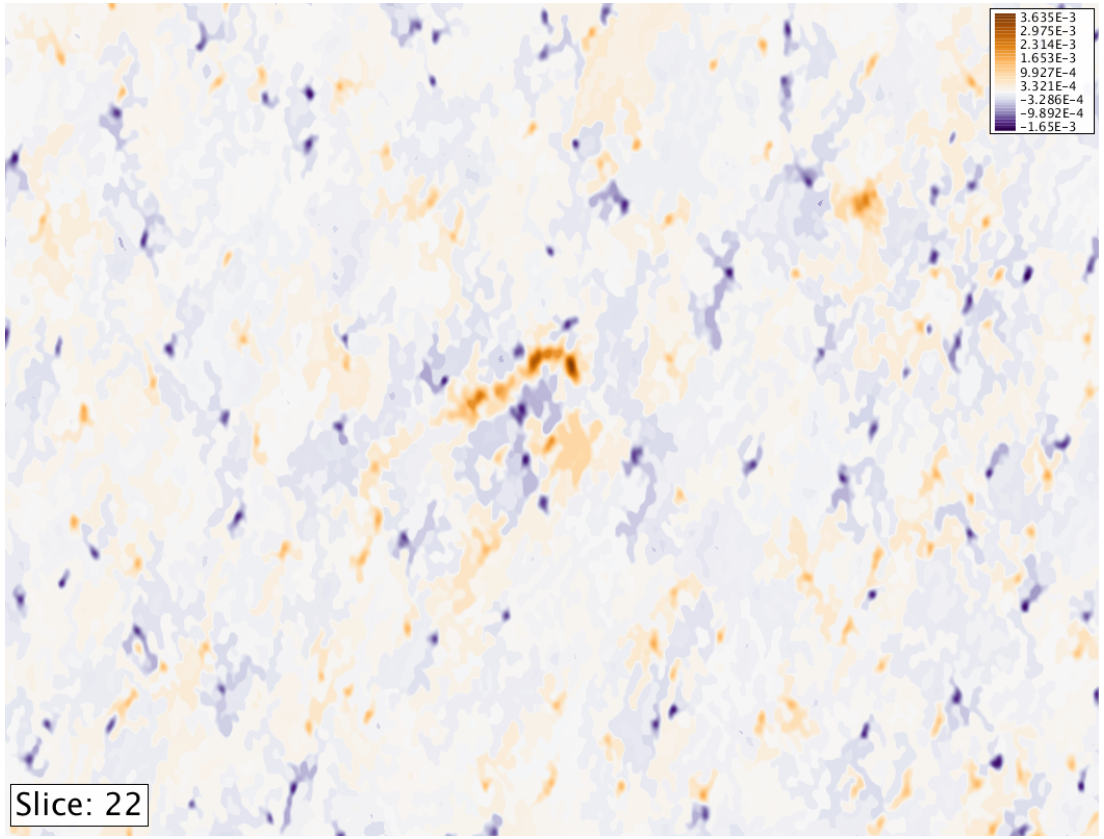

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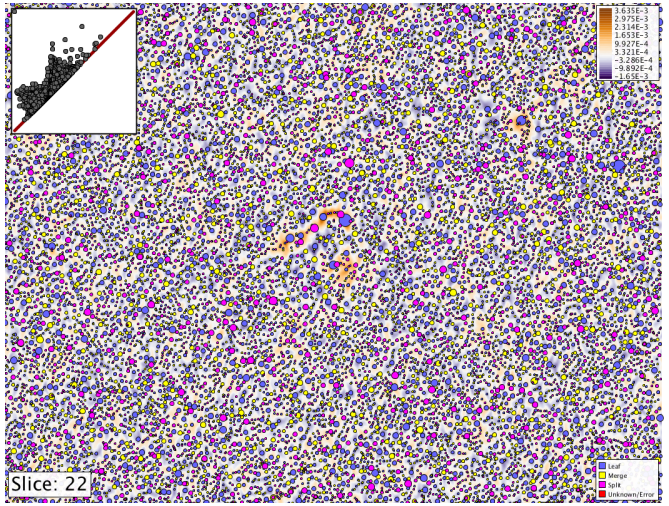

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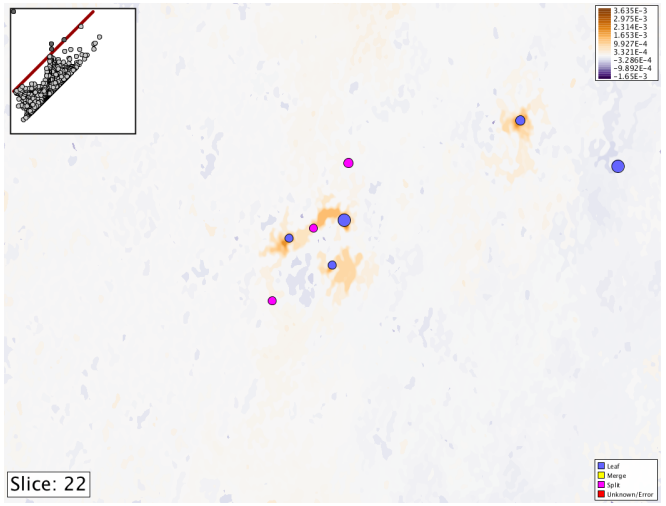

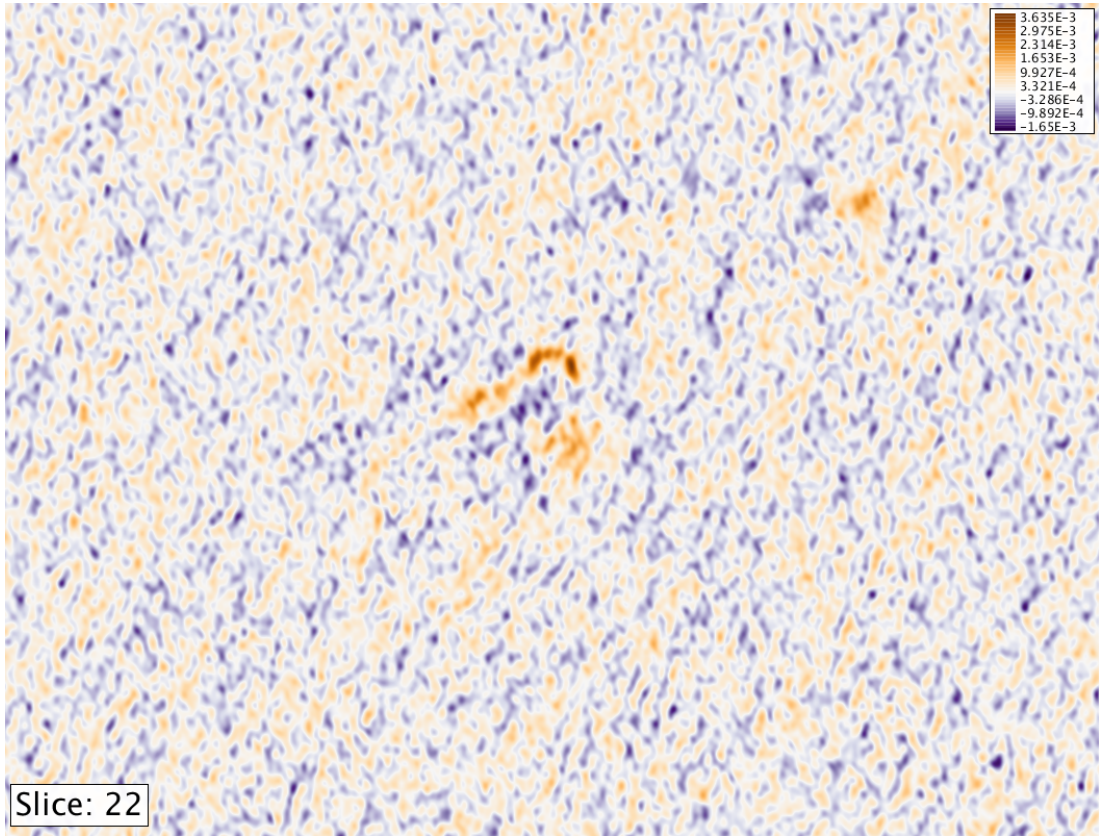

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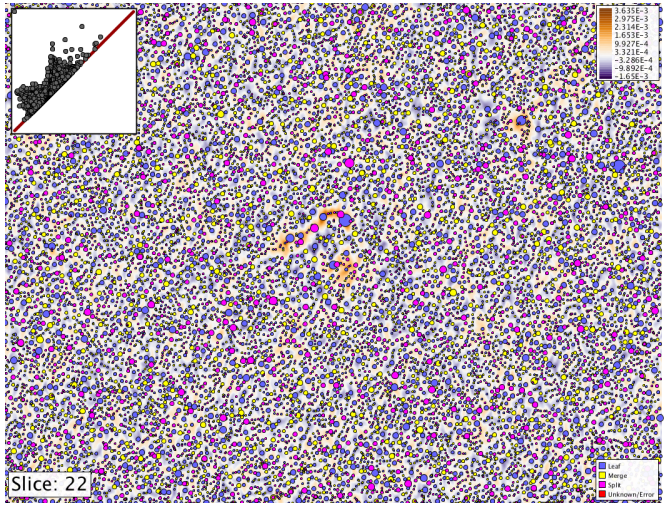

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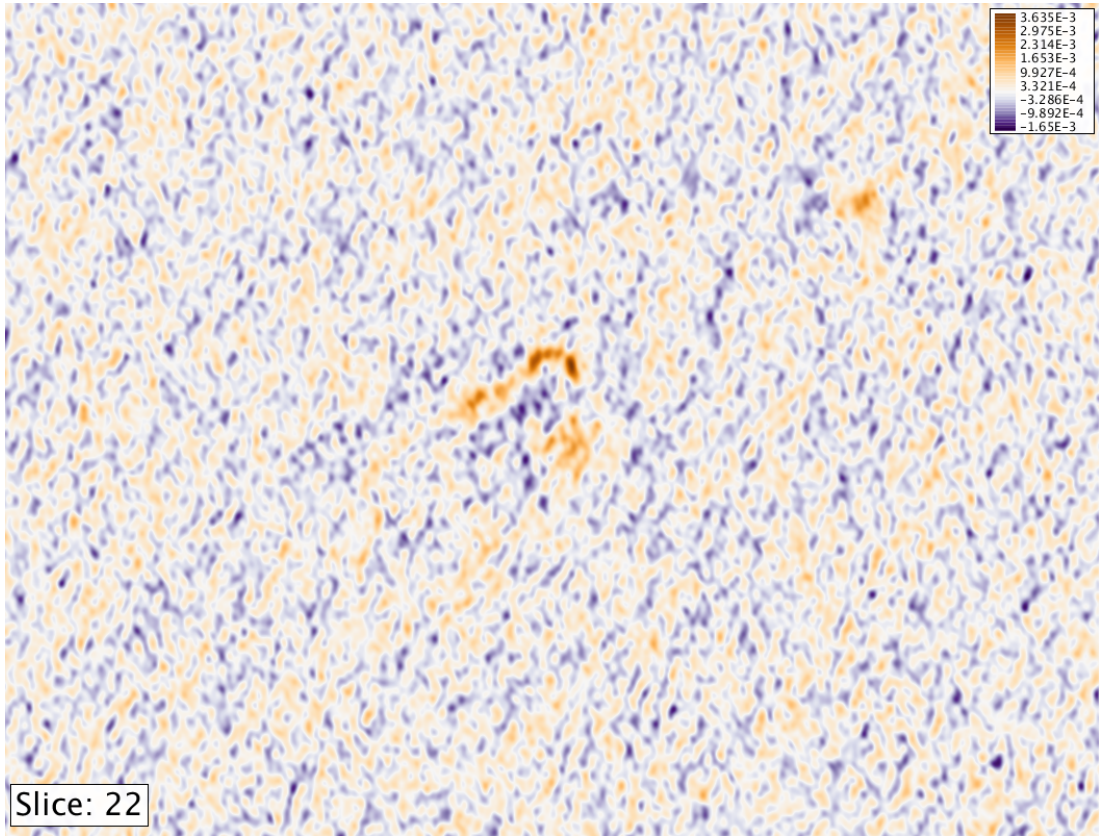

Stepping through Slices

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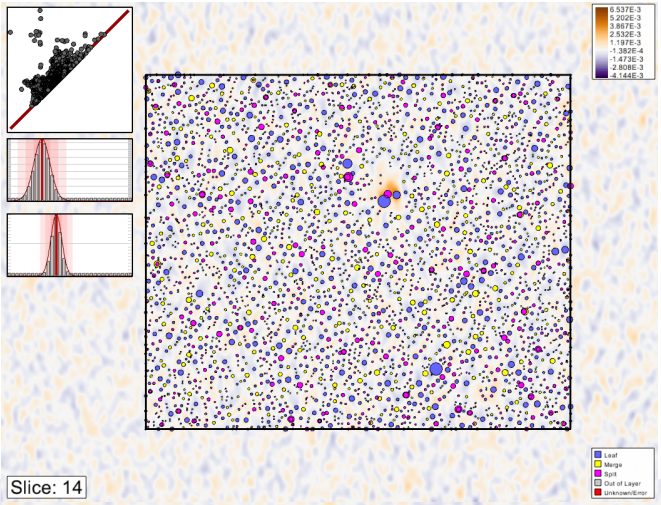

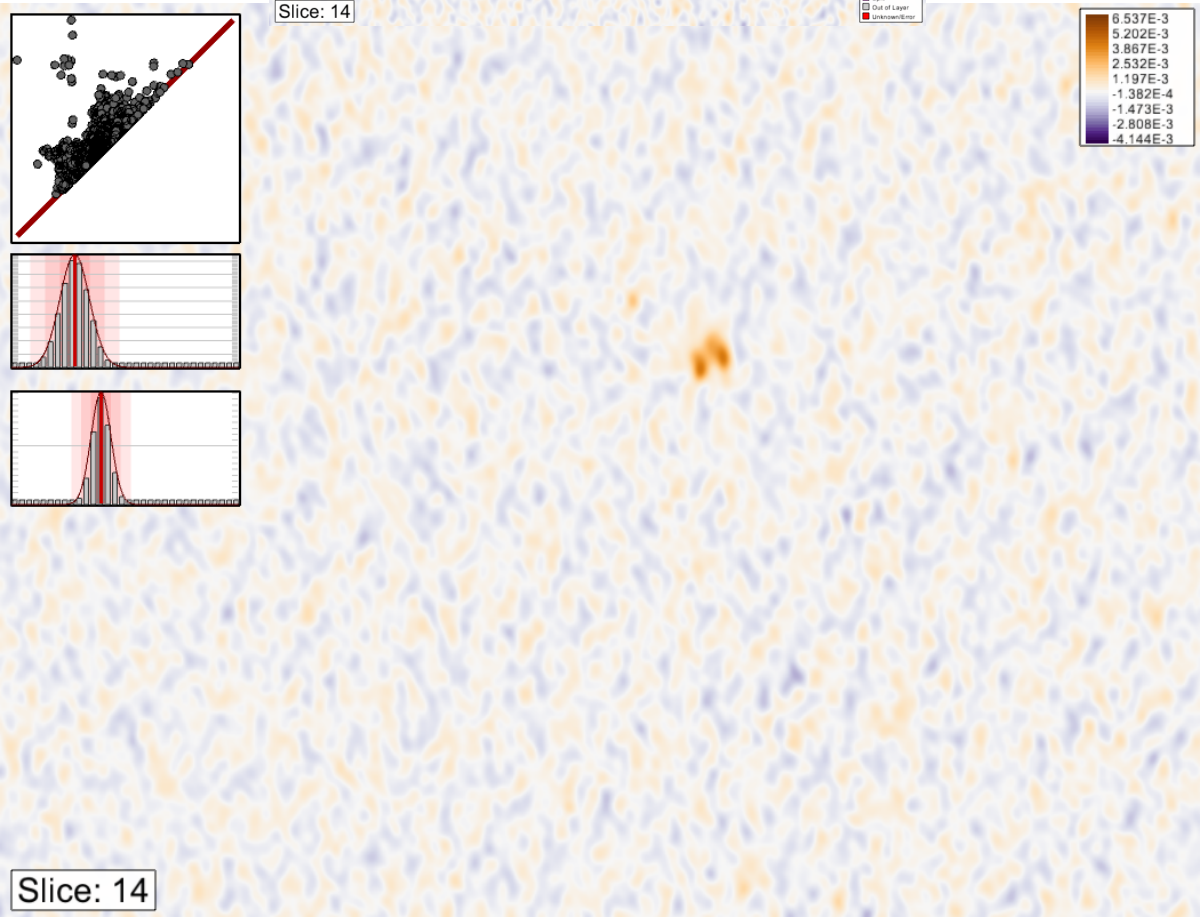

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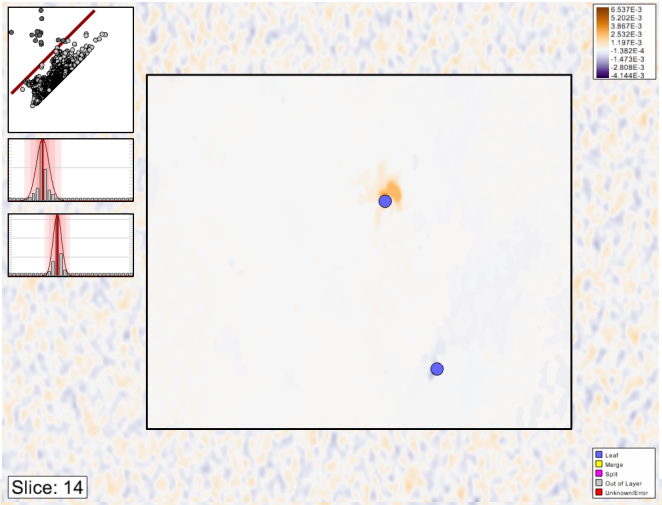

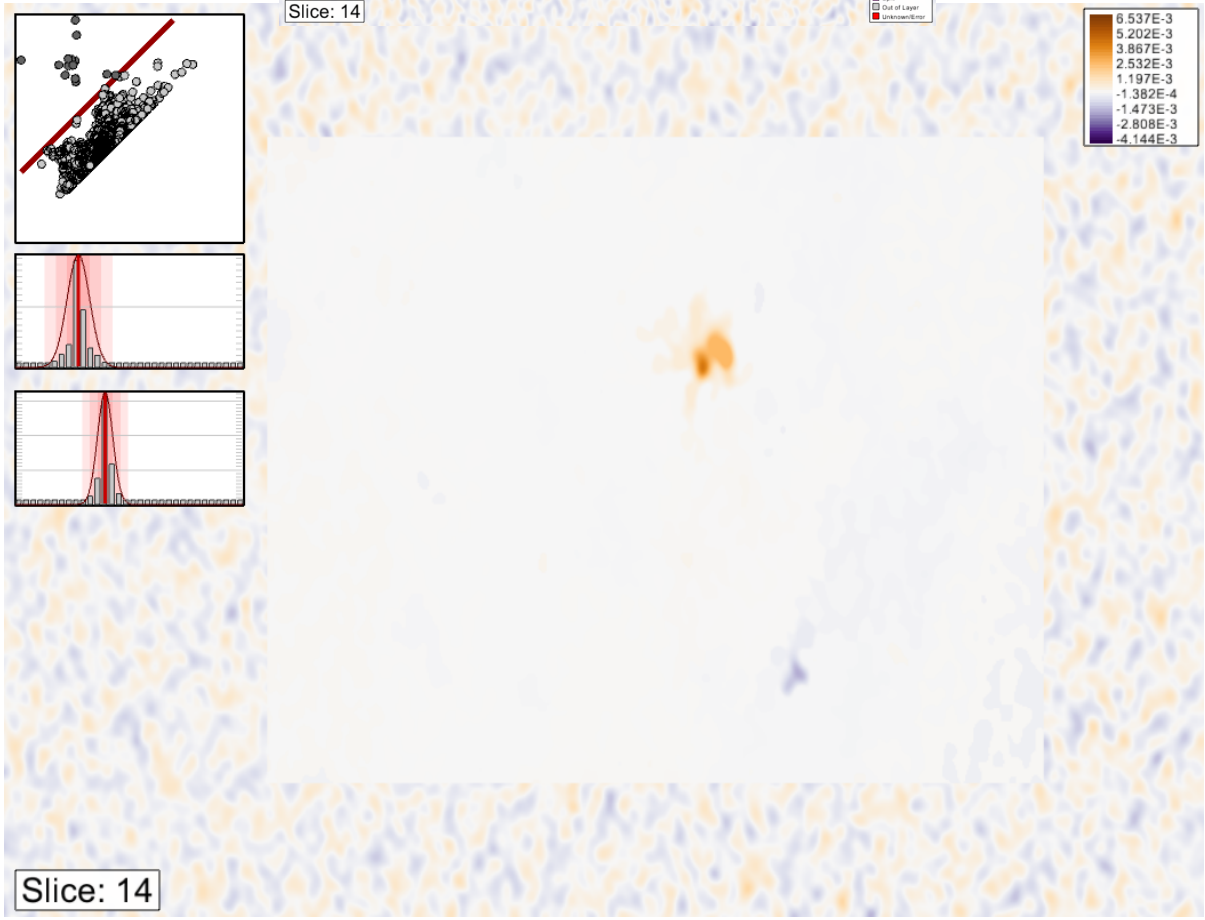

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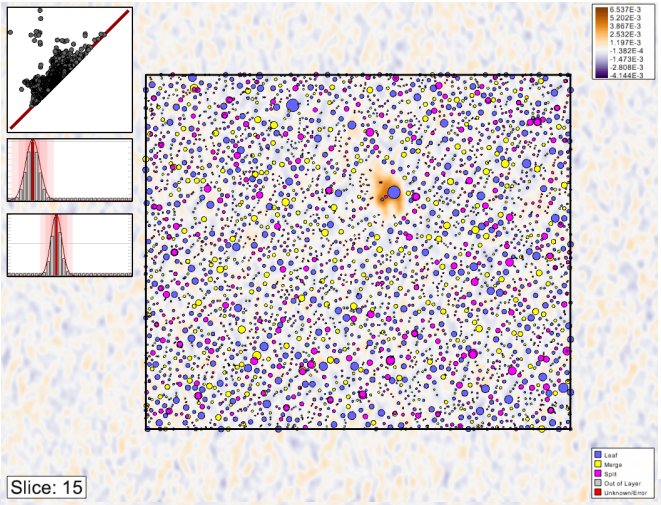

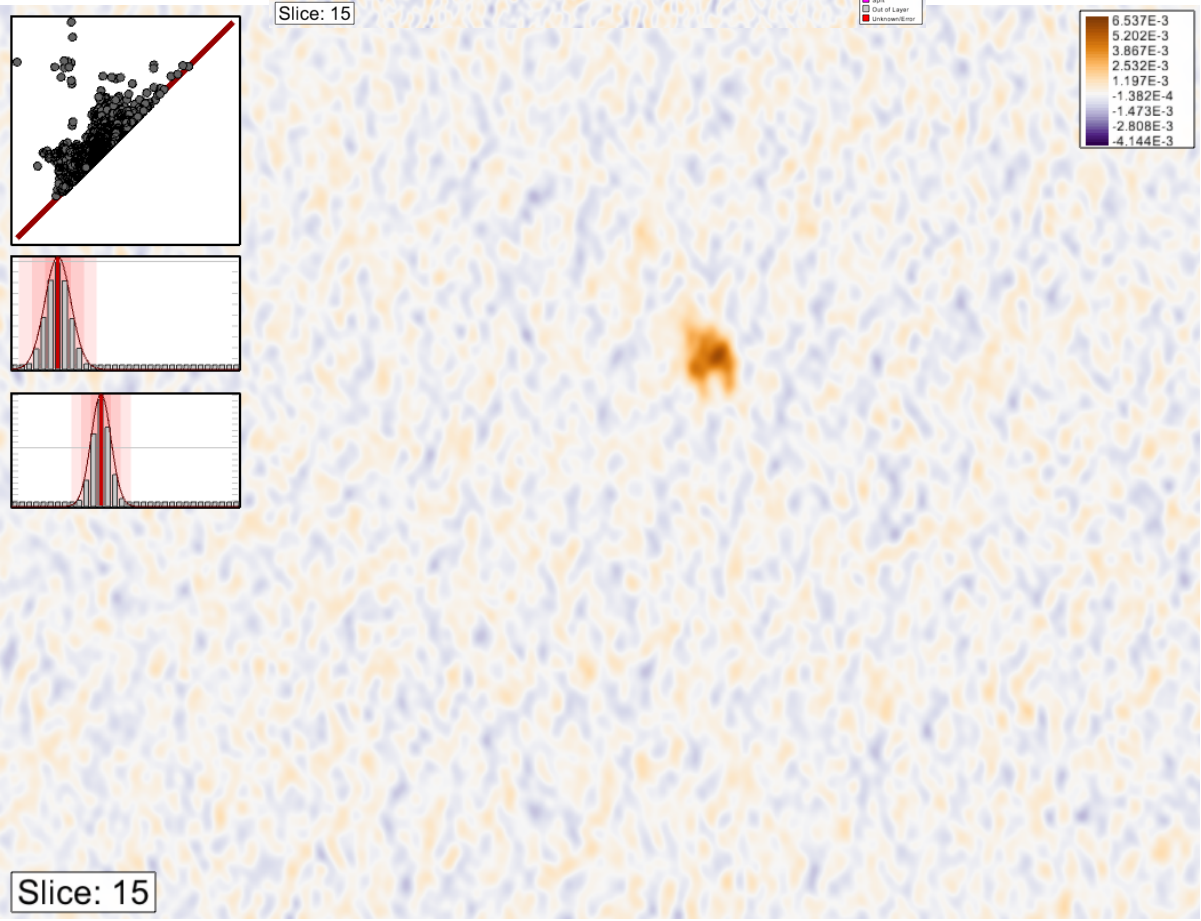

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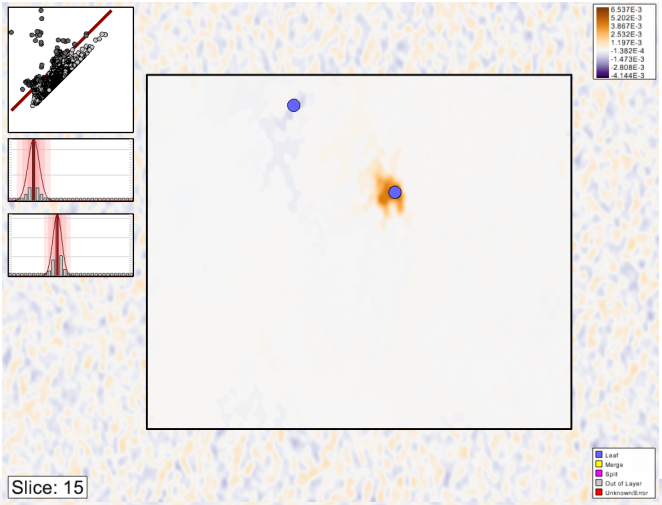

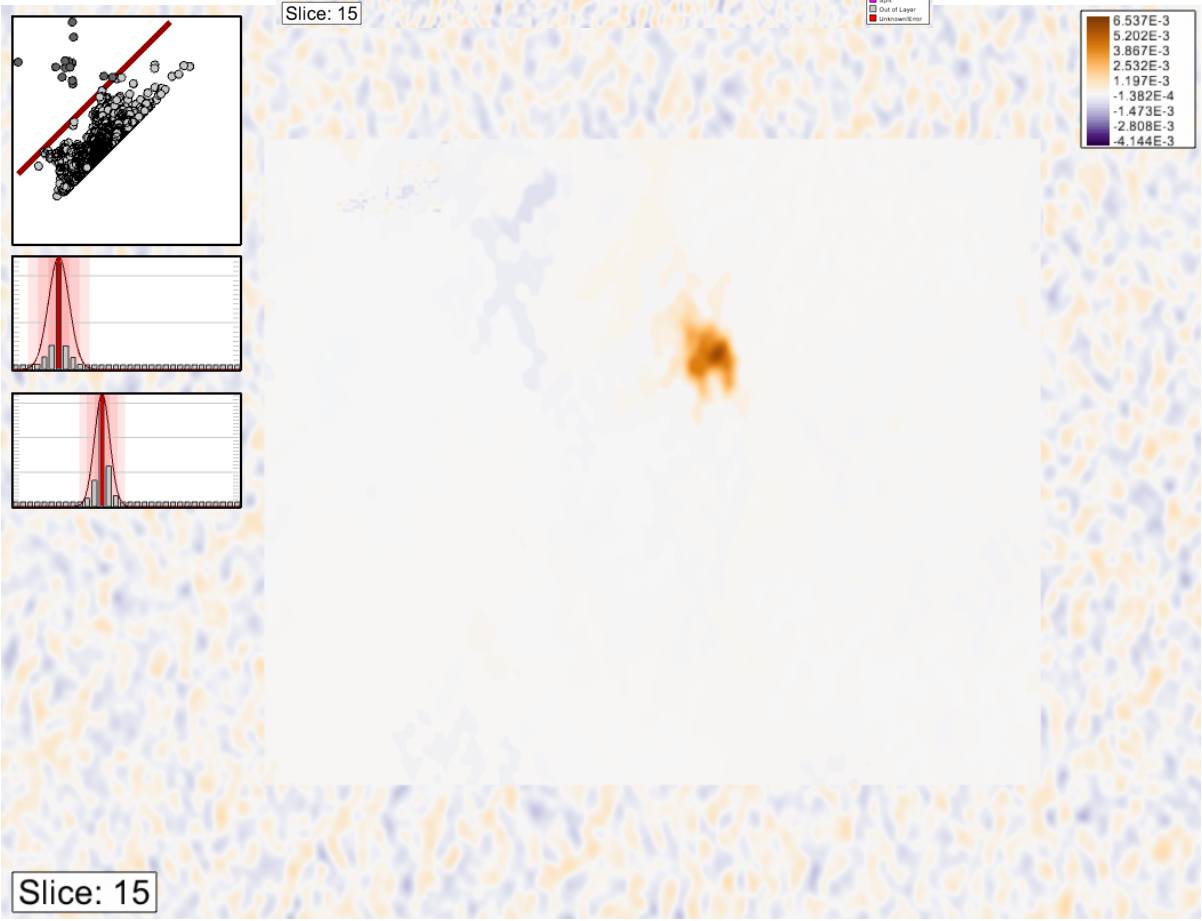

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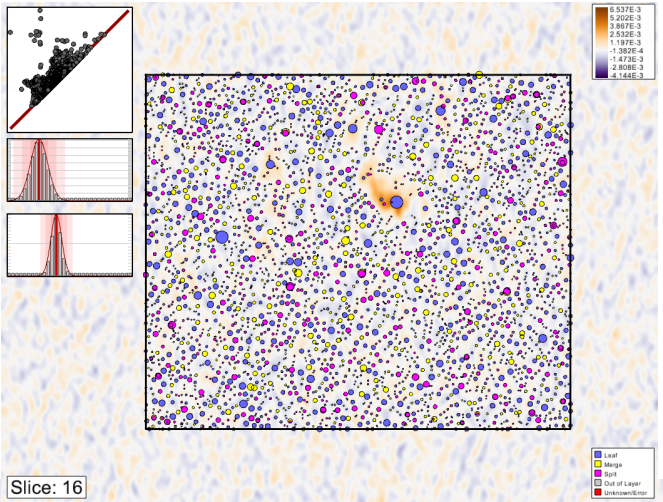

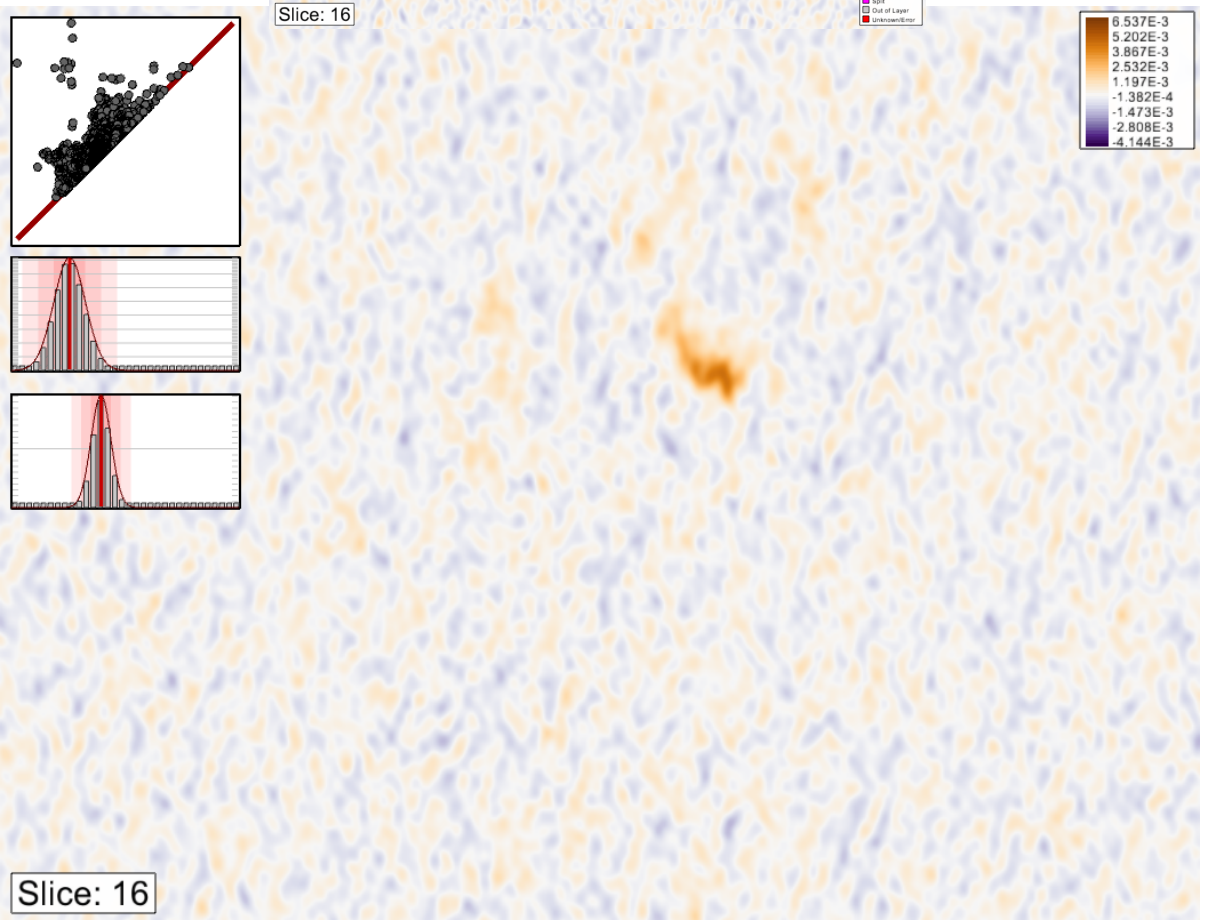

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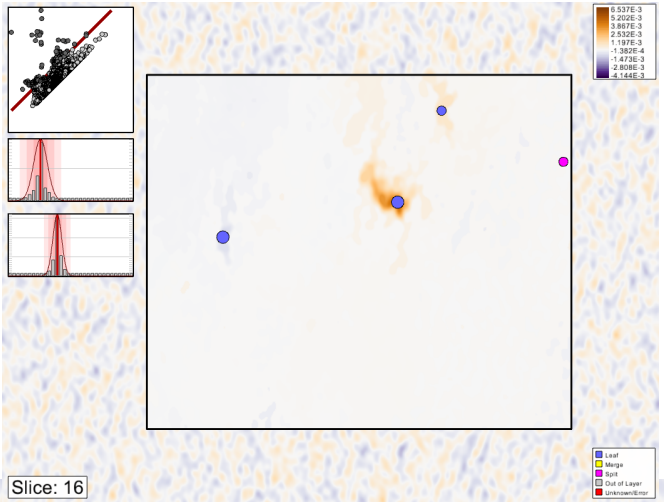

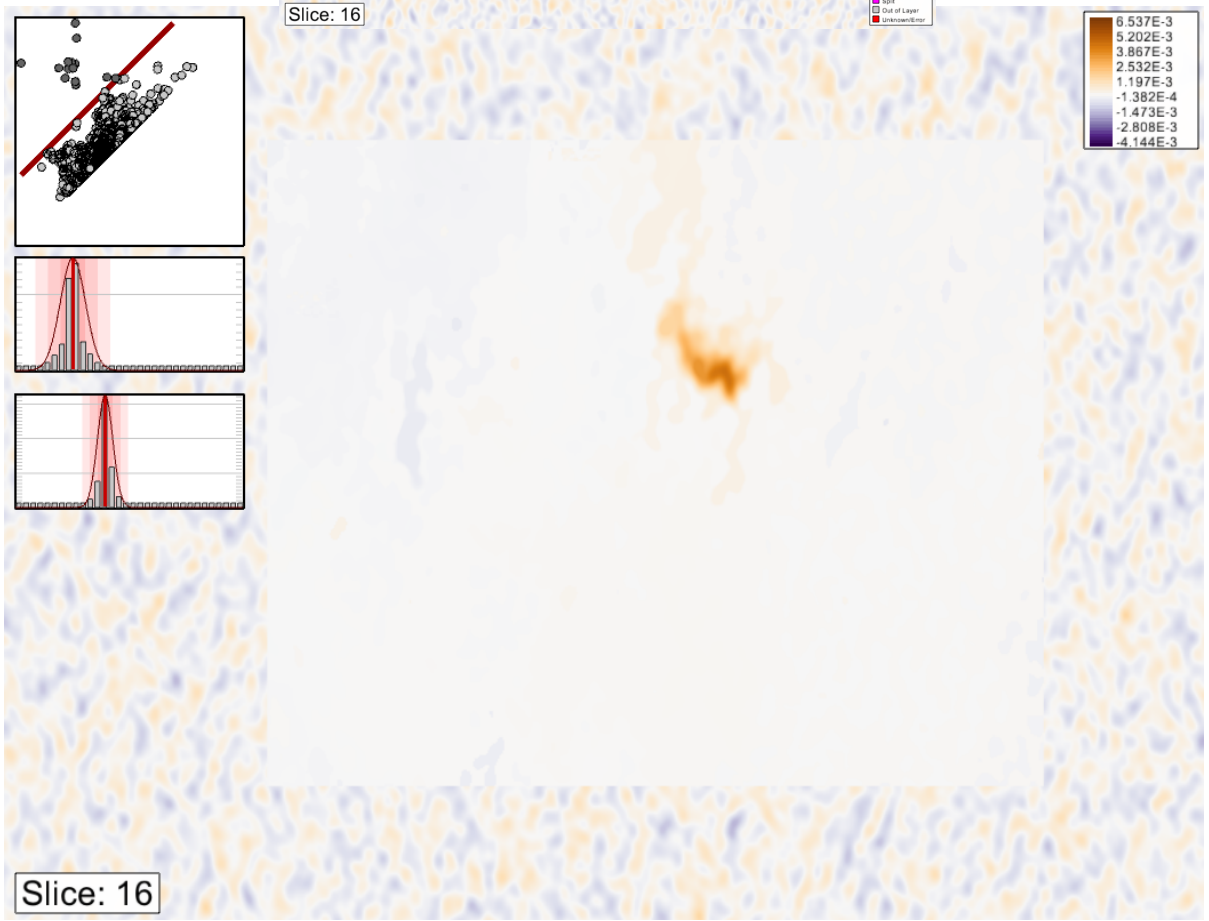

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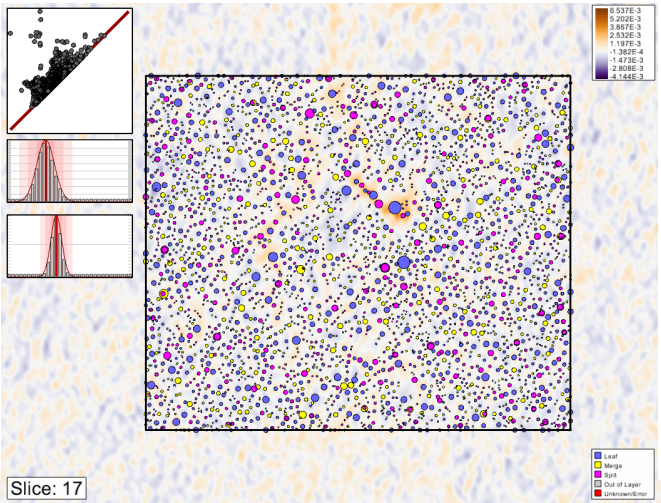

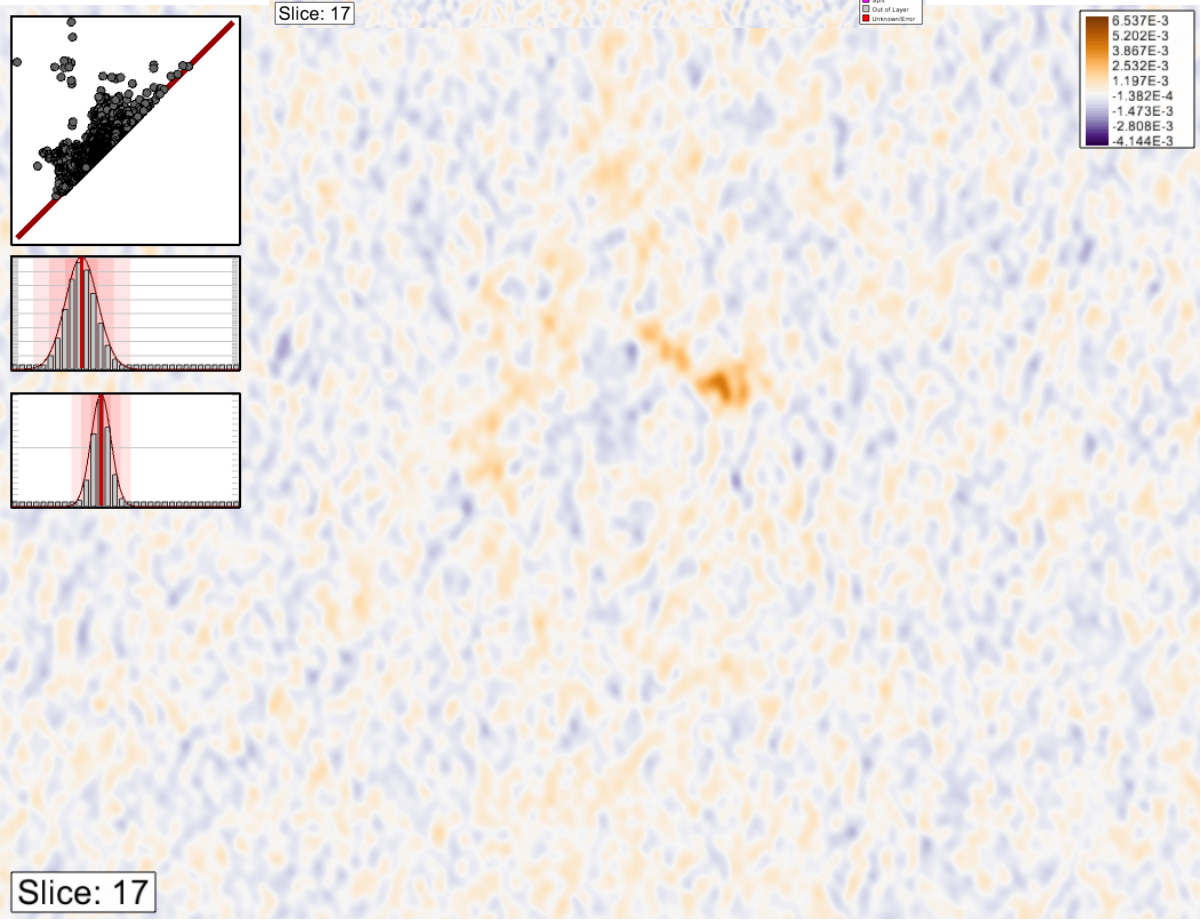

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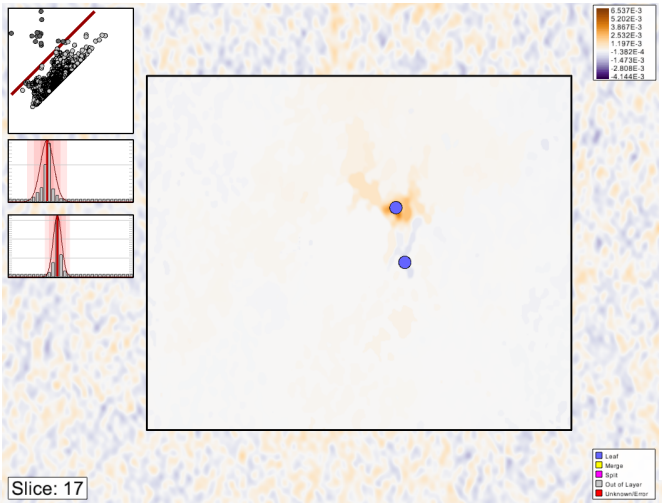

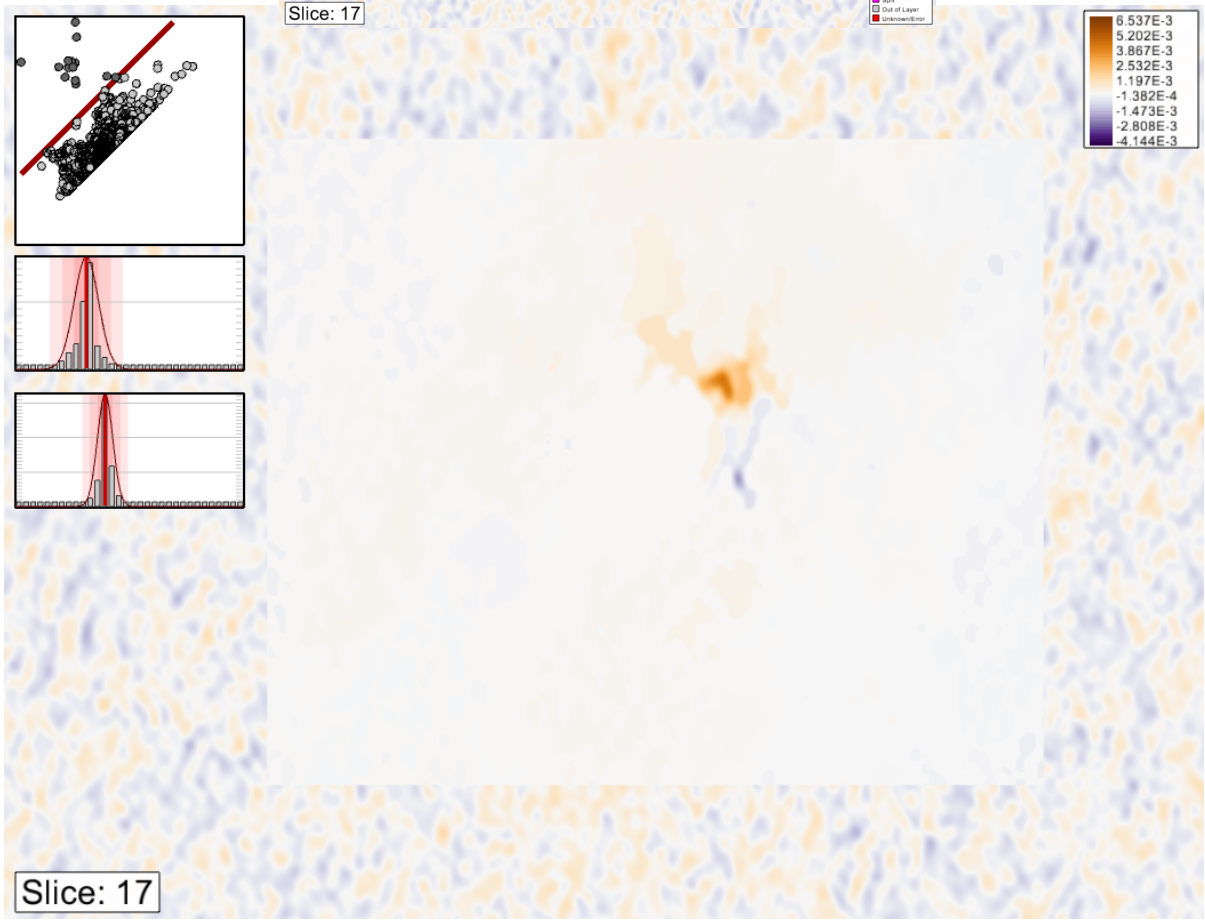

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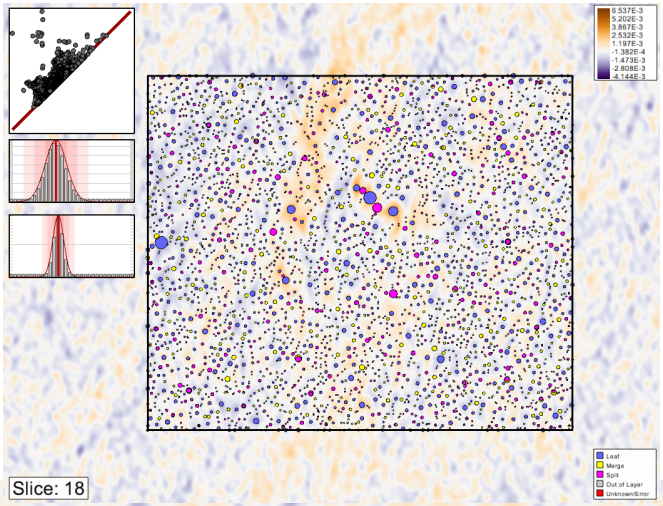

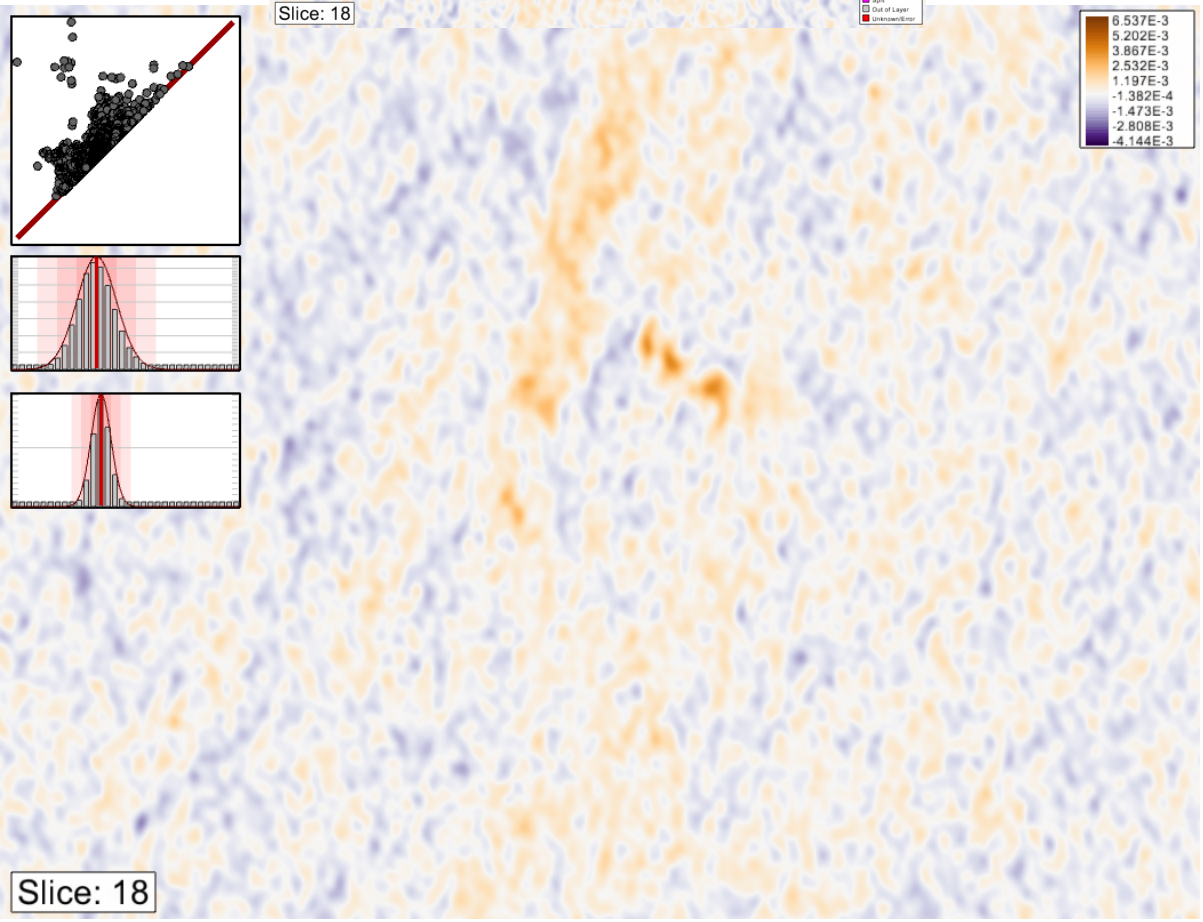

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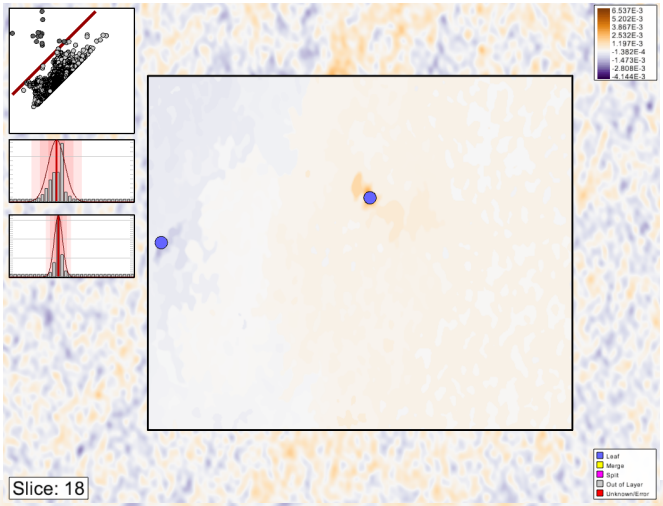

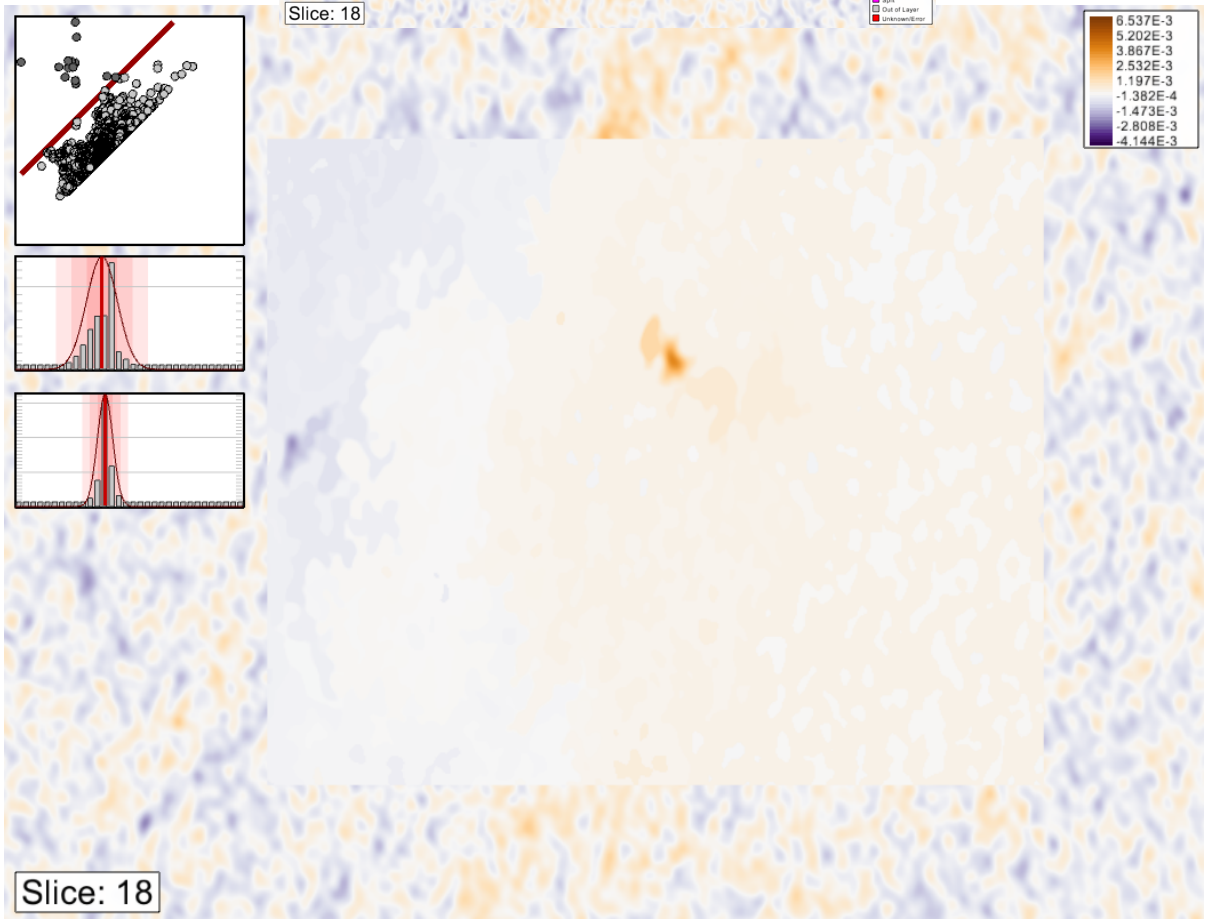

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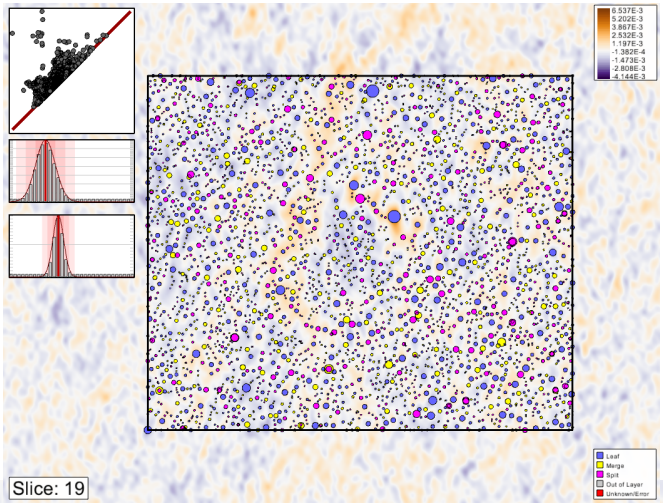

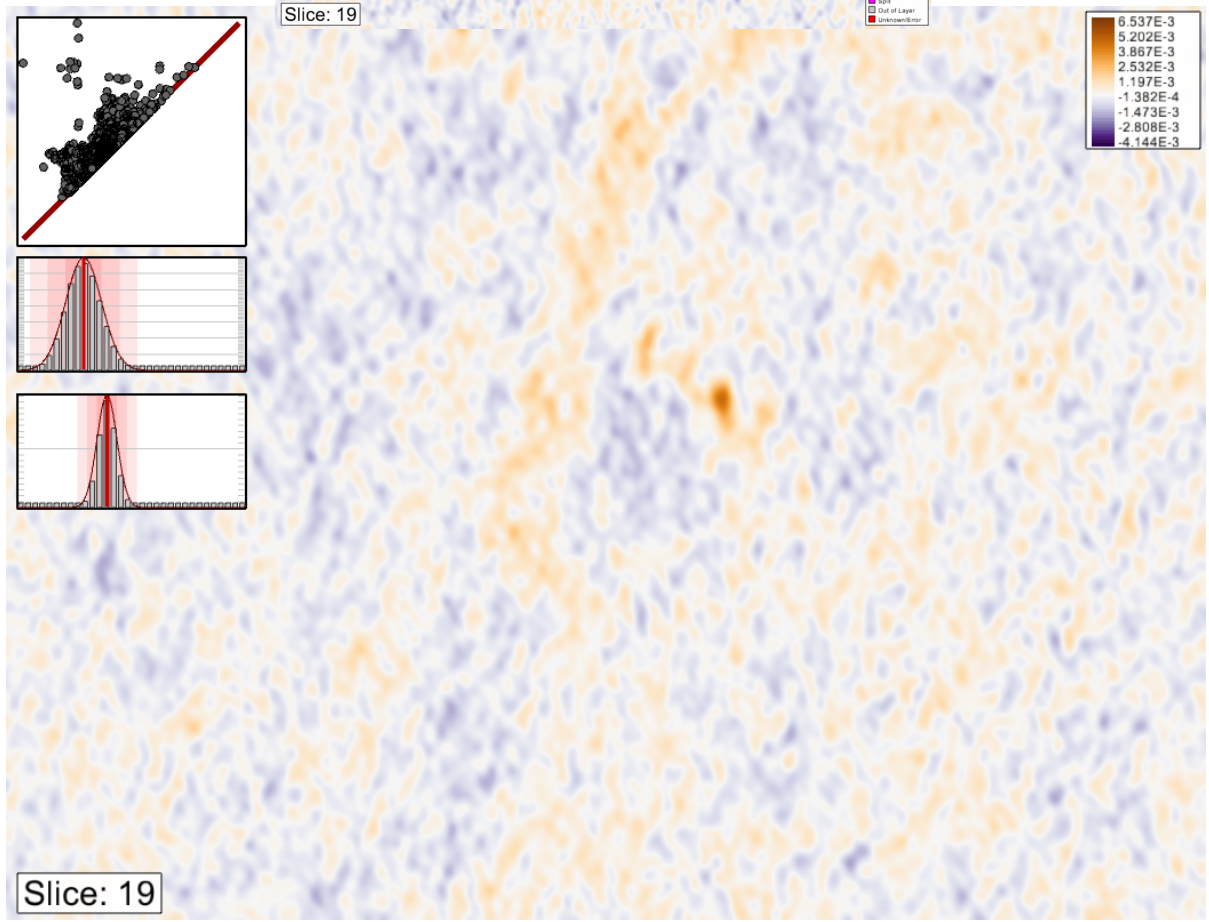

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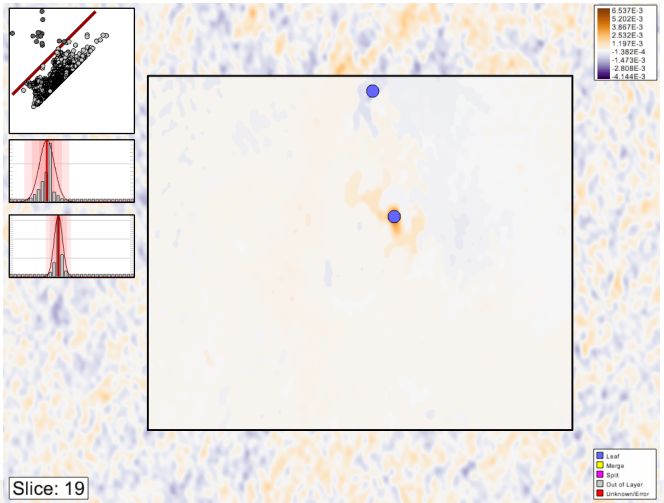

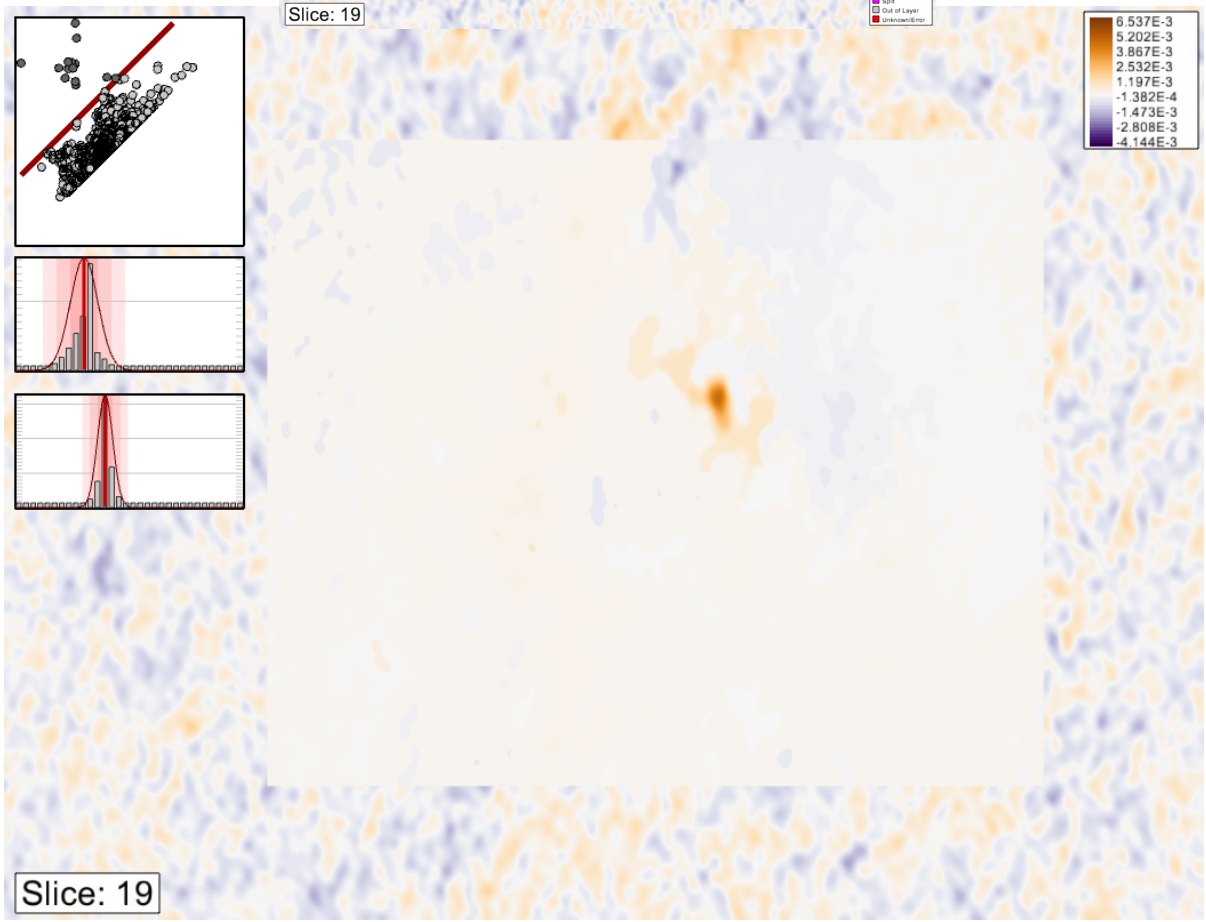

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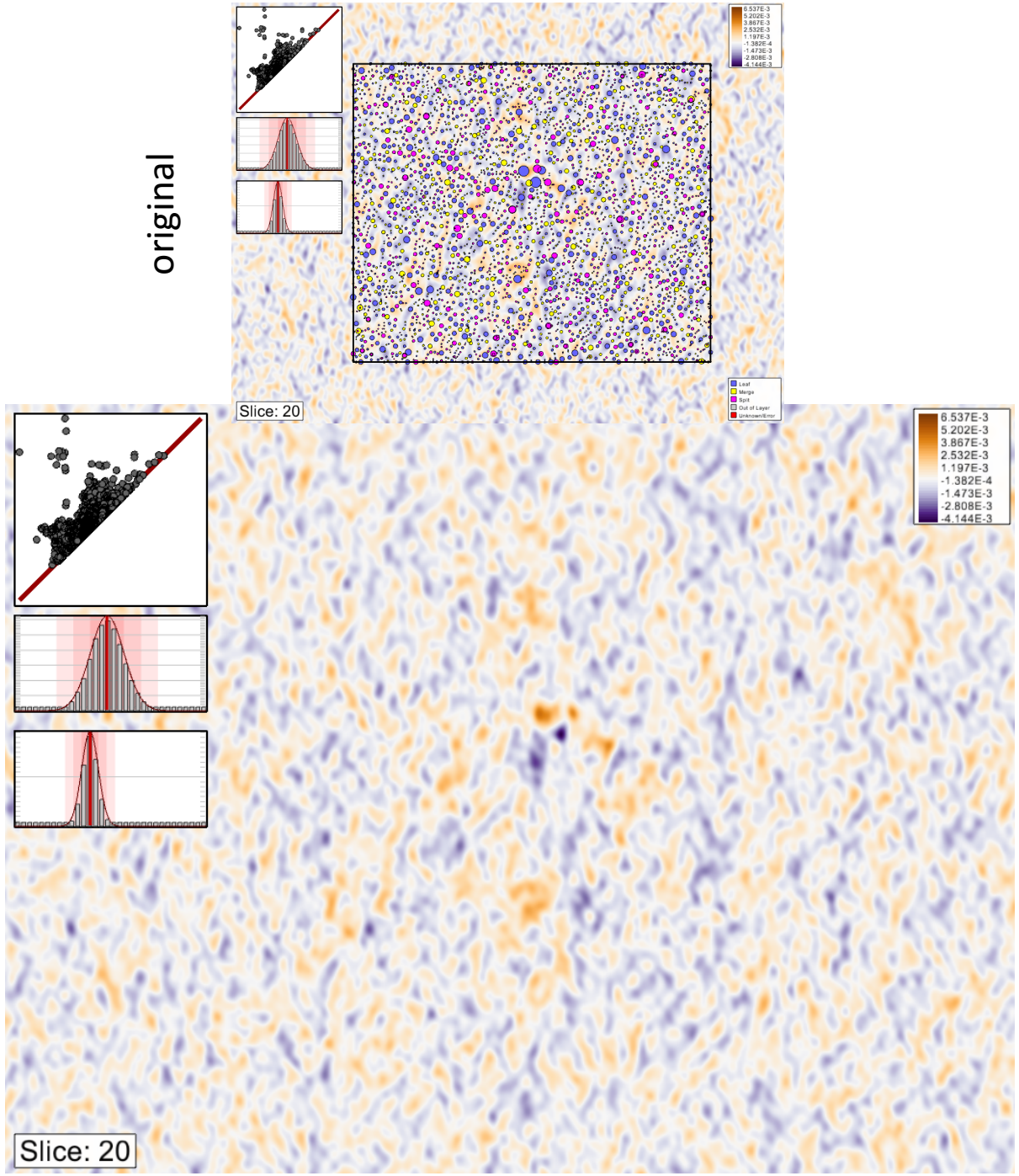

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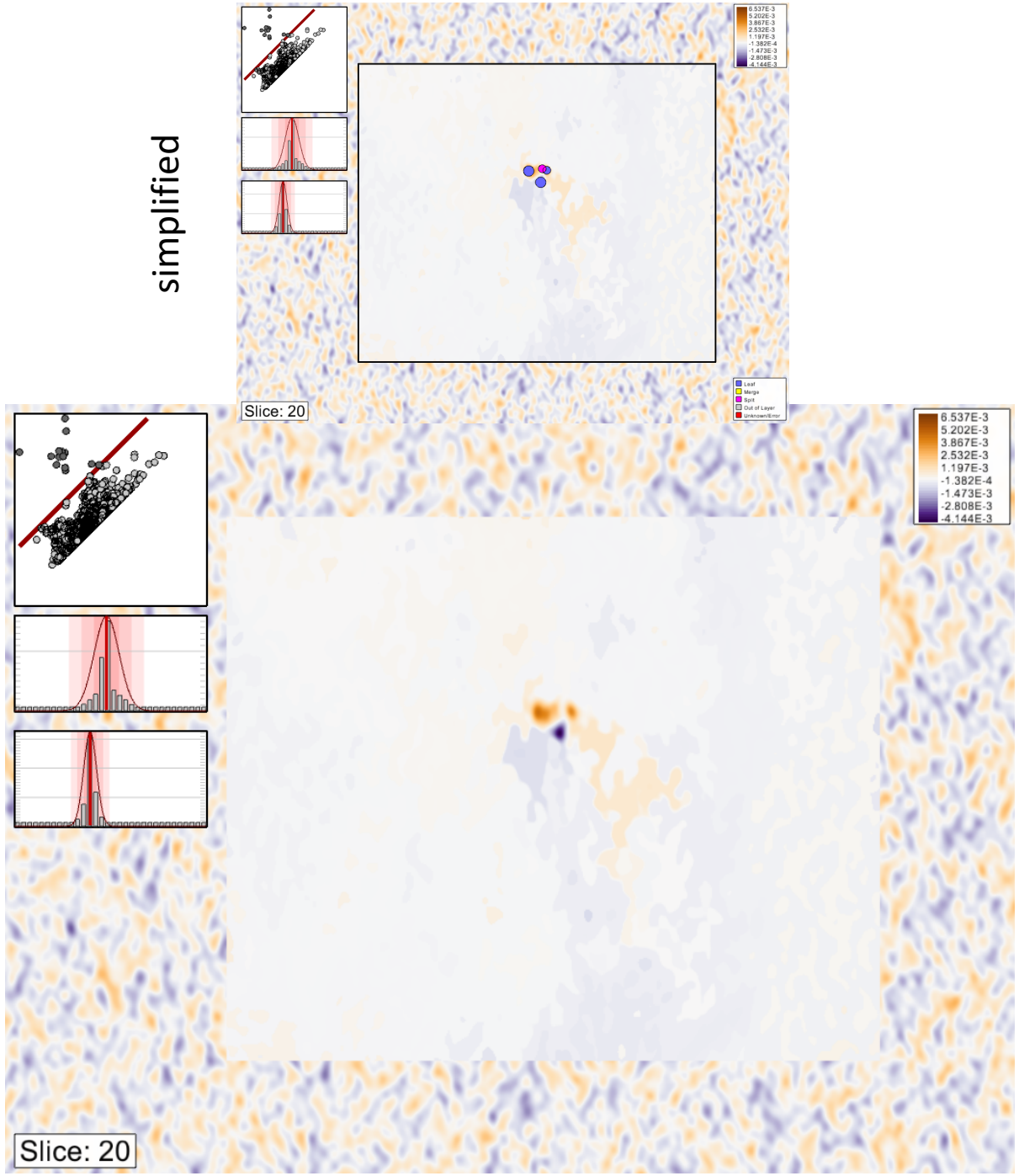

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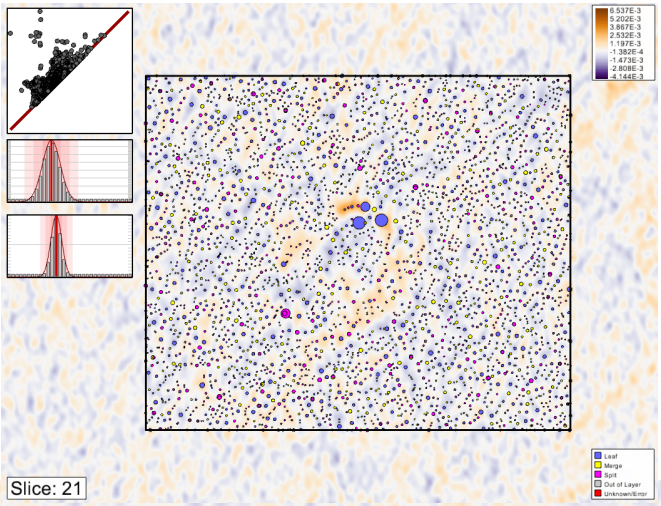

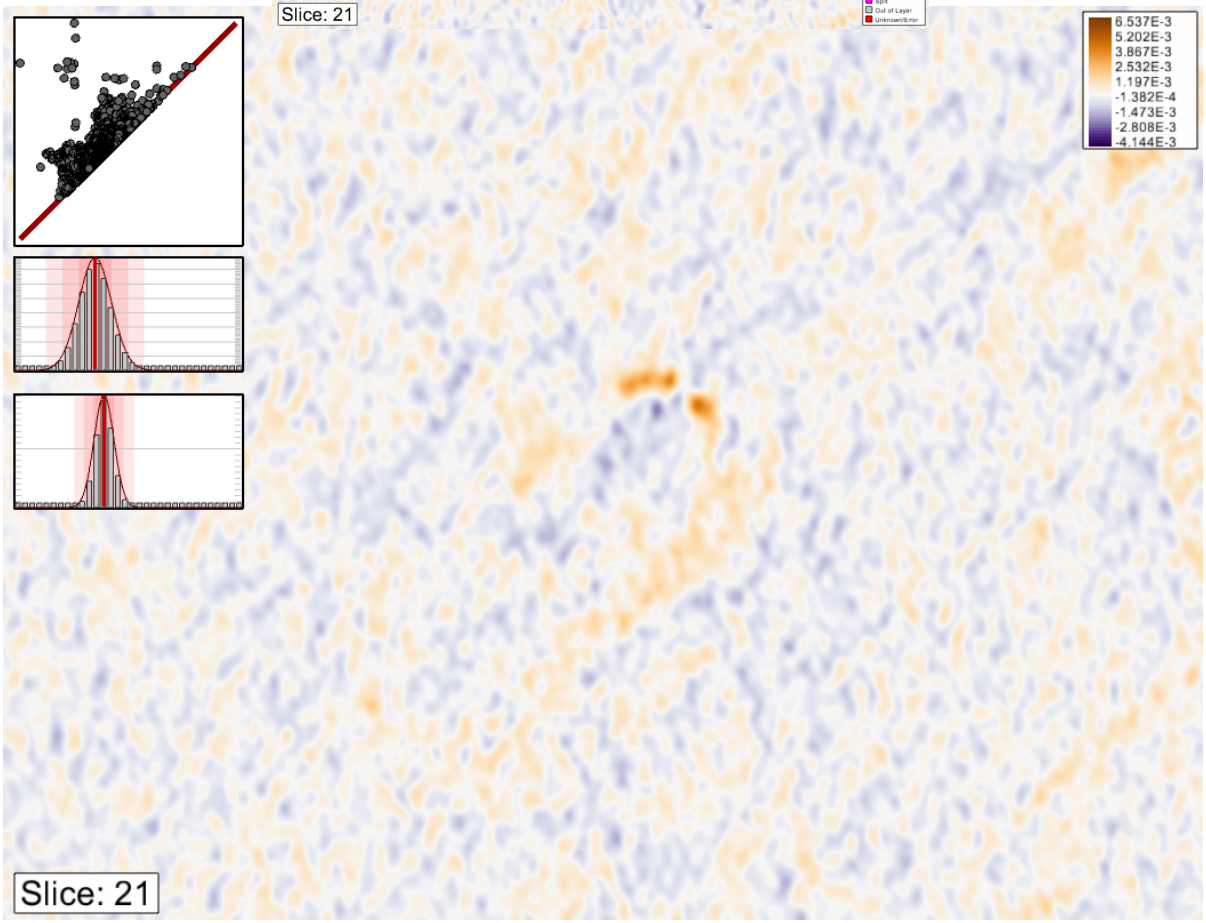

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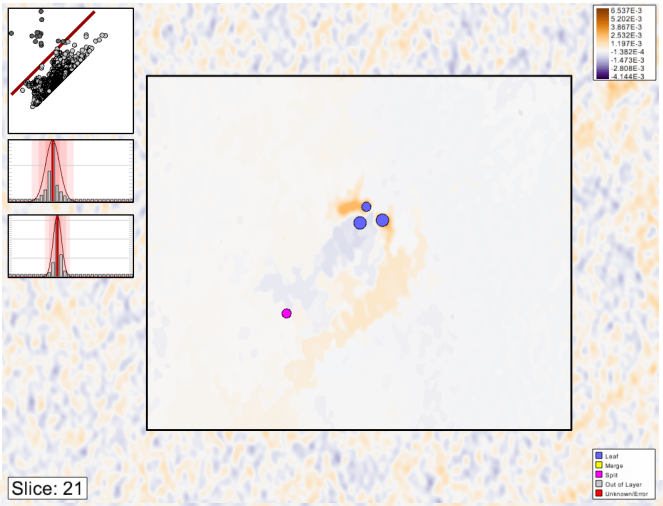

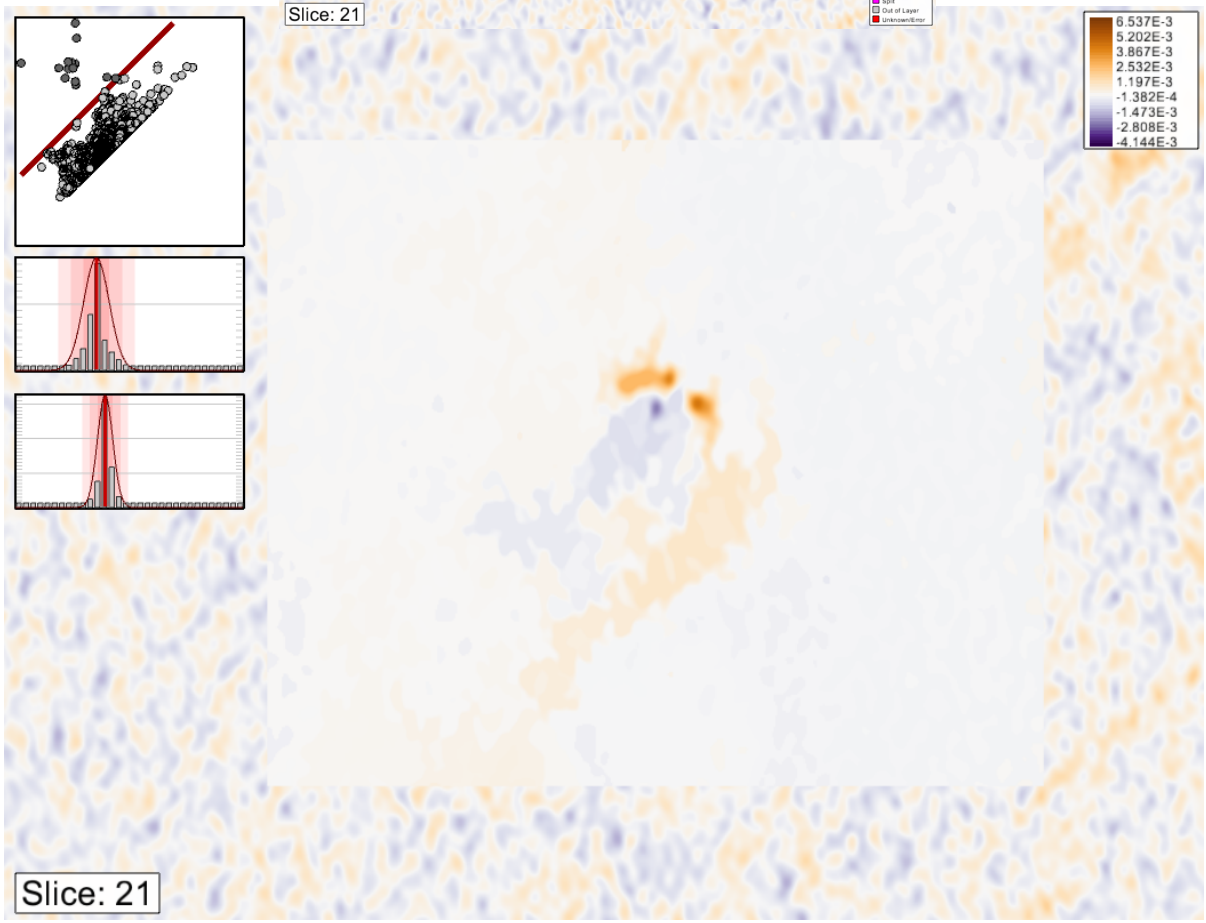

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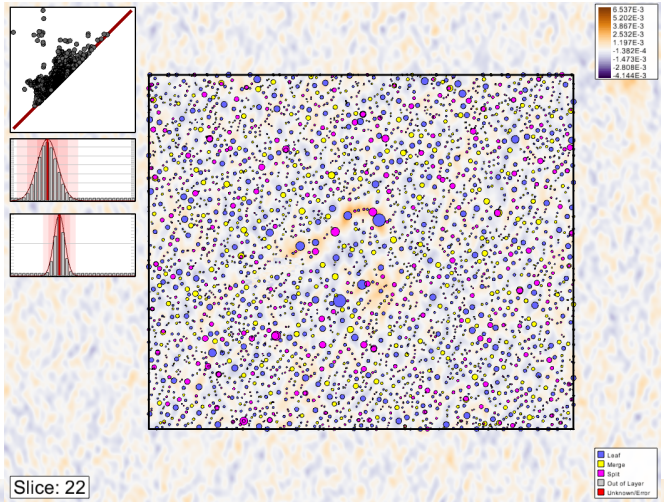

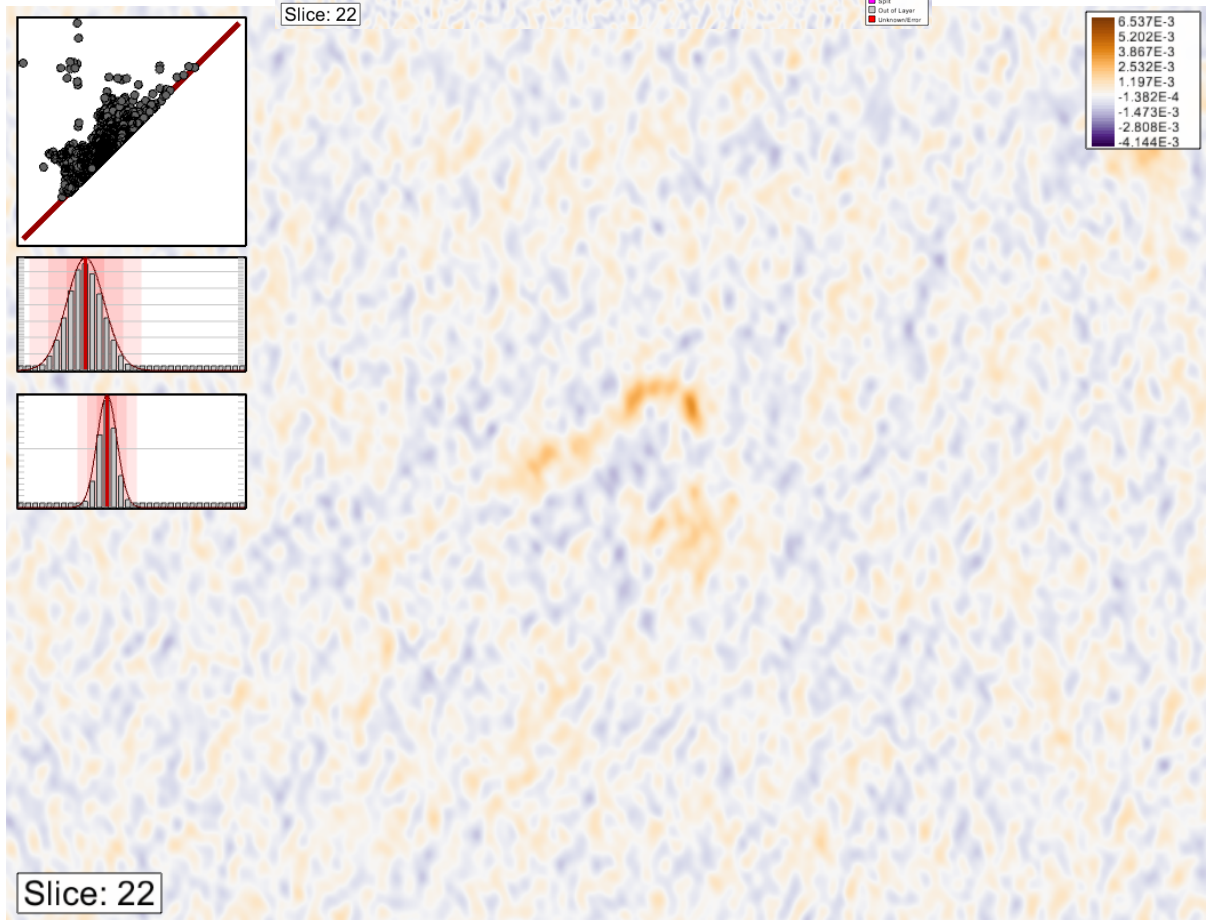

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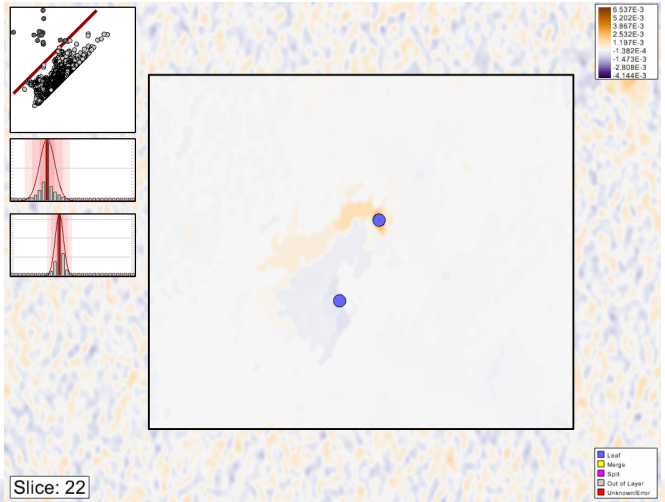

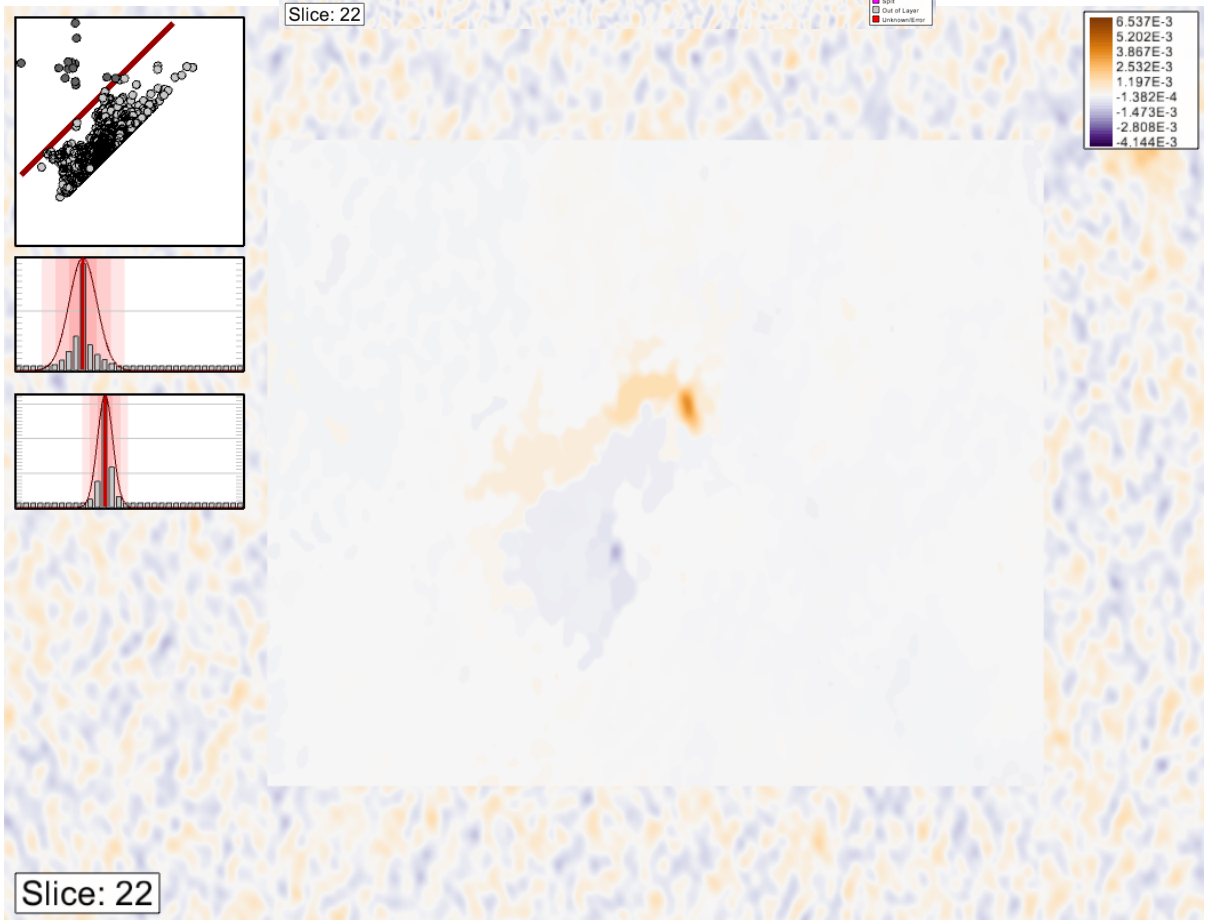

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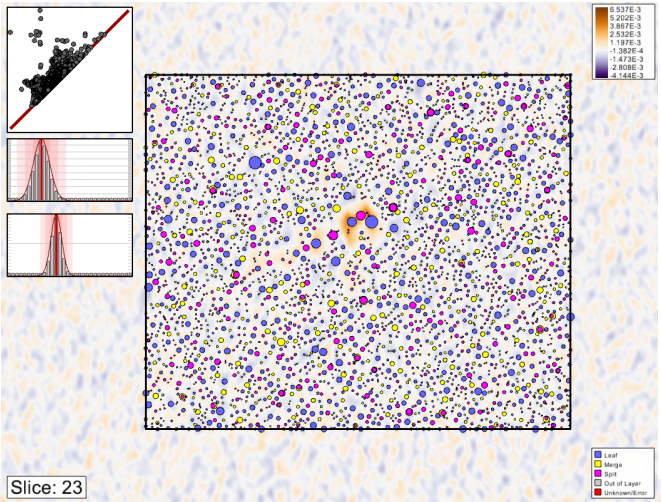

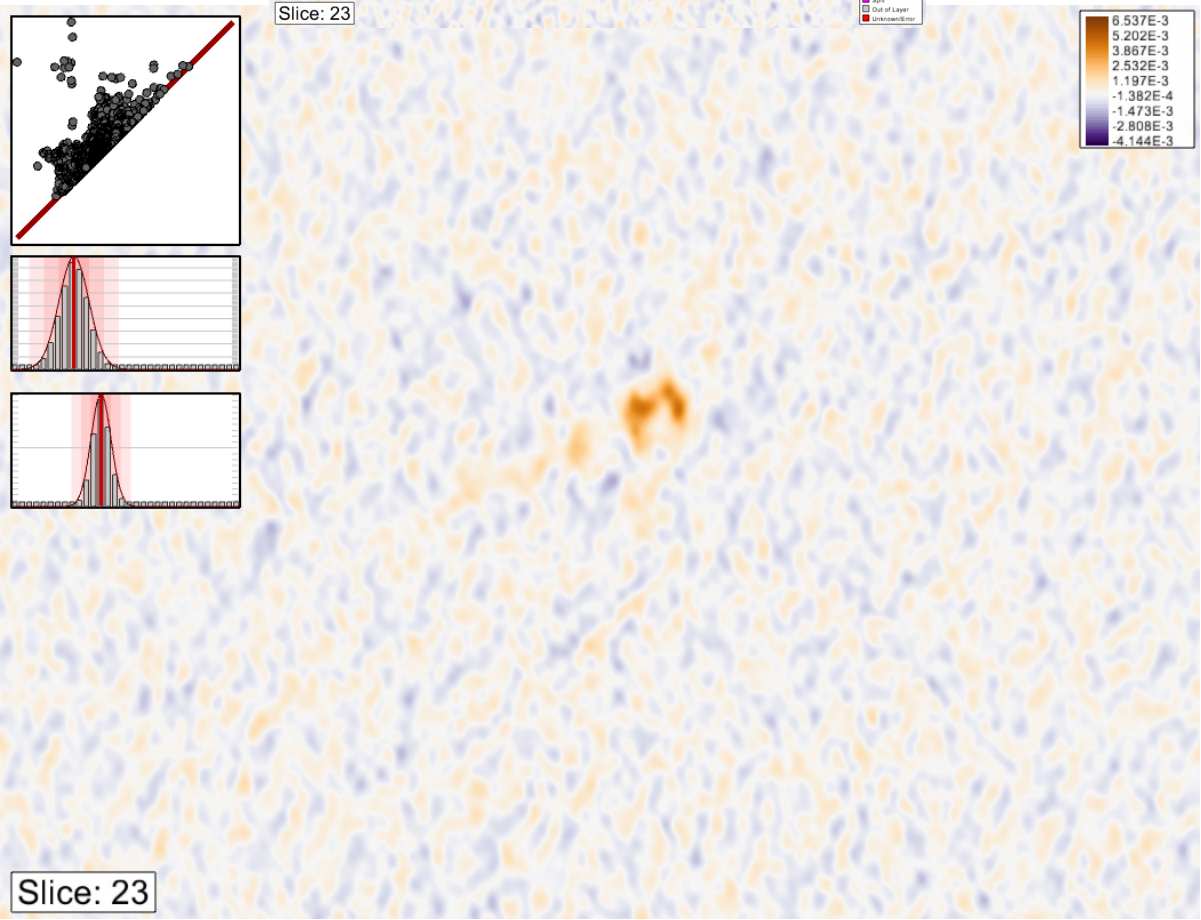

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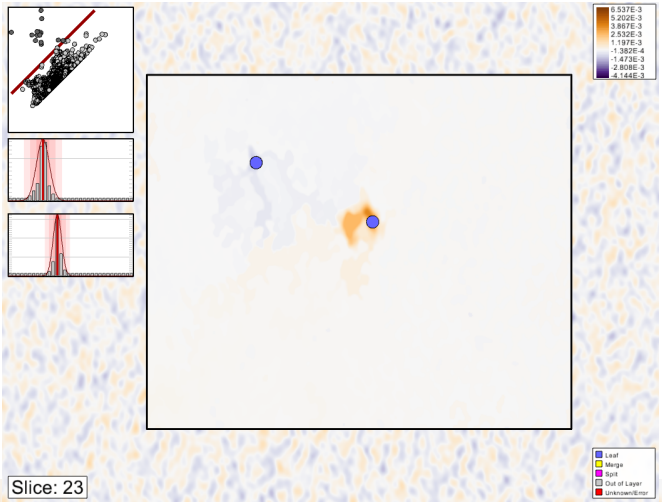

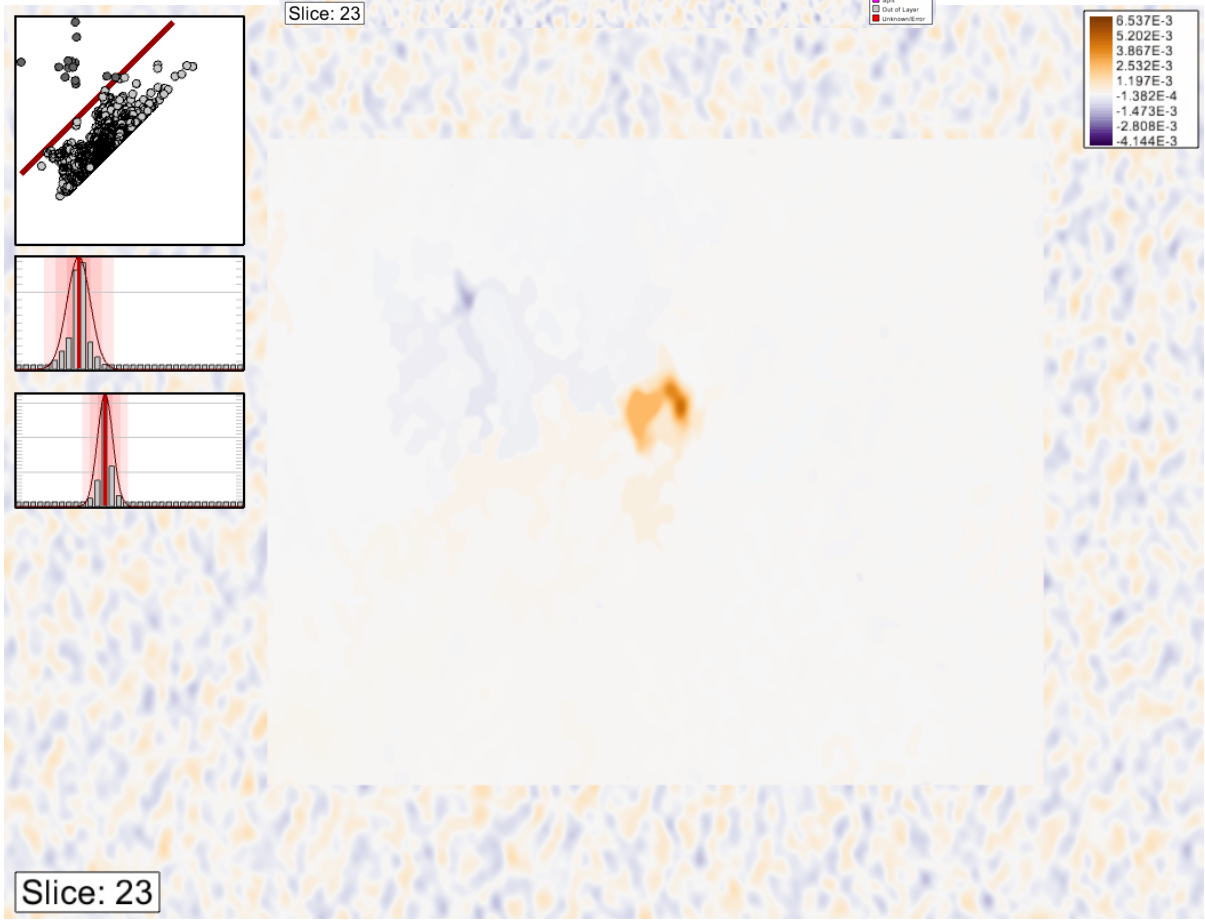

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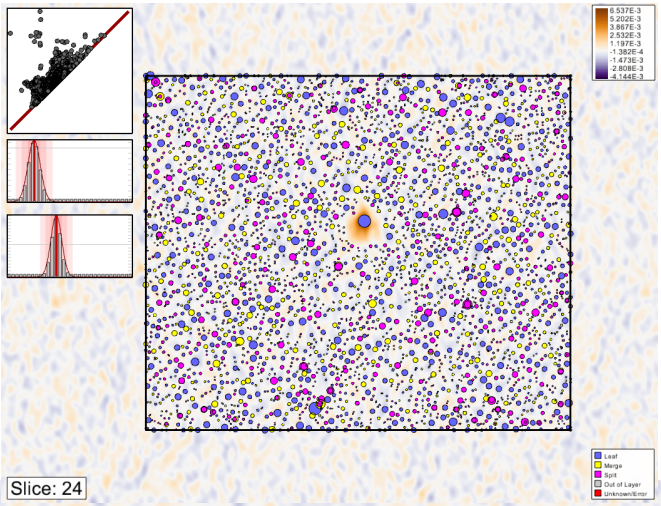

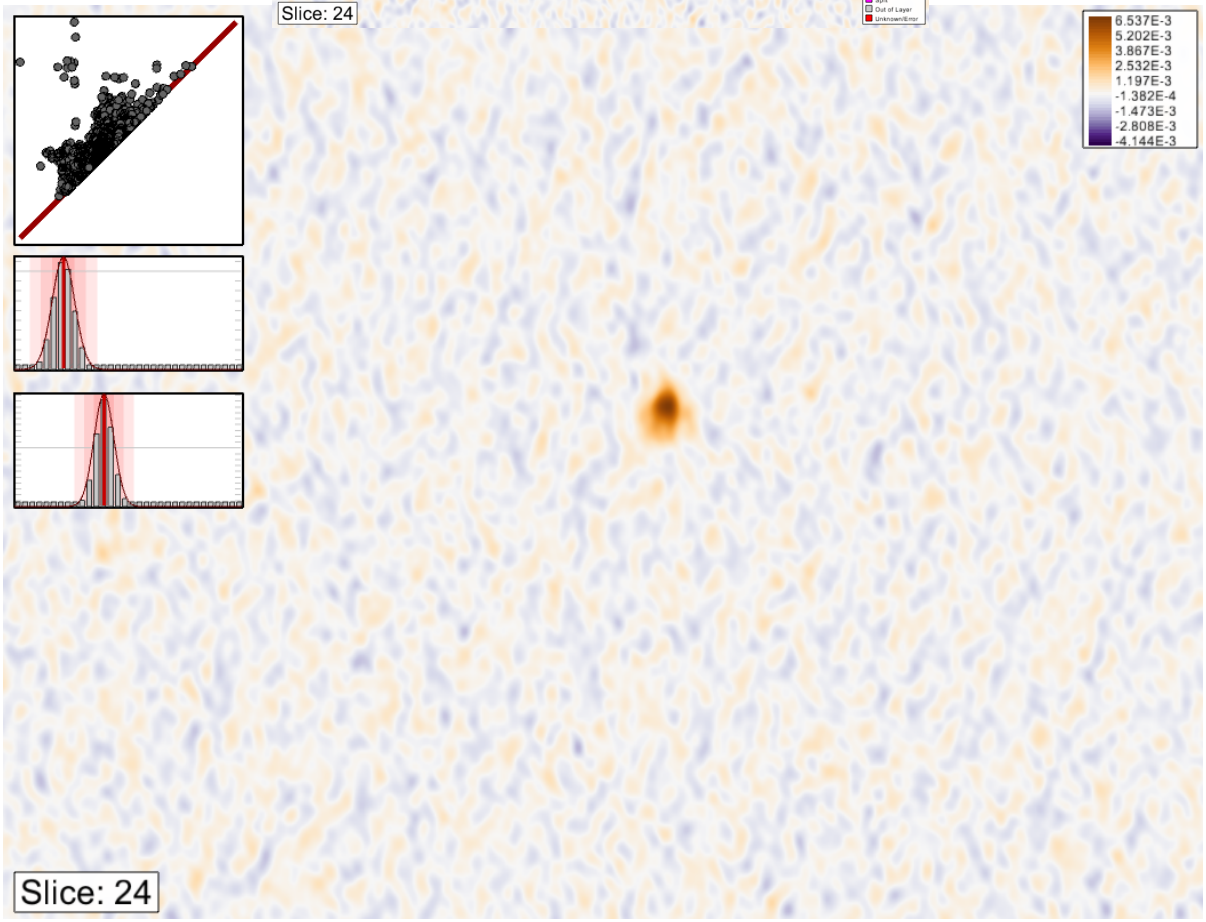

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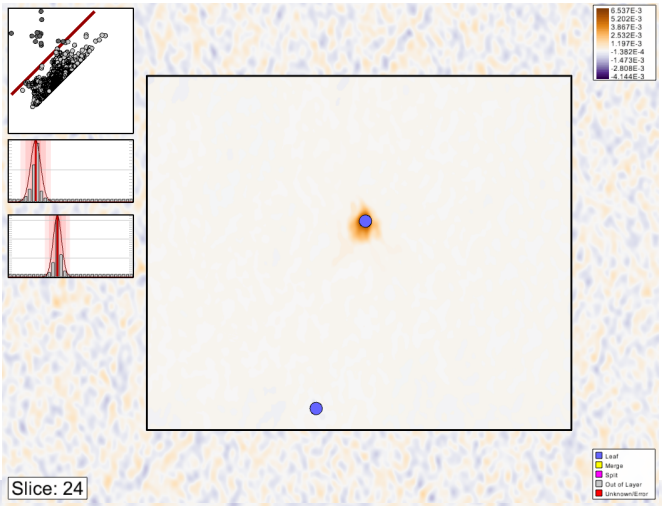

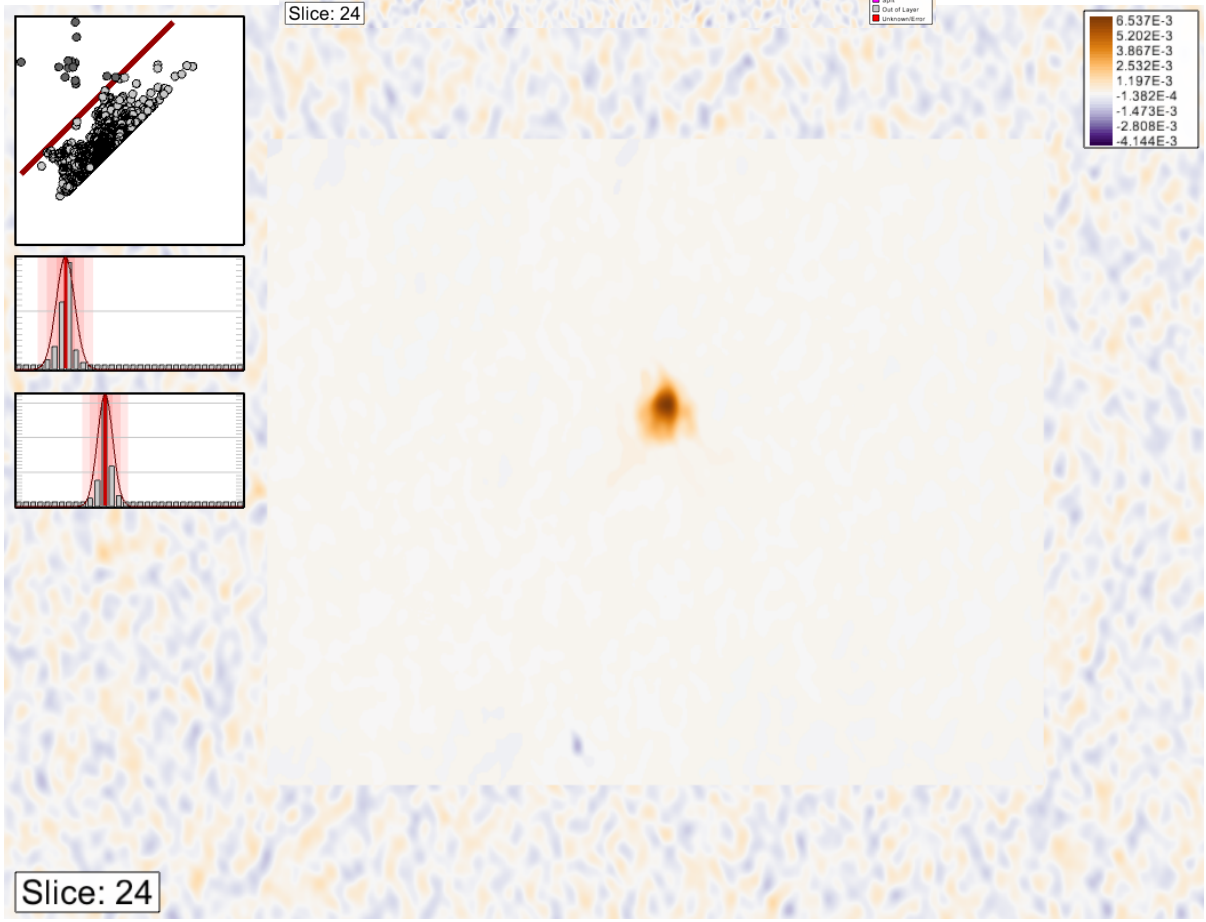

Moment 0 Analysis

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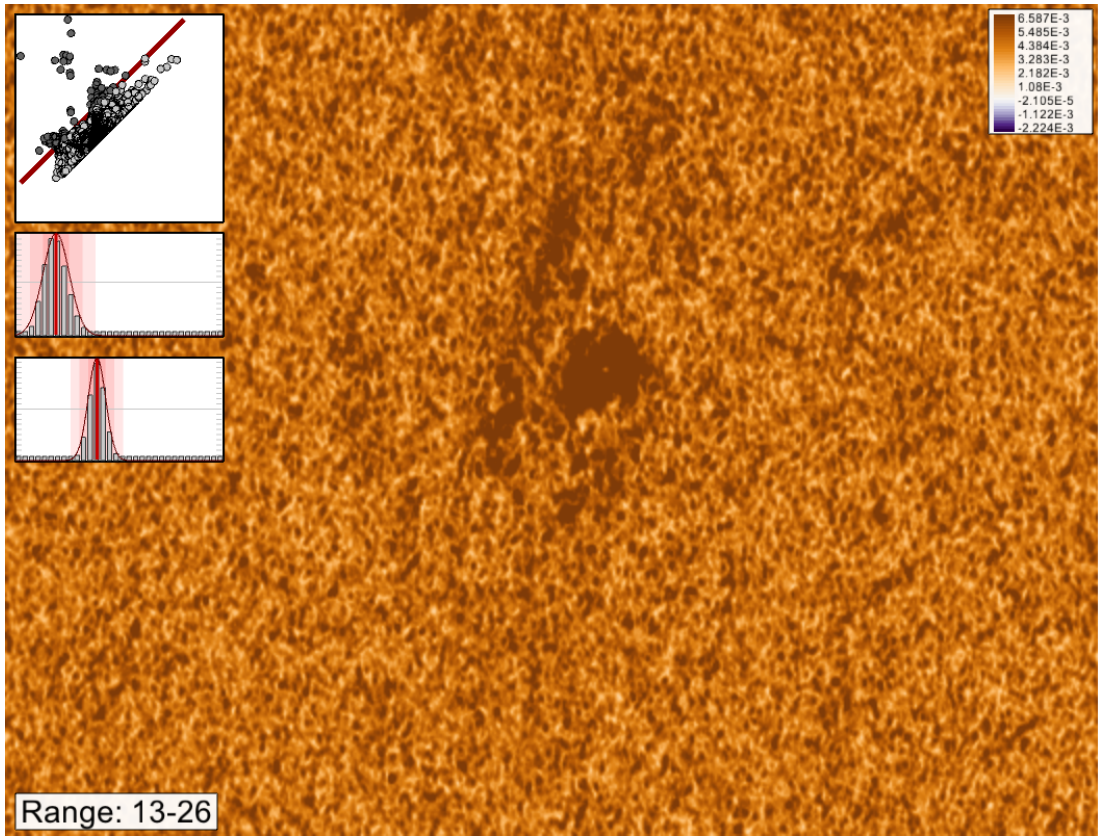

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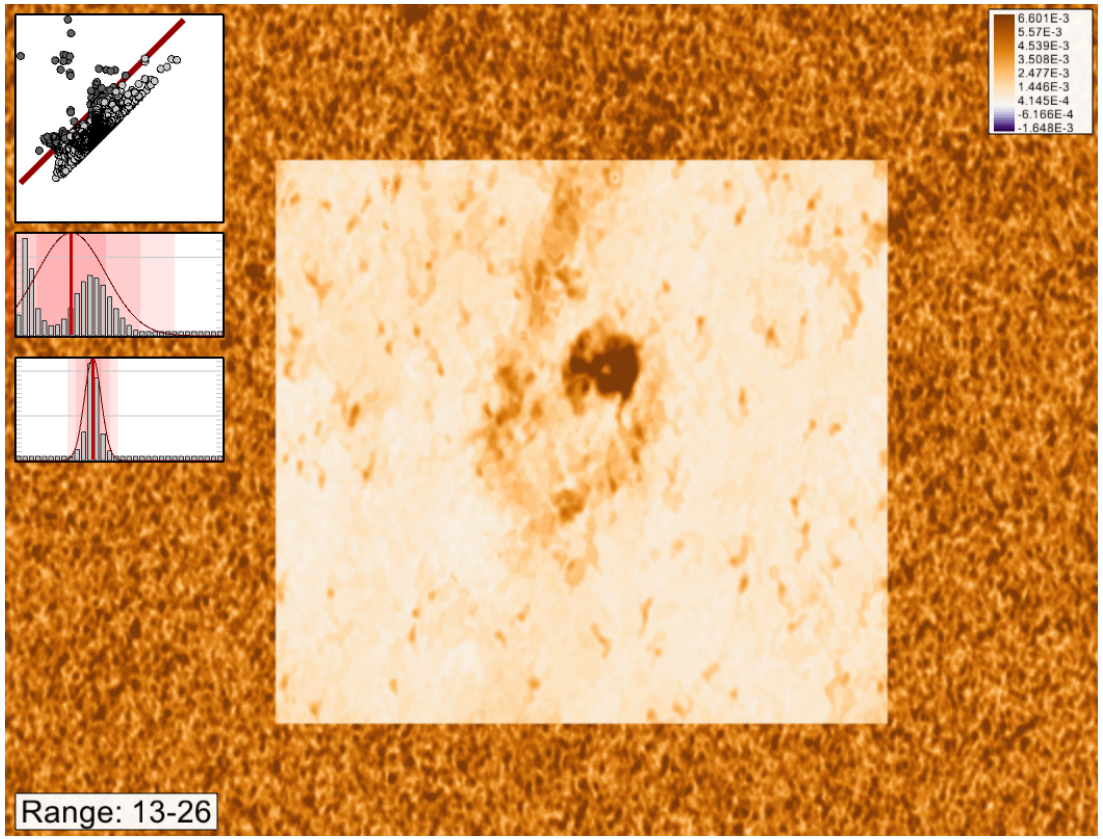
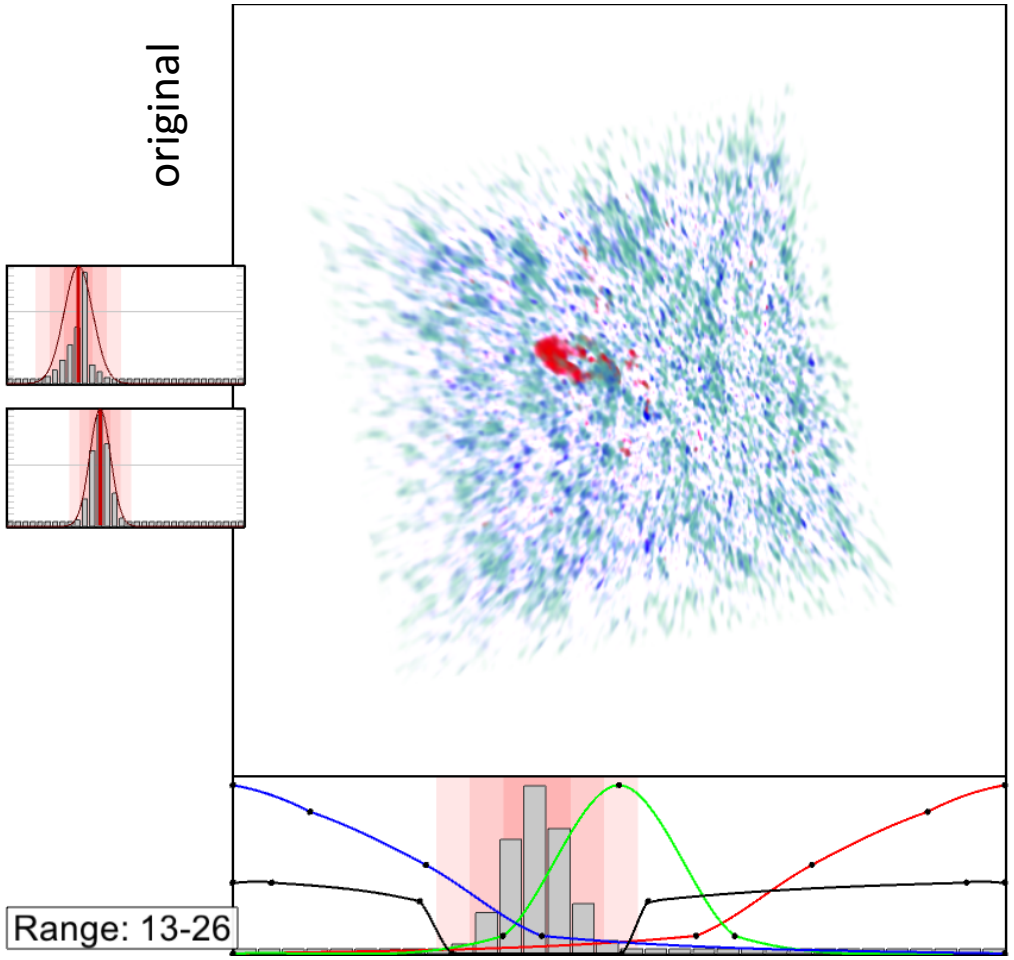


Volume Rendered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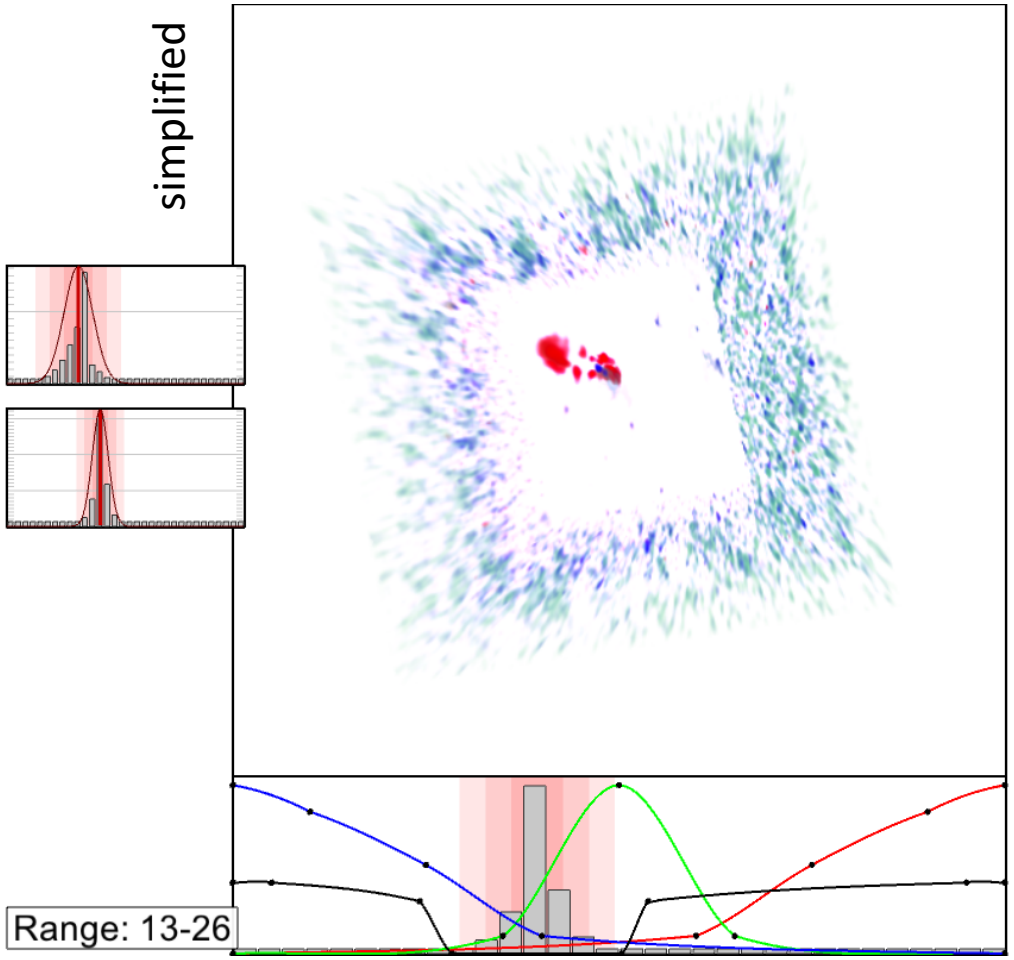
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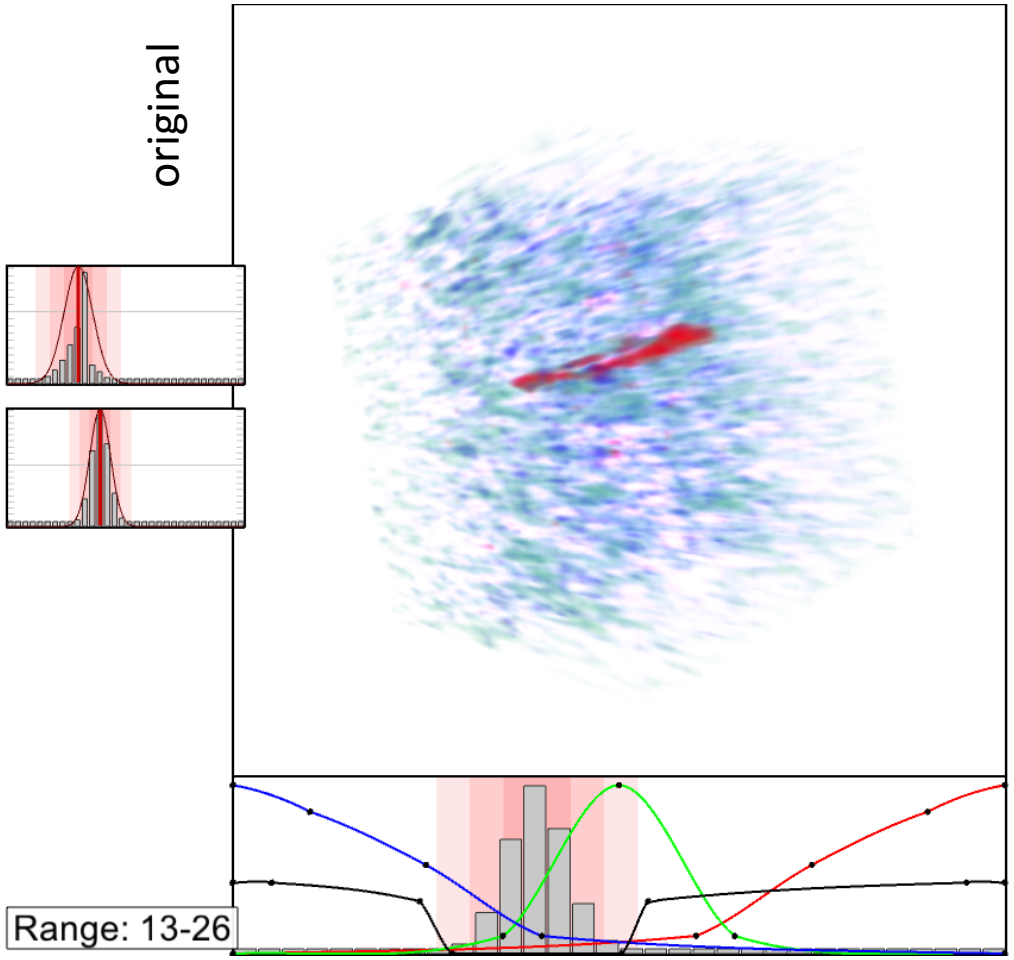
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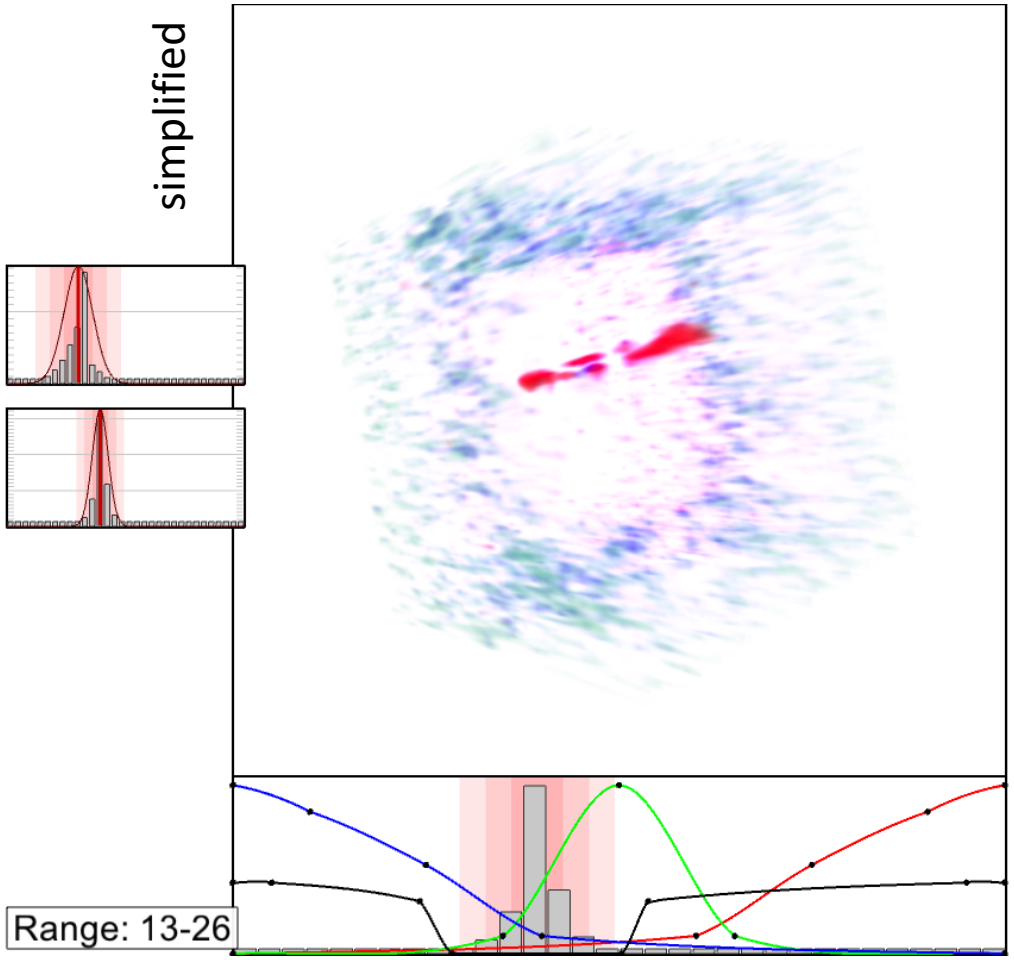
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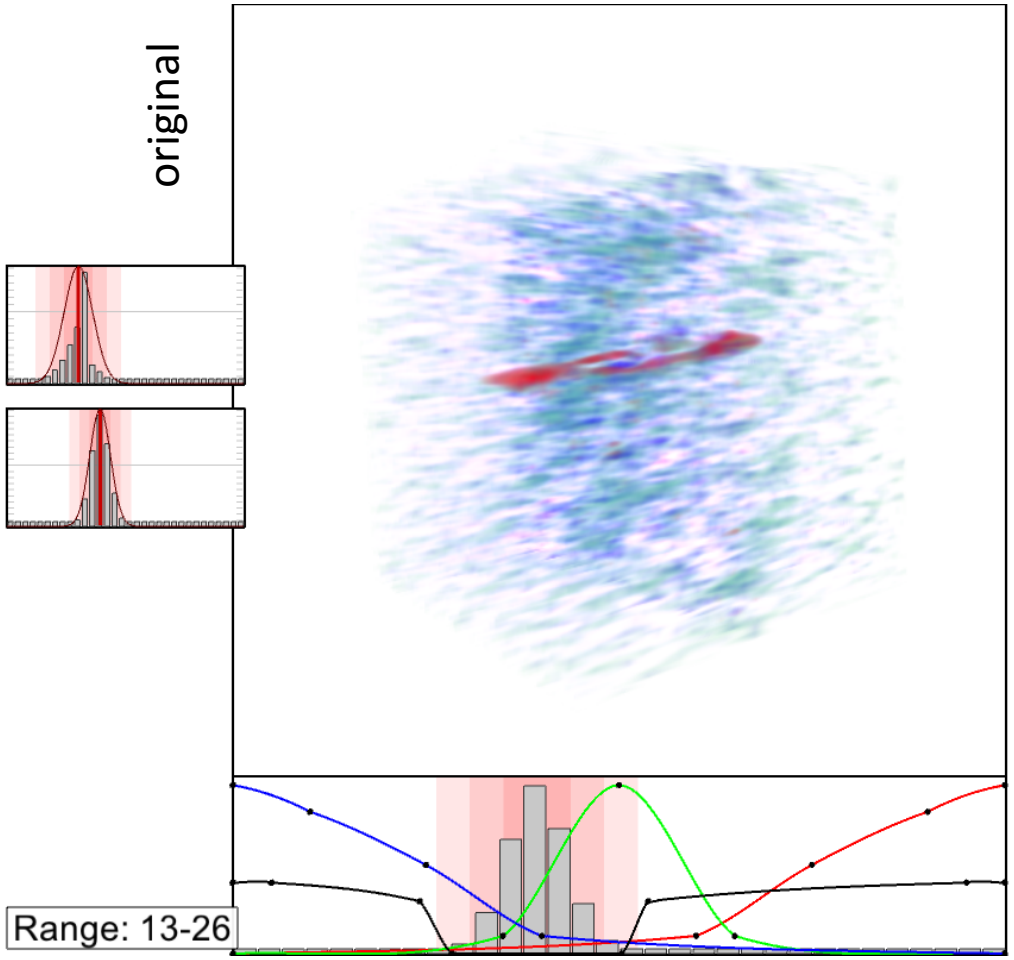
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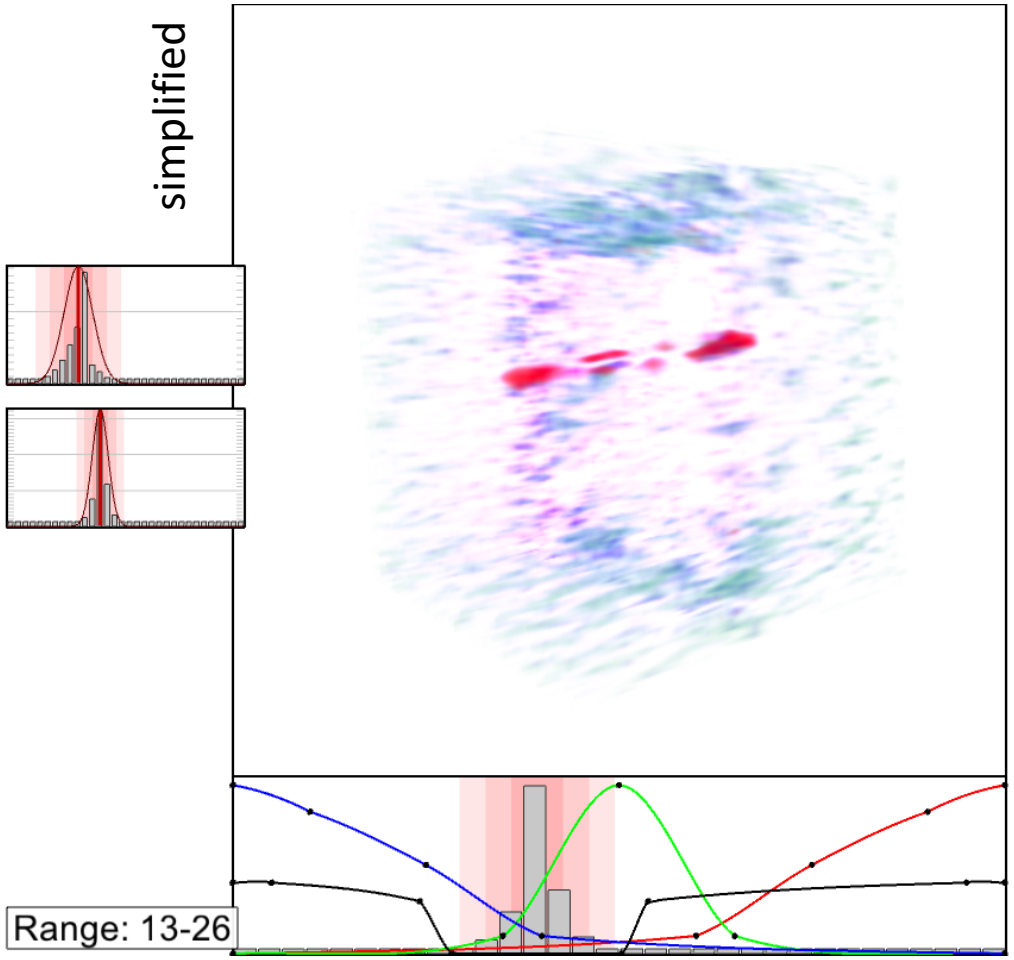
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- Video
- https://youtu.be/TUJ9j82mYn8

SUMMARY

Early results convincing

Open questions remain

Scalar field simplification choice

Scalability of software

Related visualization needs

Additional uses of the contour trees

Scientific impact of simplification

Other TDAV data structures

SOFTWARE

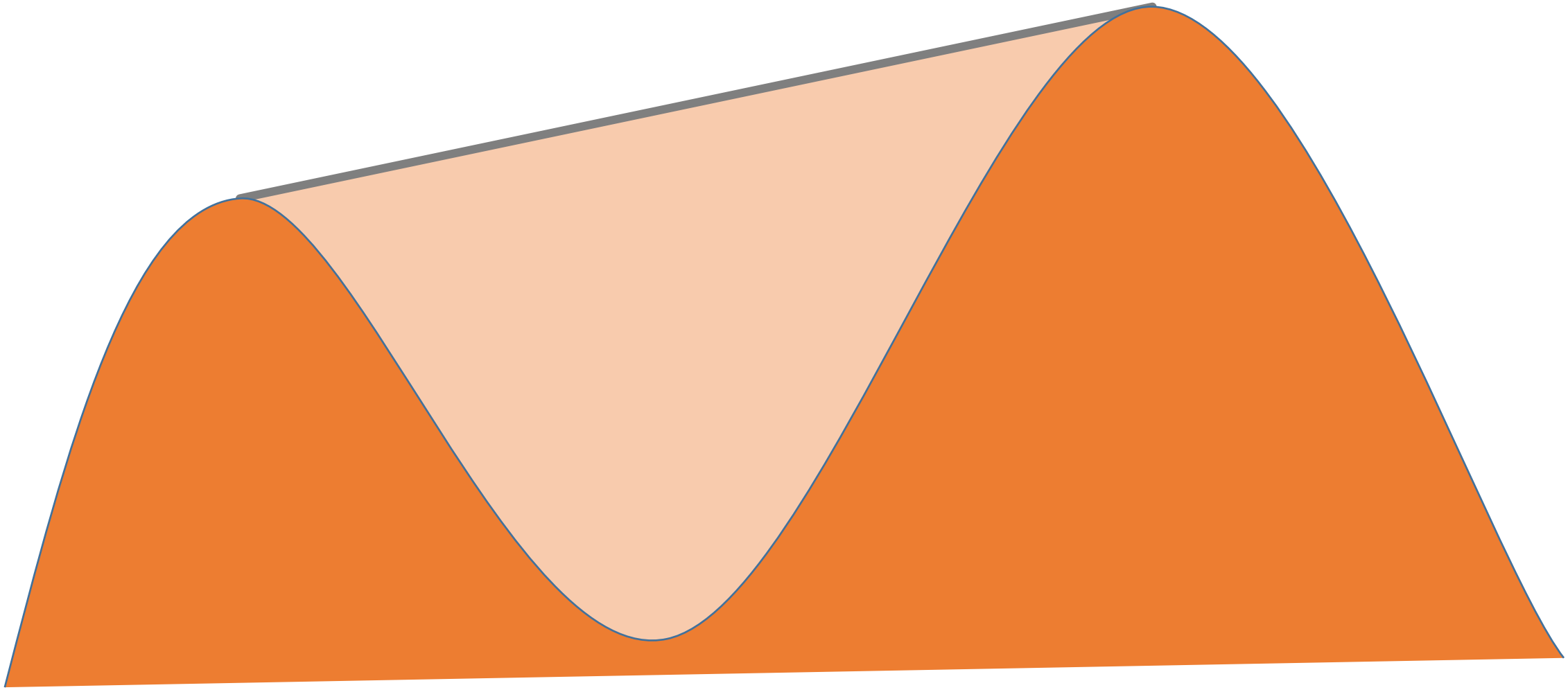
Software will be publicly released before the end of the year

We invite interested users to contact us for early access

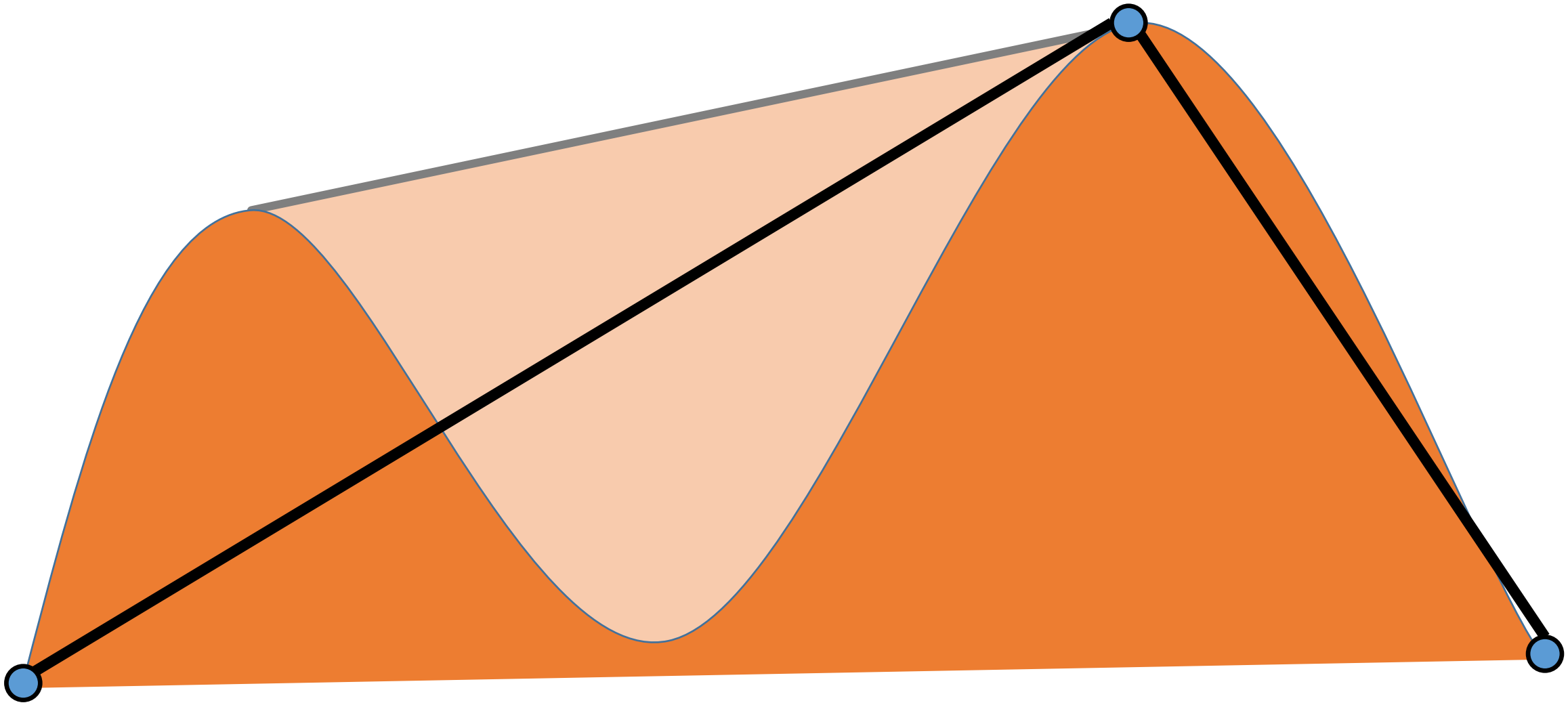
More Research Questions

A Bit More Technical Details

Alternative Simplifications



Alternative Simplifications



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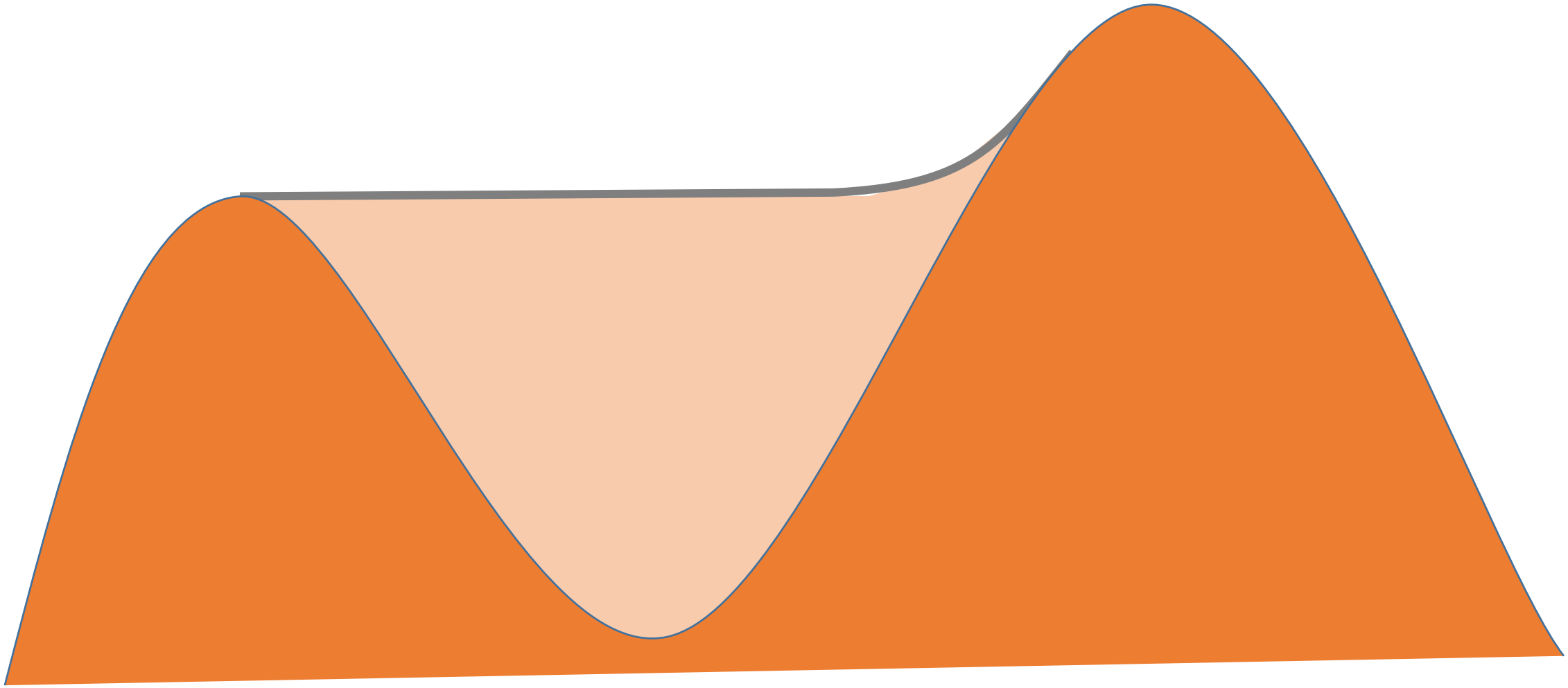

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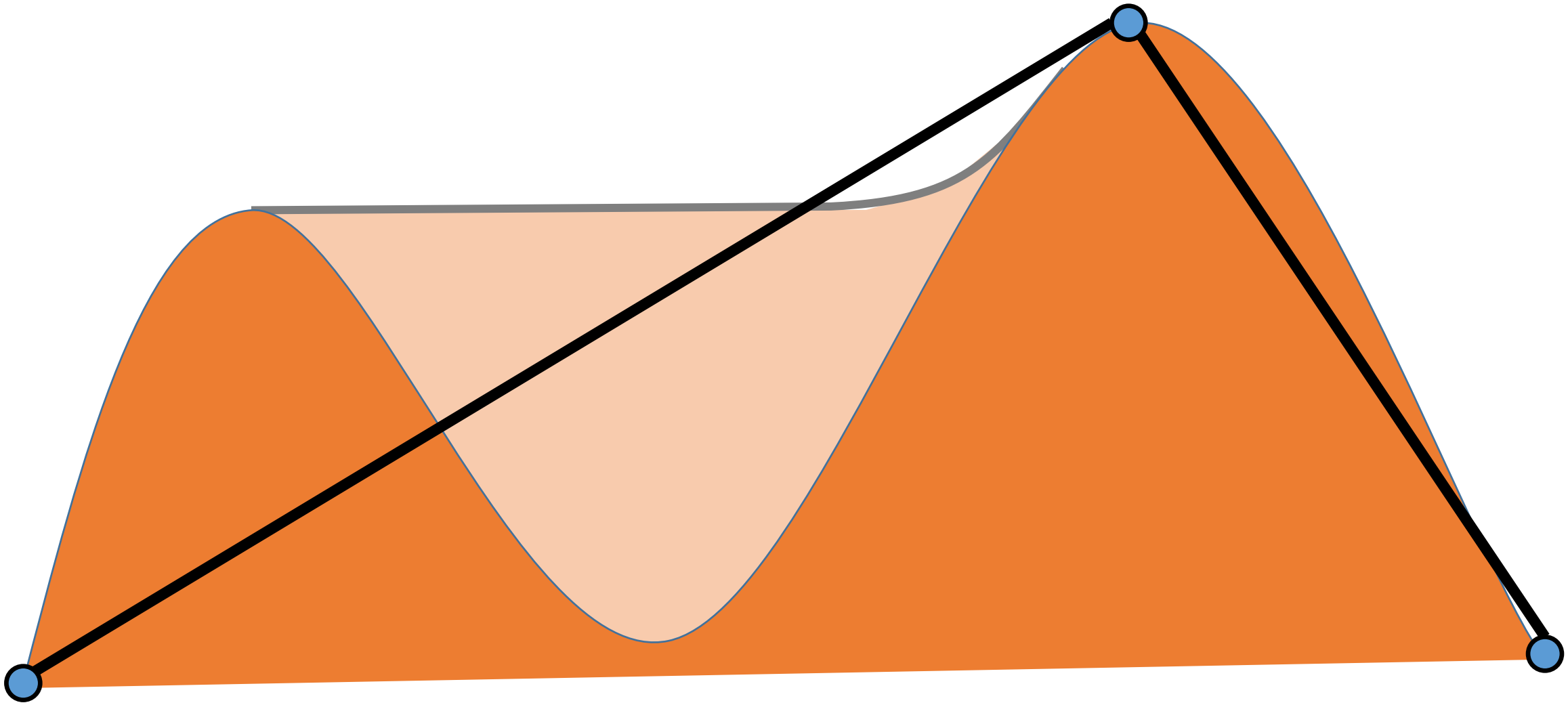
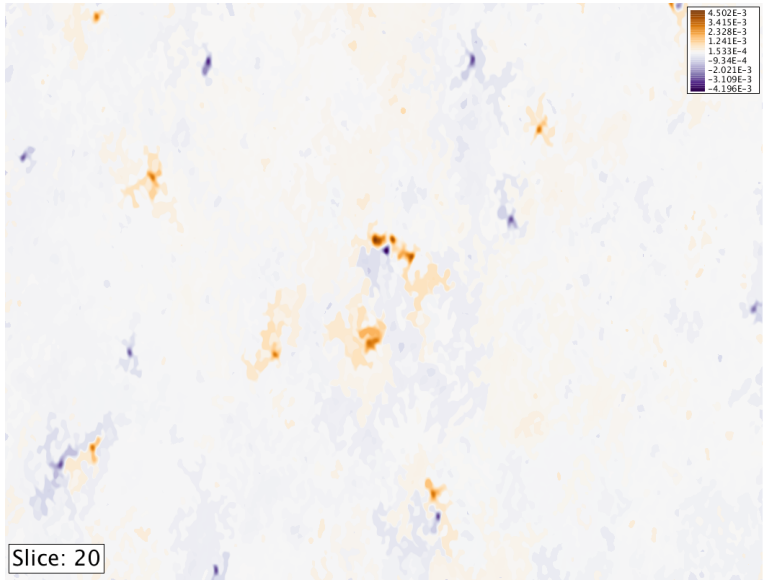
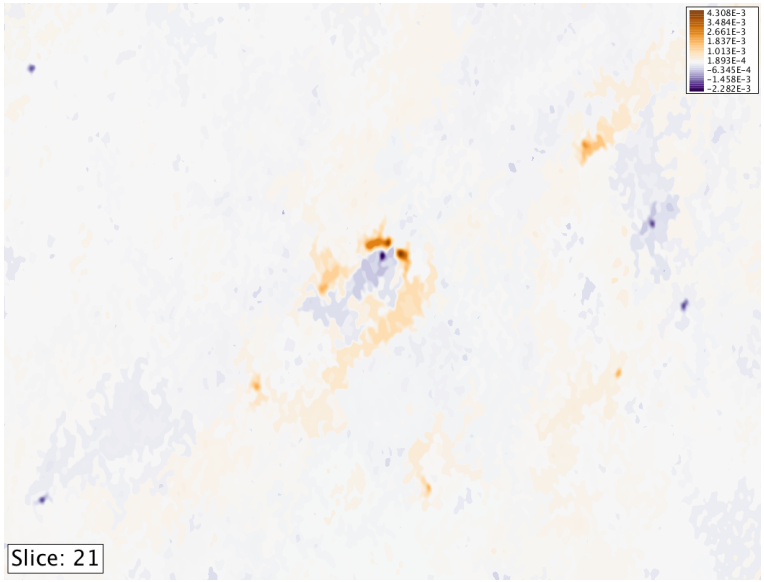
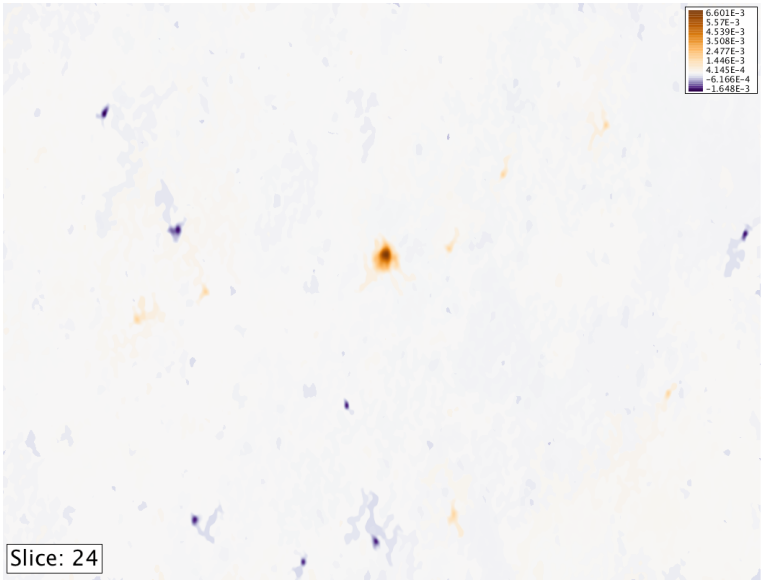


Outstanding issue: multiple slices

- How to co-simplify?
- Multiple 2D vs 3D contour trees?







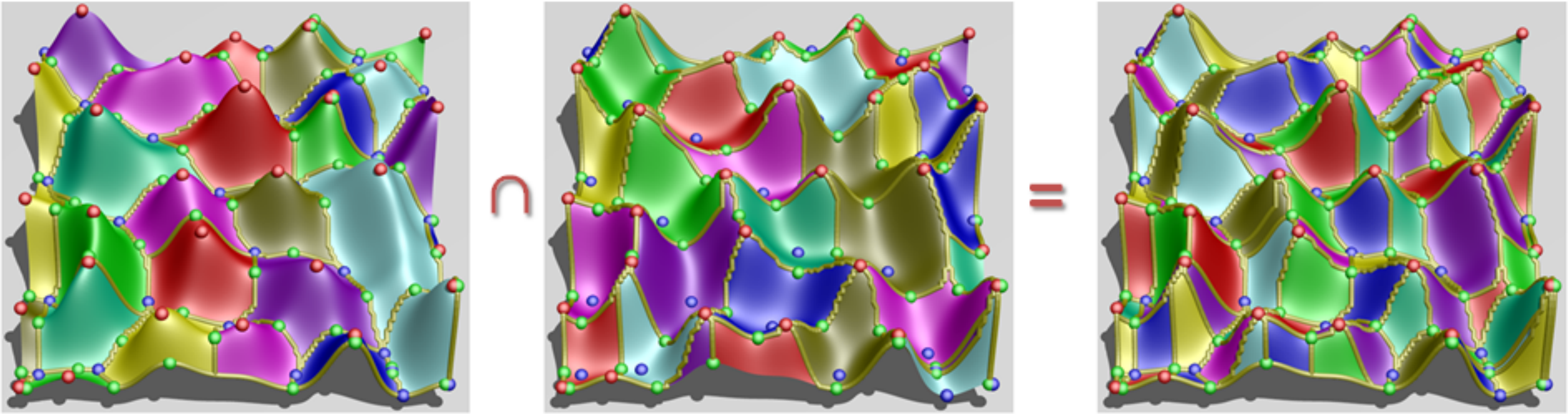
Outstanding issue: Local vs. global contour tree

- Precomputation?
- Data storage and query?
- Efficient computation on parallel machine(s)?

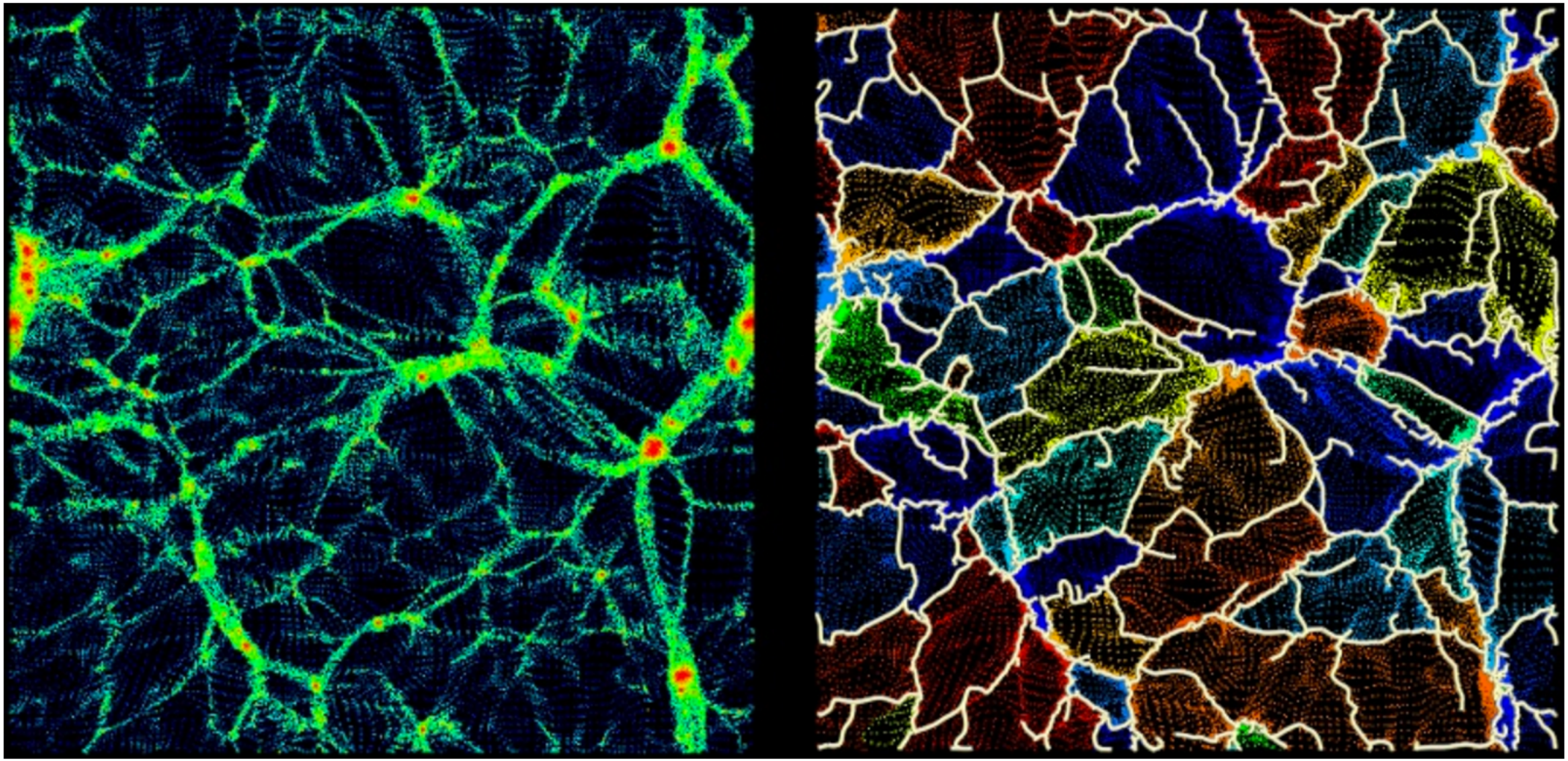
PART II: DATA HAS SHAPE AND WHAT TDAV CAN DO FOR YOUR DATA

VOIDS, WALLS, FILAMENTS, CLUSTERS, AND THEIR CONFIGURATION WITHIN THE COSMIC WEB

Morse-Smale Complex

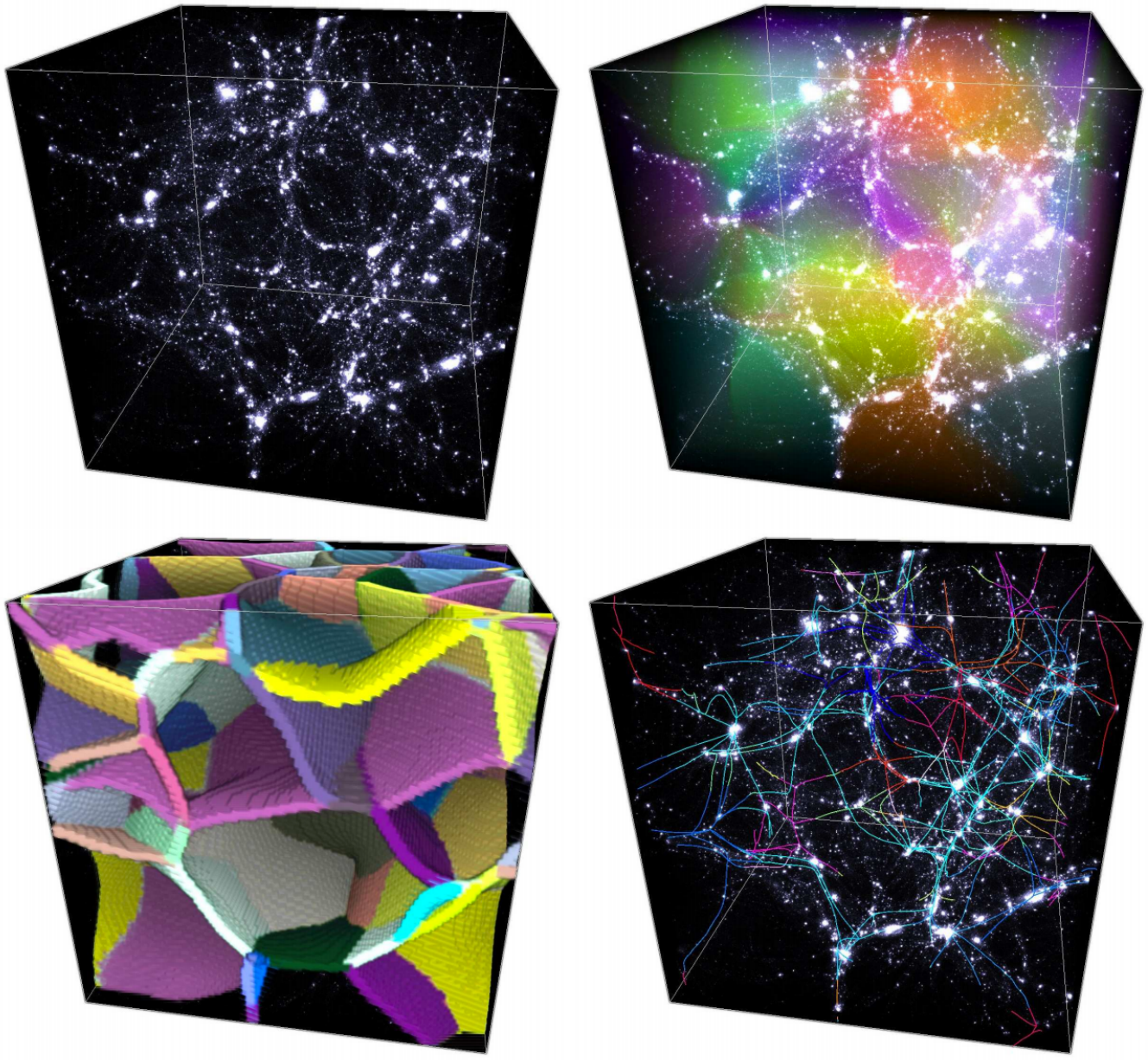


TDA+ASTRONEMY POTENTIALS



FILAMENTS STRUCTURE T. SOUSBIE, *DISPERSE*

TDA+ASTRONEMY POTENTIALS



FILAMENTS STRUCTURE T. SOUSBIE, 2010,

Questions?

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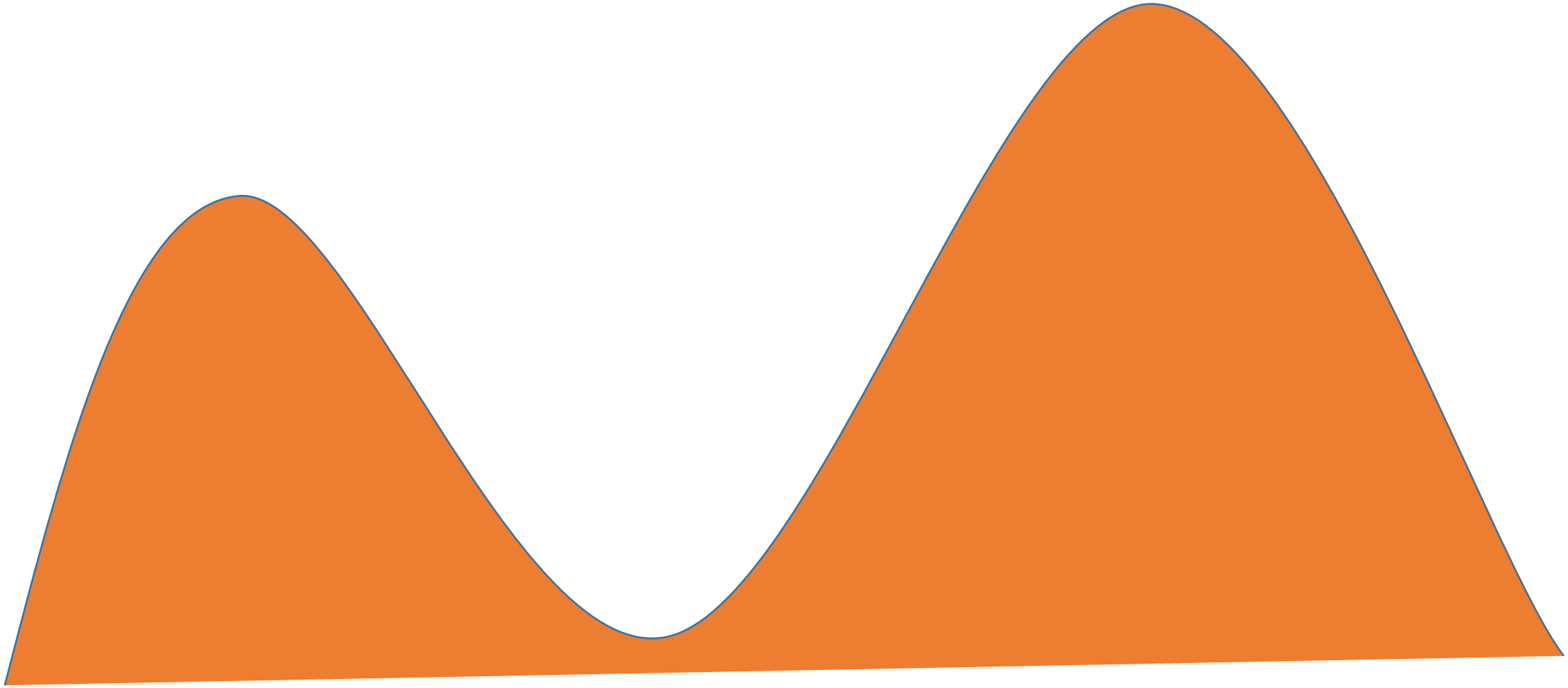
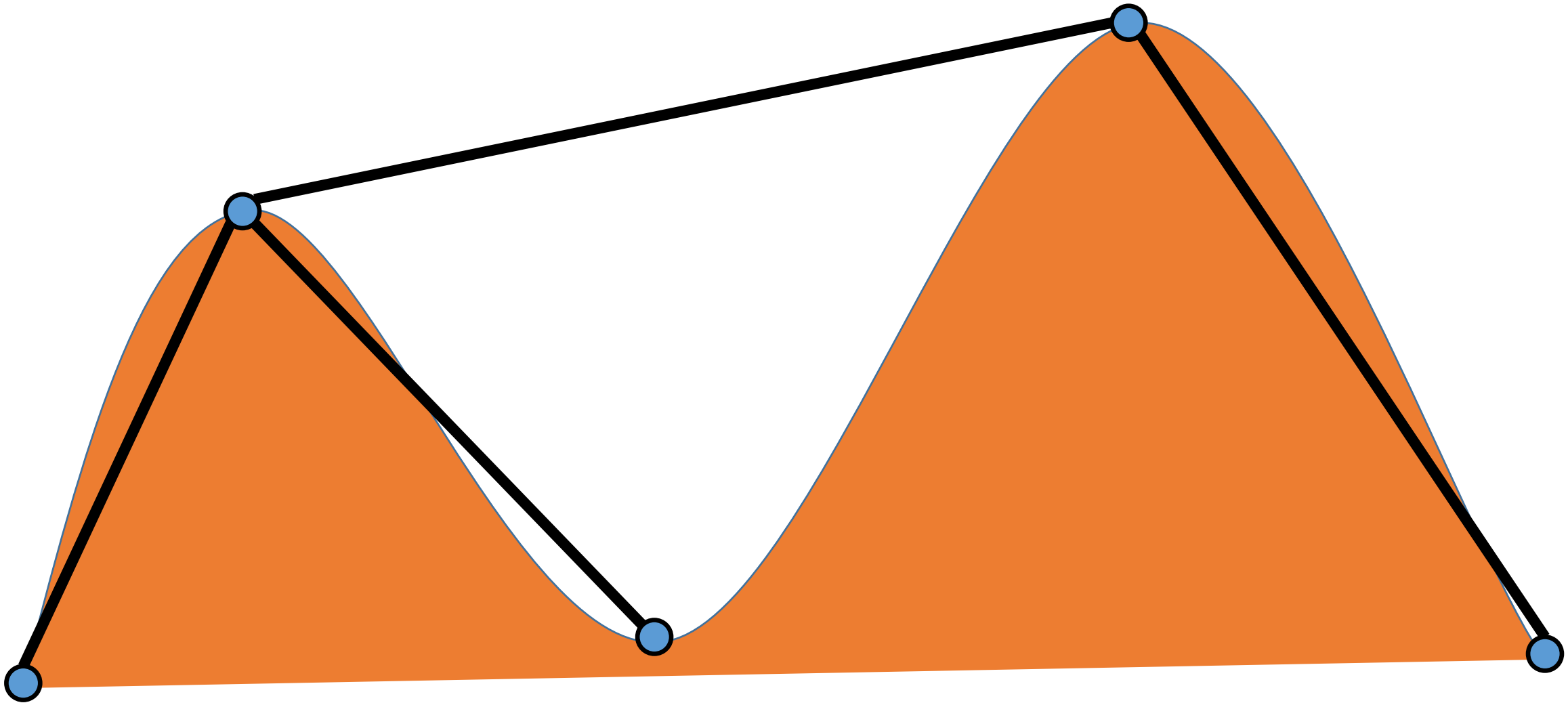
EXTRA

Outstanding issue: Boundary Conditions



Outstanding issues: Boundary Conditions



Outstanding issues: Boundary Conditions

- Are boundaries true critical points?