Exploring Multi-Streaming in the Universe

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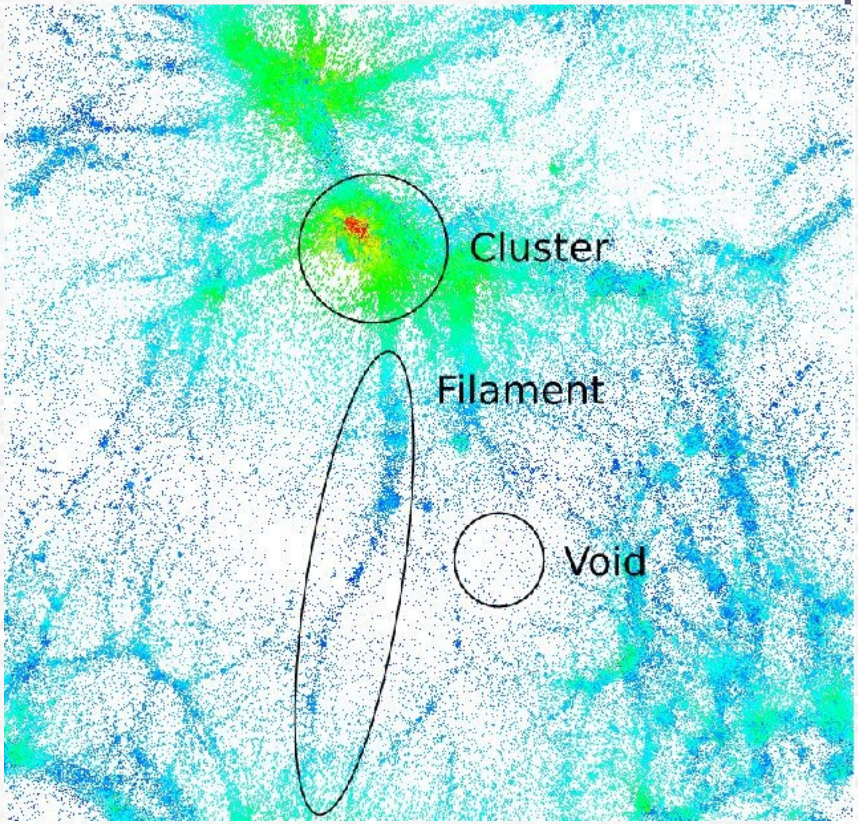
ISSDM
INSTITUTE FOR SCALABLE SCIENTIFIC DATA MANAGEMENT

Science Problem

- Study formation of large scale structures such as filaments, clusters, and pancakes



Simulation

- Particle based simulations with ID, position, and velocity of each particle
- Initially evenly distributed with Gaussian random density field
- Collisionless Vlasov-Poisson dynamics
- Simulation starts in linear regime under influence of gravity
- Evolution transition to quasi-linear, then to non-linear regimes

Multi-streaming

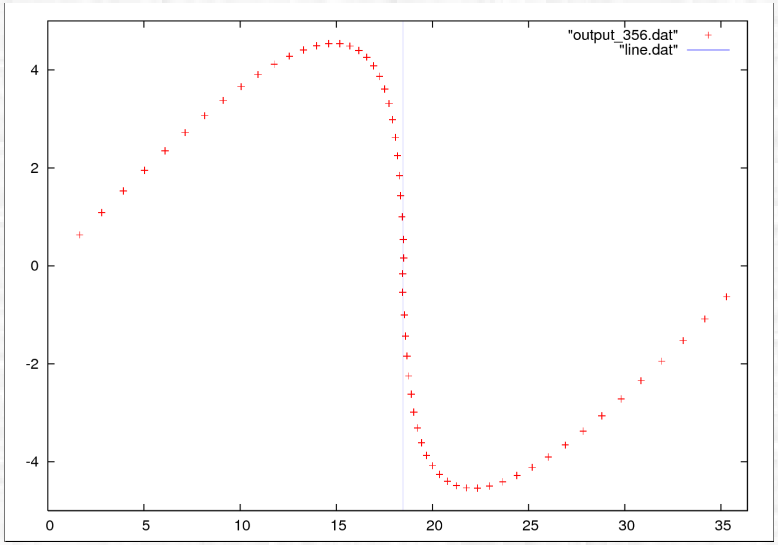
- Challenge: find where, when, and how of multi-streaming events.
- Multiple descriptions
  - Shandarin/Zeldovich criterion: particles move in opposite or drastically different speeds.
  - Caustics: “where particles from different lagrangian positions and velocities converge at a given eulerian location”
  - Associated with transition from linear to quasi-linear to nonlinear regimes.
  - “Irrotational but not a potential flow”, and others

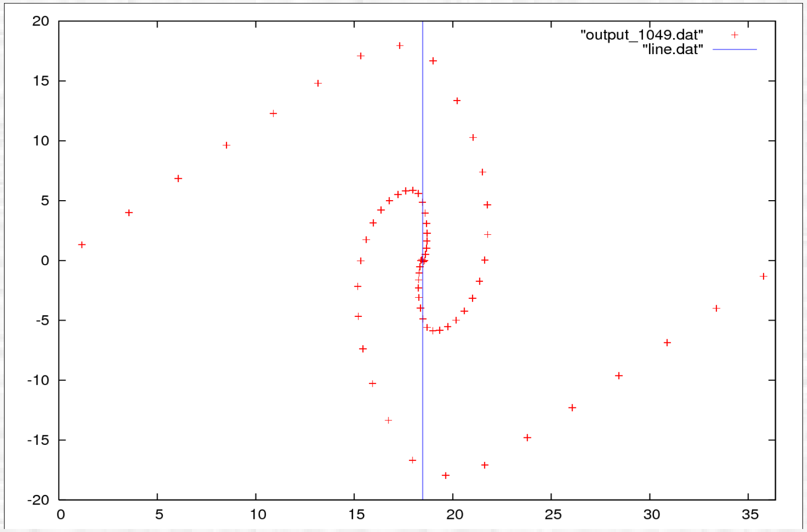
Feature Extraction Strategies

- Halo-finder (existing density based methods)
- Extension of Shandarin/Zeldovich criterion from 1D to 3D (sign change in tetrahedral volume)
- Measure of dissimilarity of velocities at a point
- Measure of high shear in flow field
- Measure of linearity
- Vorticity and divergence
- Critical point analysis
- etc.

Shandarin/Zeldovich Criterion

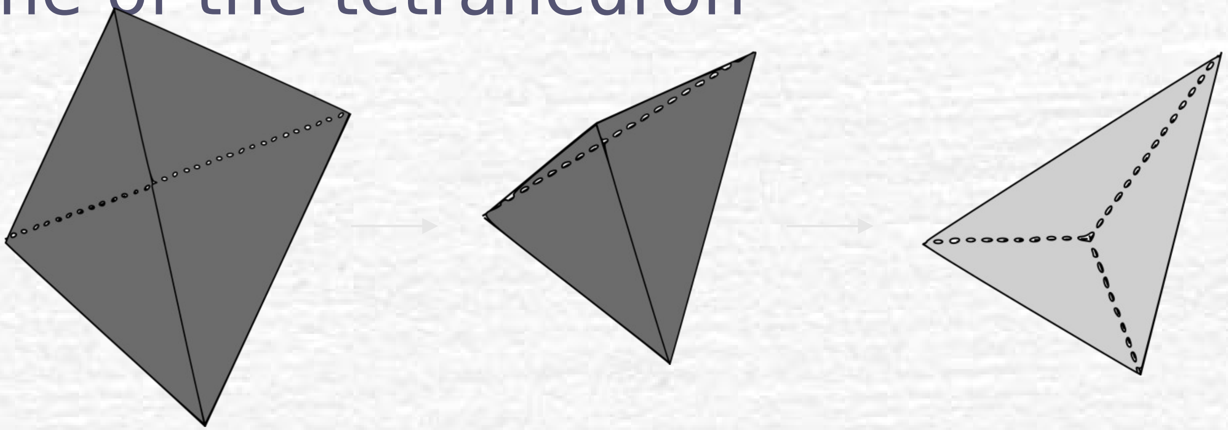
- One dimensional phase portrait





Extension to 3D

- Track 4 vertices of a tetrahedron.
- If particles are going in opposite direction or going at different speeds, then after some time, there will be a sign-change in the volume of the tetrahedron



Velocity variance

- Measure local “velocity dispersion”
- Treat each velocity component as a random variable
- Calculate local covariance matrix
- Calculate the trace of the matrix

Measure shear in flow

- Calculate velocity gradient tensor
- Perform eigen-analysis
- Identify regions with high shear e.g. use von Mises criterion

$$\text{max\_shear} = \sqrt{\frac{(\lambda_1 - \lambda_2)^2 + (\lambda_1 - \lambda_3)^2 + (\lambda_2 - \lambda_3)^2}{2}}$$

Vorticity

- Measure local tendency of particles to spin
- Interested in regions with high vorticity magnitude

$$\text{vortMag} = \left\| \nabla \times \vec{V} \right\|$$

Divergence

- Measure of a vector field’s source-like or sink-like behavior
- Hypothesis: multi-streaming regions have a sink-like property that attracts neighboring particles.

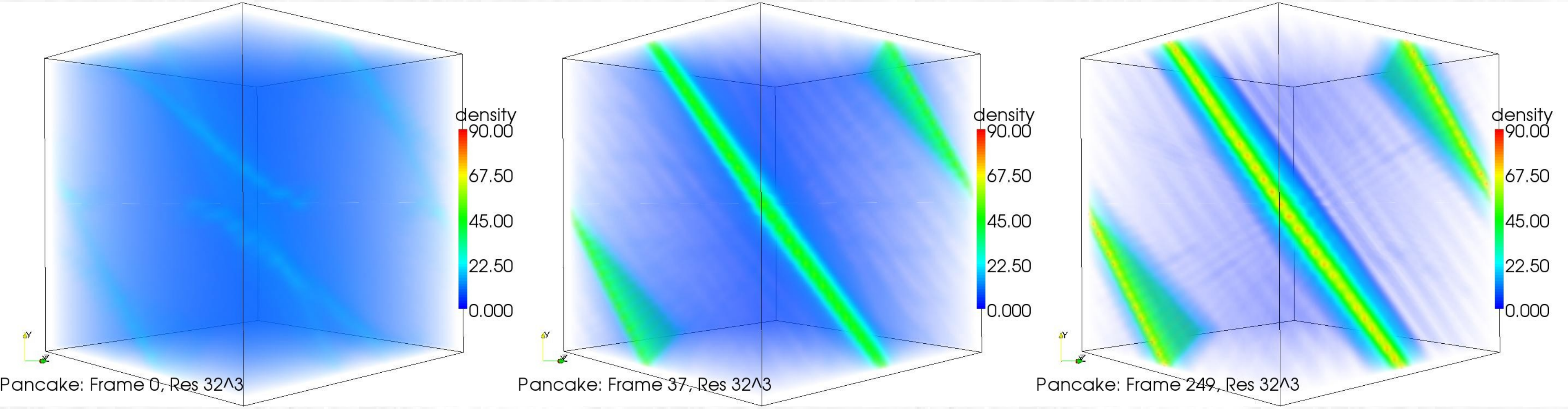
$$\mathrm{div} = \frac{\partial U}{\partial x} + \frac{\partial V}{\partial y} + \frac{\partial W}{\partial z}$$

Simulation Data

- The Zel'dovich pancake test data.
  - 64^3 particles (~270 K), multivariates, 250 time steps.

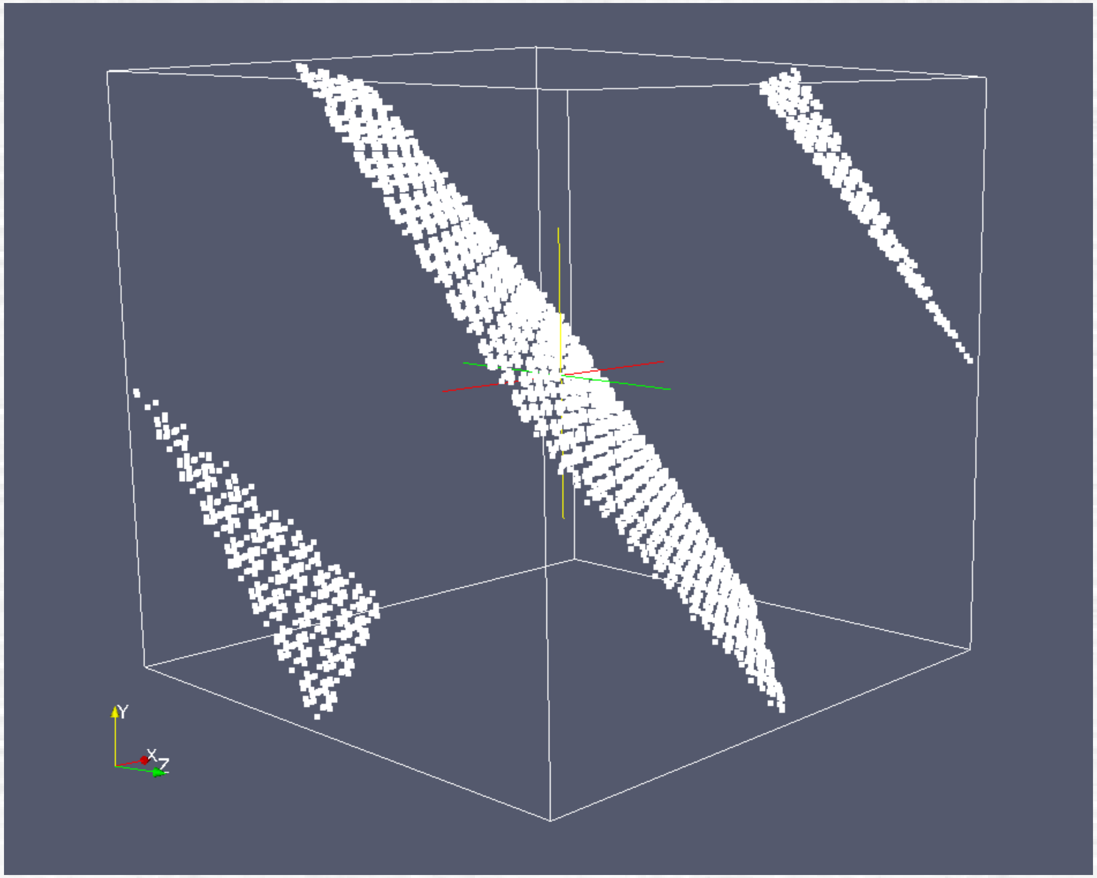
- MC^2 data (Mesh based Cosmology Code).
  - 256^3 particles (~17 M), multivariates, 251 time steps.

Pancake density

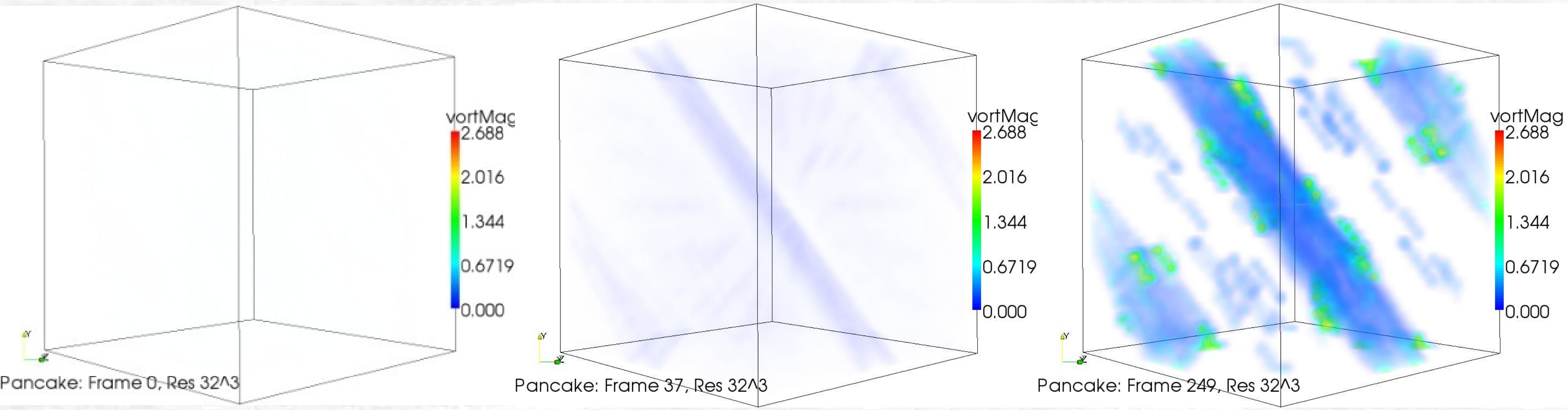


Pancake: Tracking tetrahedra

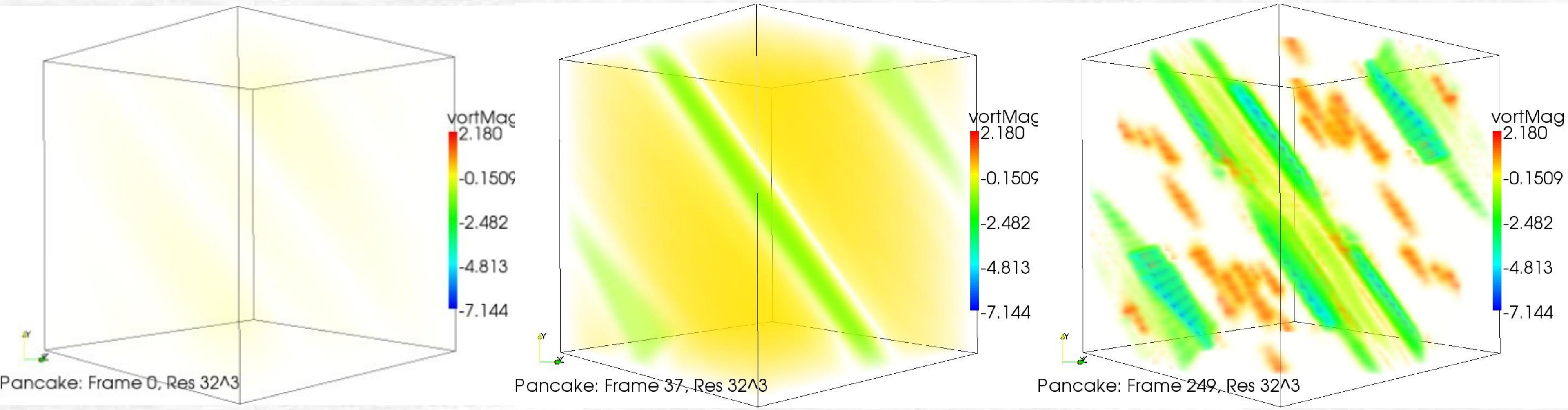
- The three multi-streaming pancake regions.



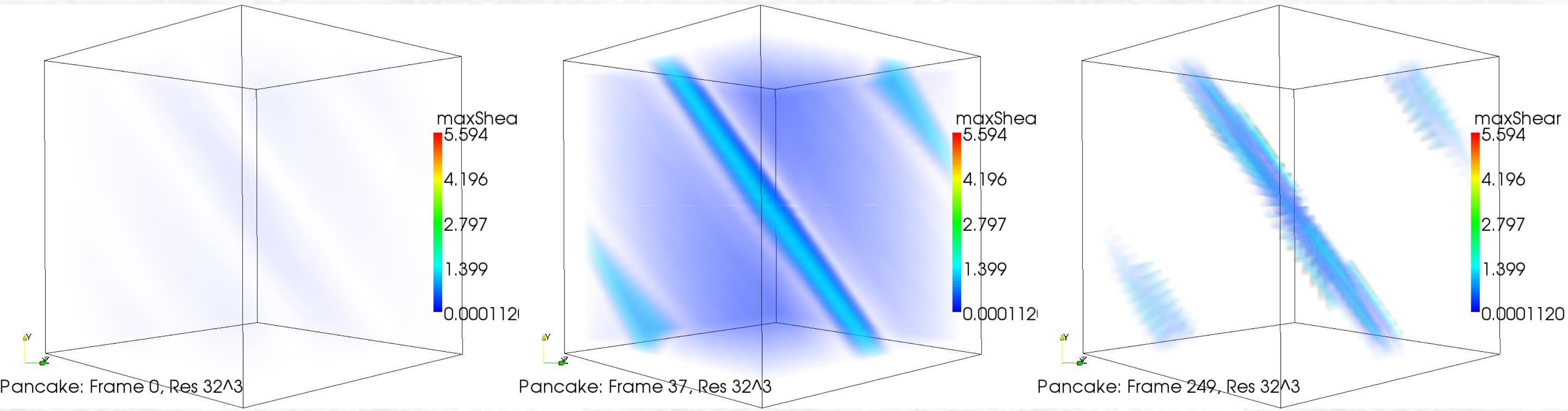
Pancake vorticity



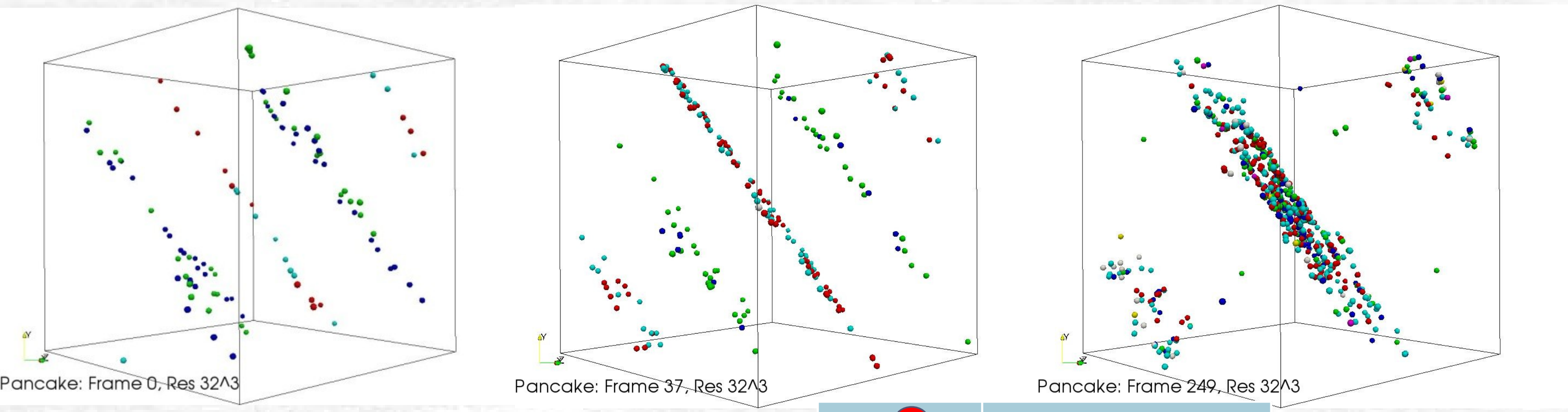
Pancake divergence



Pancake shear

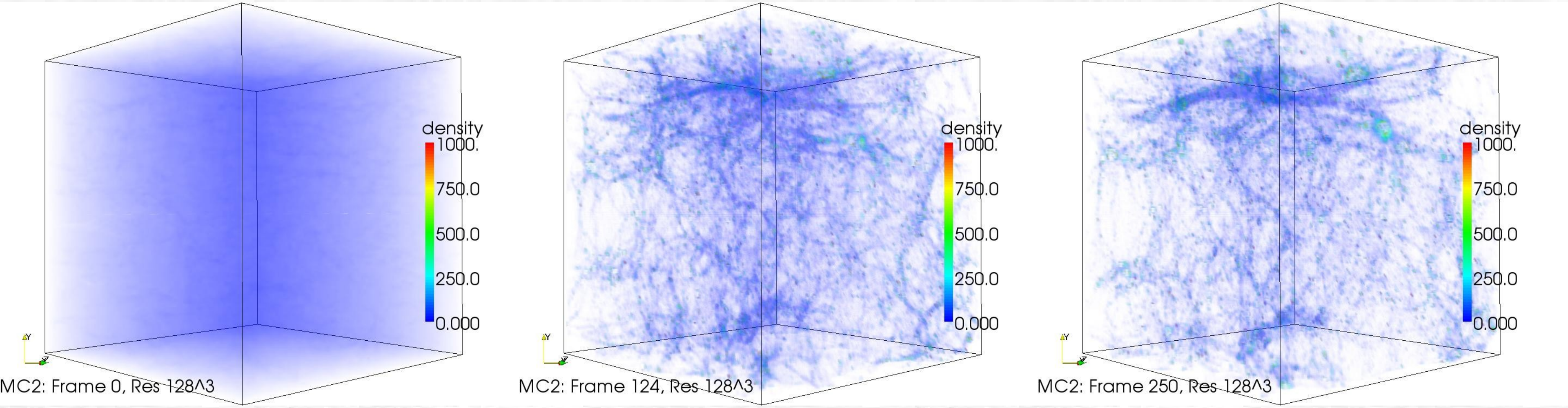


Pancake critical points

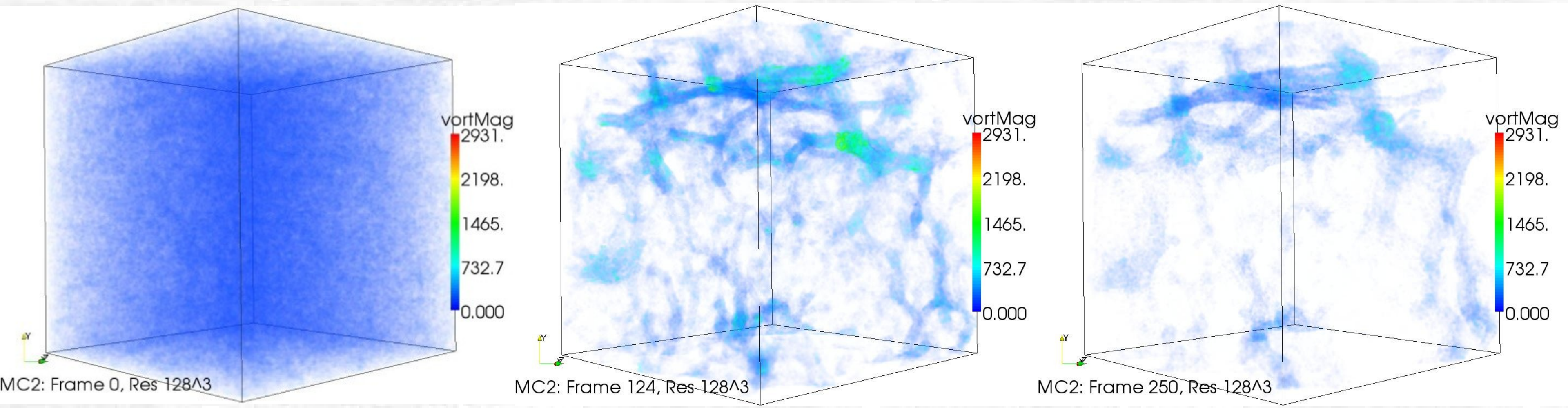


	Repelling spiral
	Repelling node
	Repelling spiral
	Repelling node
	Attracting spiral
	Attracting node
	Attracting spiral
	Attracting node

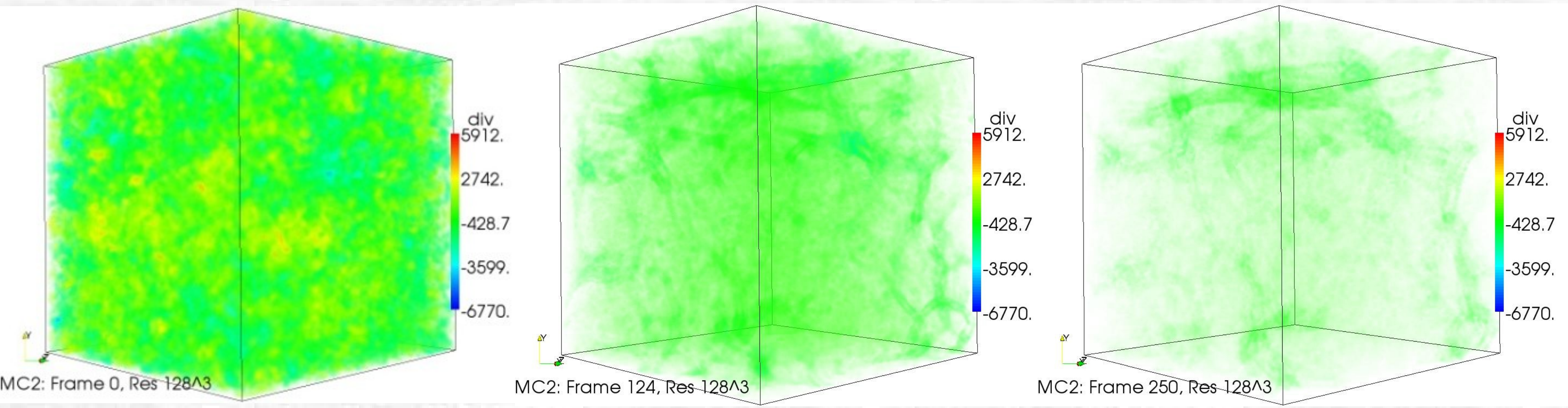
MC2 density


density
1000.
750.0
500.0
250.0
0.000
MC2: Frame 0, Res 128^3
density
1000.
750.0
500.0
250.0
0.000
MC2: Frame 124, Res 128^3
density
1000.
750.0
500.0
250.0
0.000
MC2: Frame 250, Res 128^3

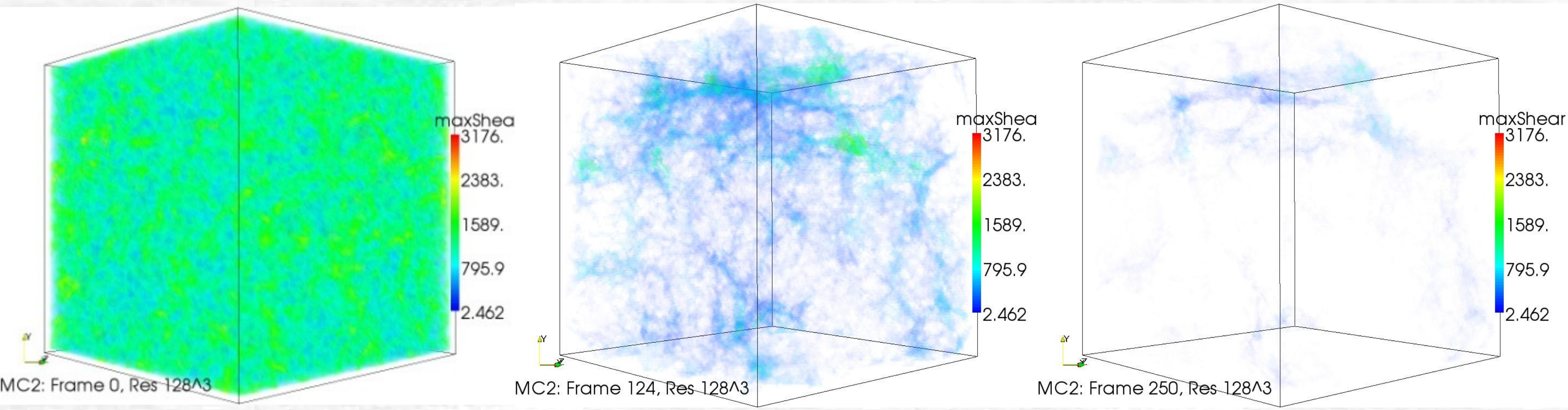
MC2 vorticity



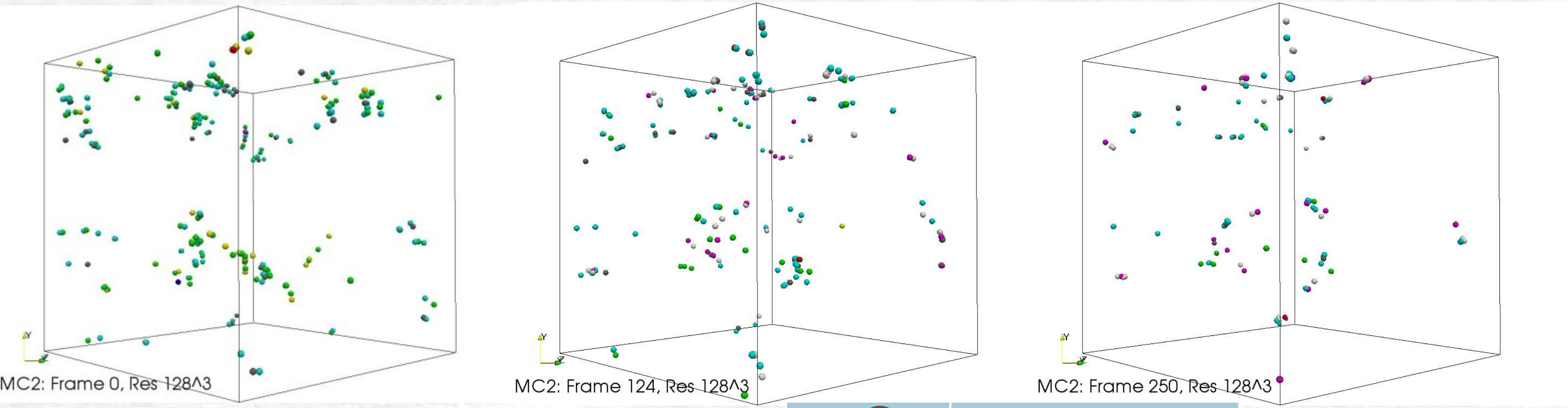
MC2 divergence



MC2 shear


maxShea
3176.
2383.
1589.
795.9
2.462
MC2: Frame 0, Res 128^3
maxShea
3176.
2383.
1589.
795.9
2.462
MC2: Frame 124, Res 128^3
maxShear
3176.
2383.
1589.
795.9
2.462
MC2: Frame 250, Res 128^3

MC2 critical points



Red	**Repelling spiral**
Green	Repelling node
Blue	Repelling spiral
Yellow	Repelling node
Light purple	Attracting spiral
Cyan	Attracting node
White	Attracting spiral
Gray	Attracting node

Current and Future Work

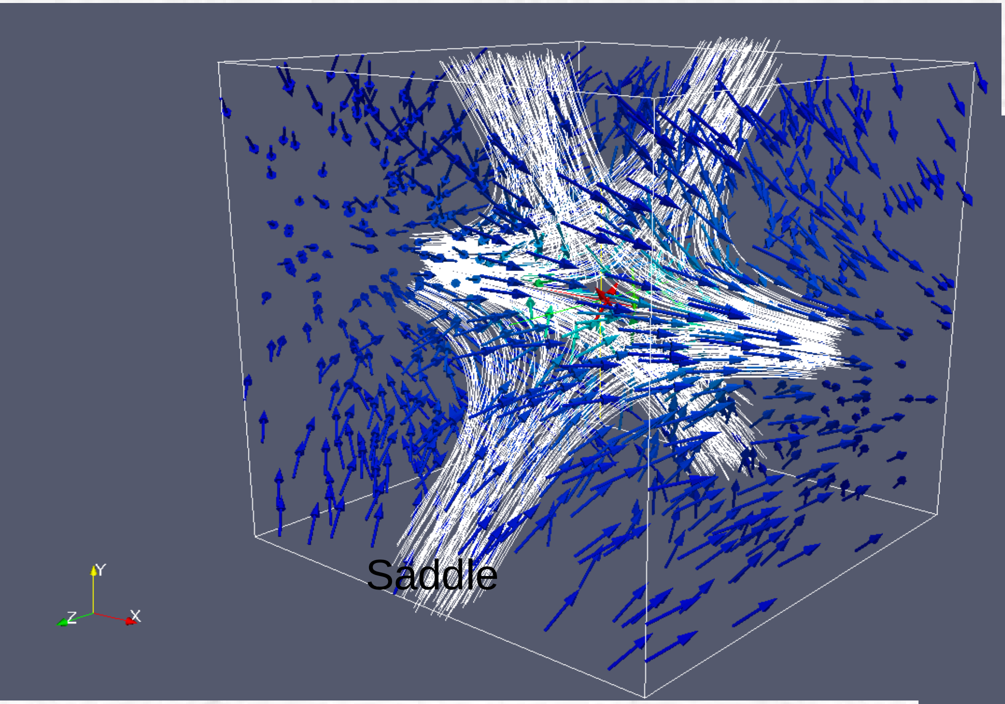
- Can identify and characterize the behavior of multi-streaming regions much better than density based methods.
- However, still cannot accurately predict the onset multi-streaming.
- Will have to validate findings so far.
- Modify to use cloud-in-cell algorithm.
- Compare different feature extraction strategies
- Explore alternative formulations of multi-streaming.

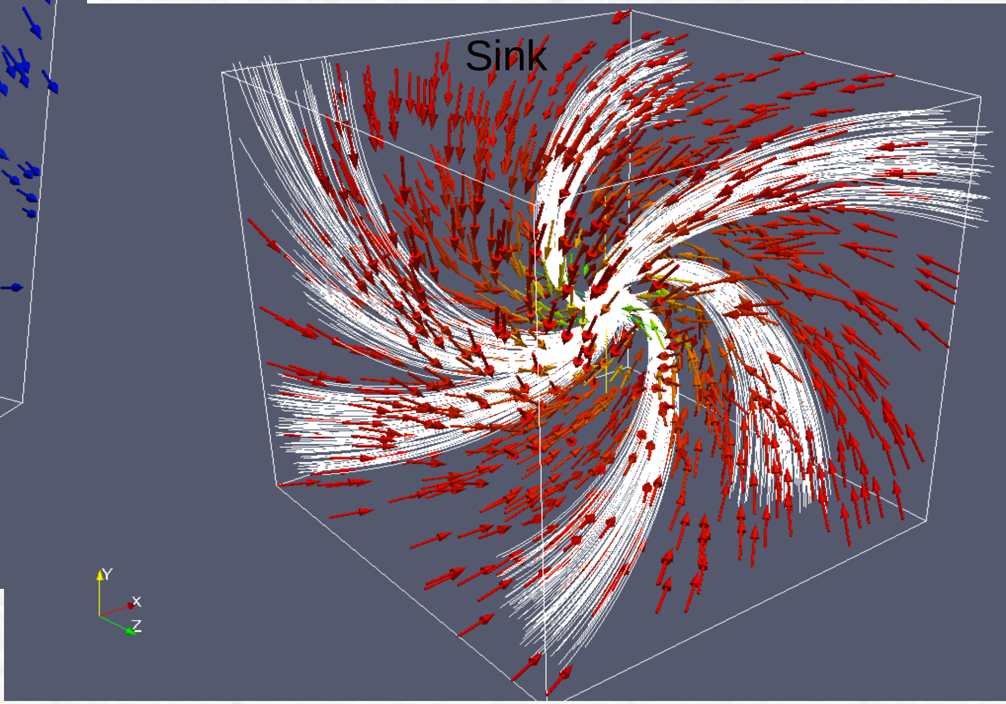
Status

- One MSCS graduate: Eddy Chandra
- New graduate student: Uliana Popov
- Paper under review: Pacific Visualization 2010
- Proposal under review: DOE

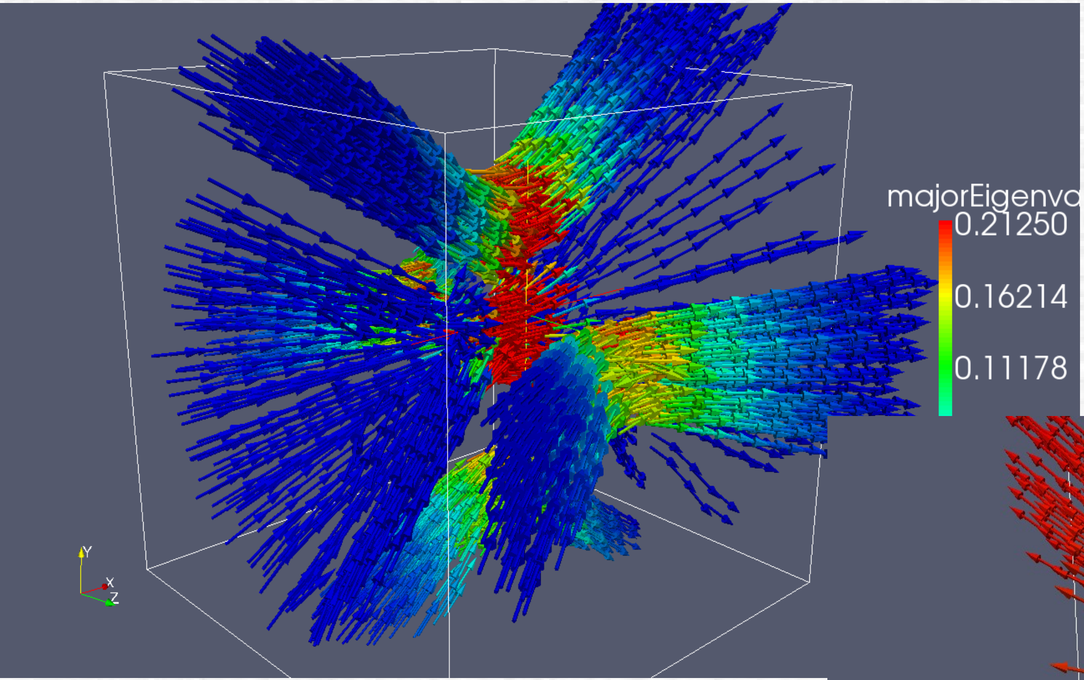
Test Data

- Some 3D critical point types:



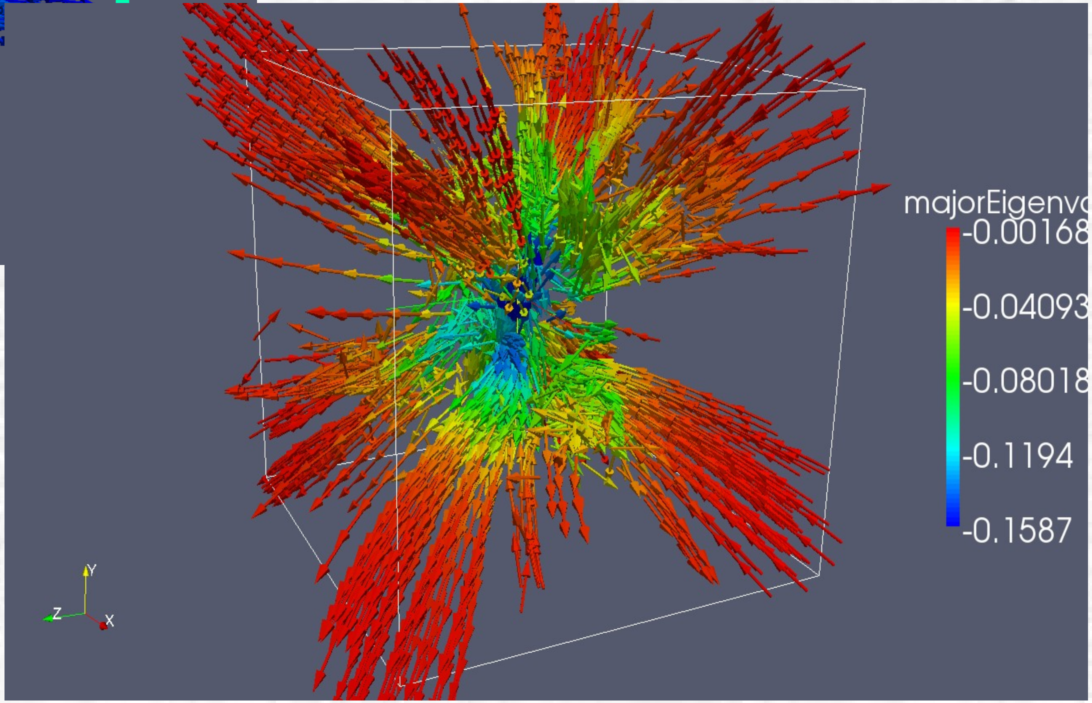


Test Data: Major Eigenvector Field (method 1)

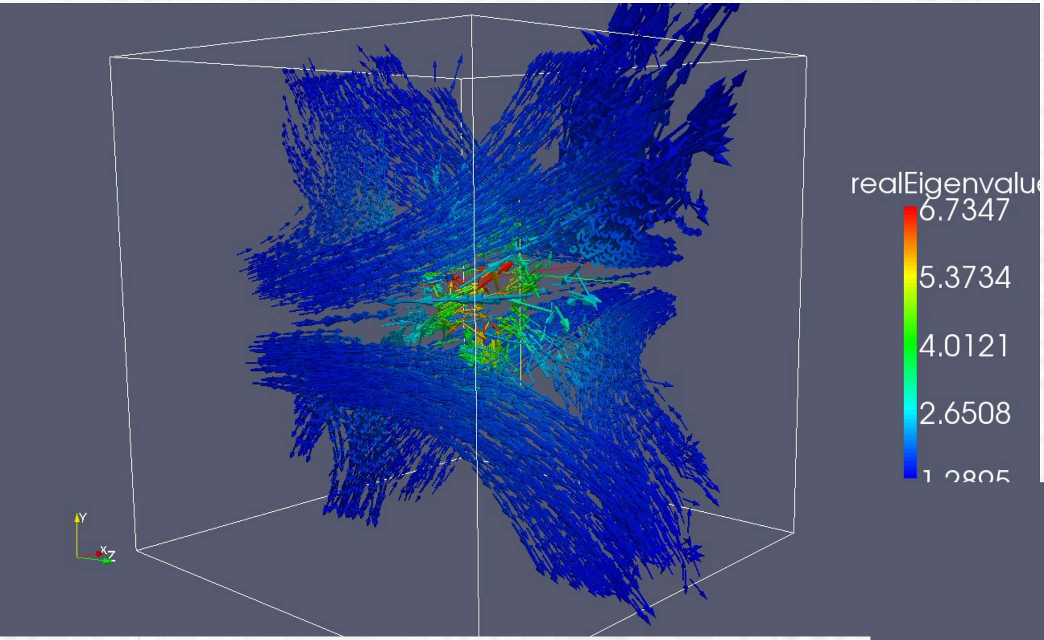


Saddle

Sink

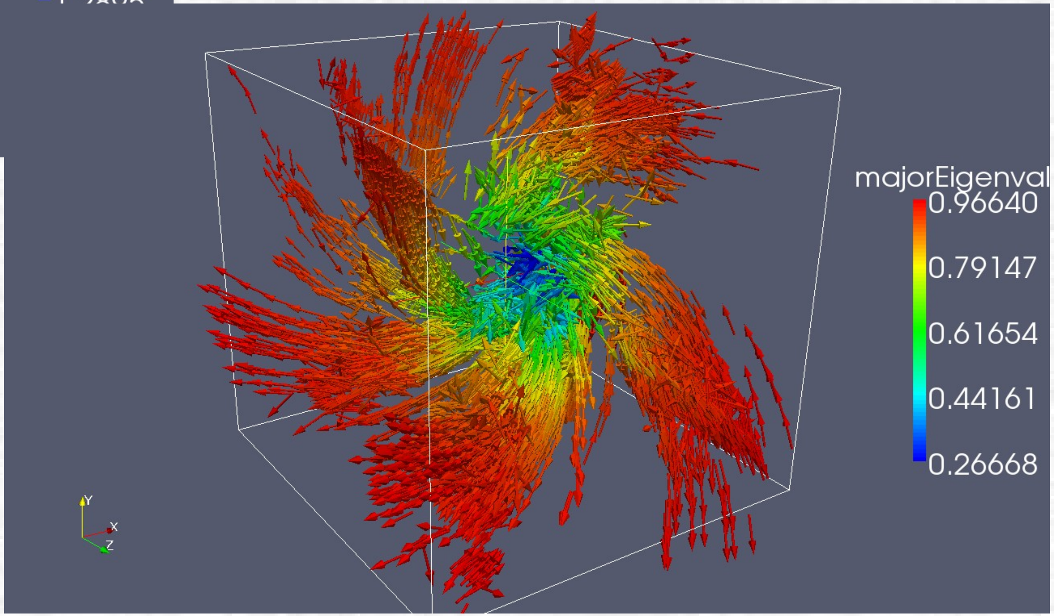


Test Data: Major Eigenvector Field (method 2)

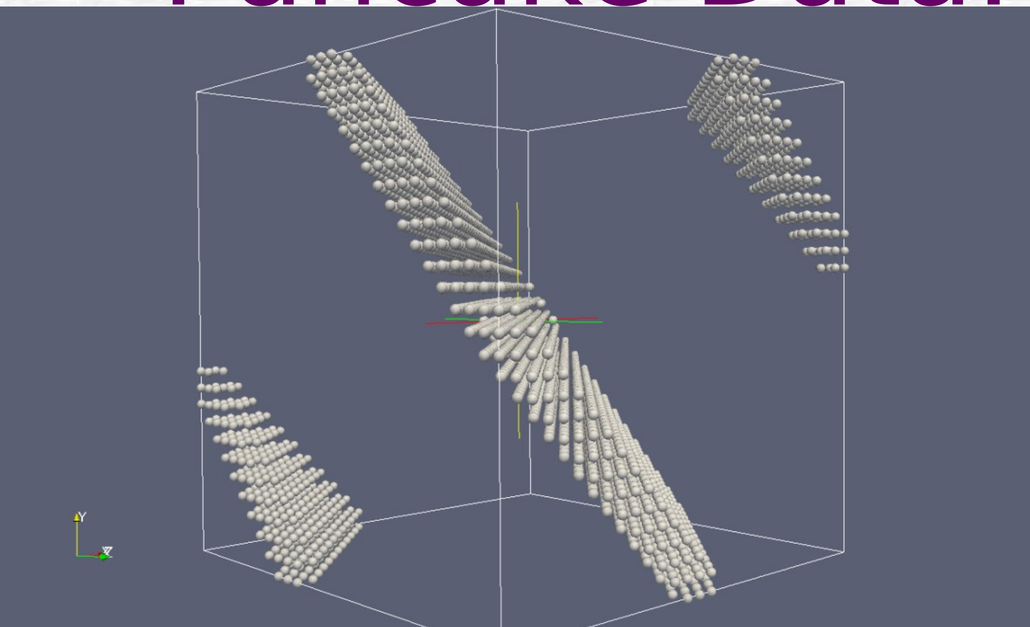


Saddle

Sink



Pancake Data: Eigenvalues

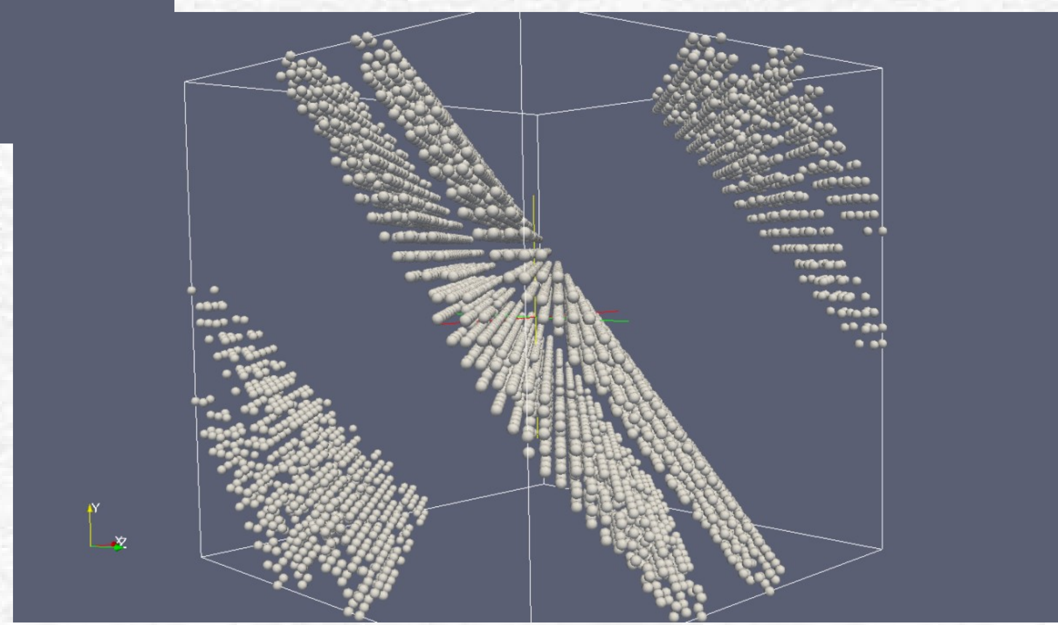


Method 1

Minor eigenvalues

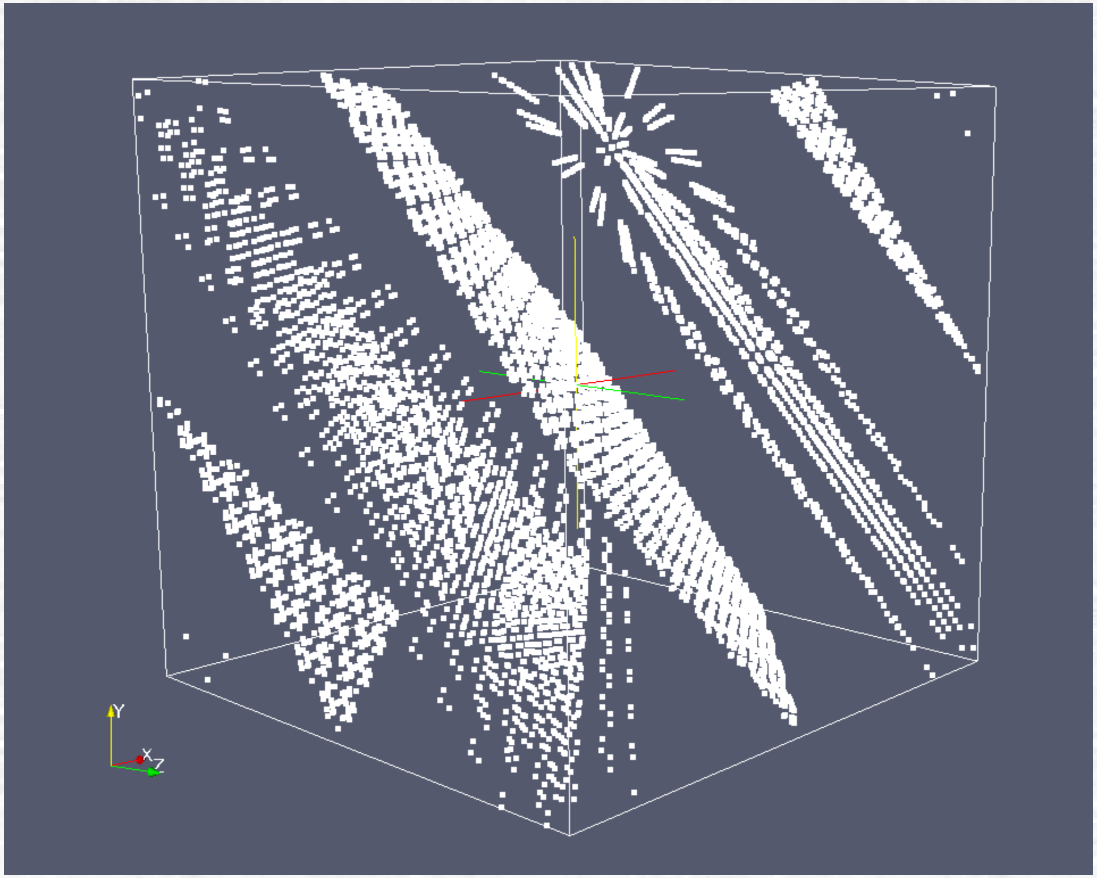
Method 2

Max – min eigenvalues



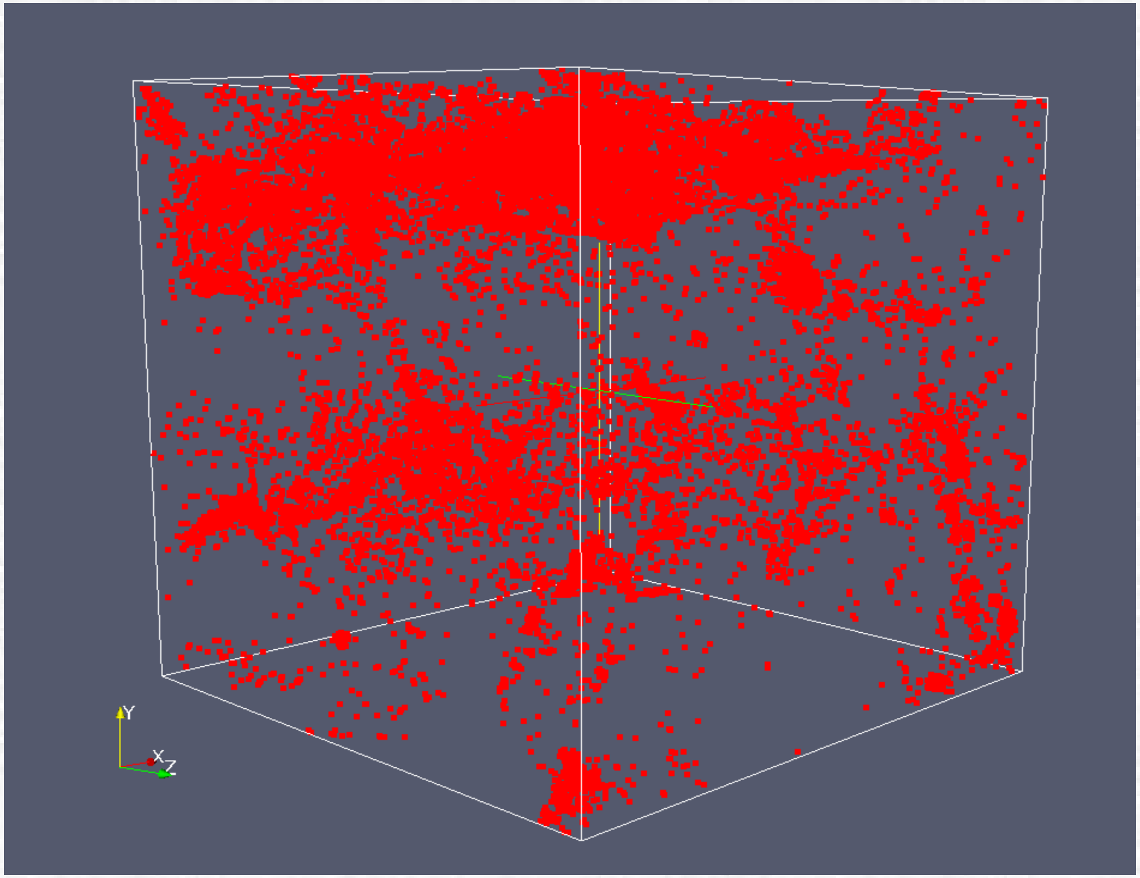
Pancake: Dot Product

- The threshold is set between 0 and 0.05.

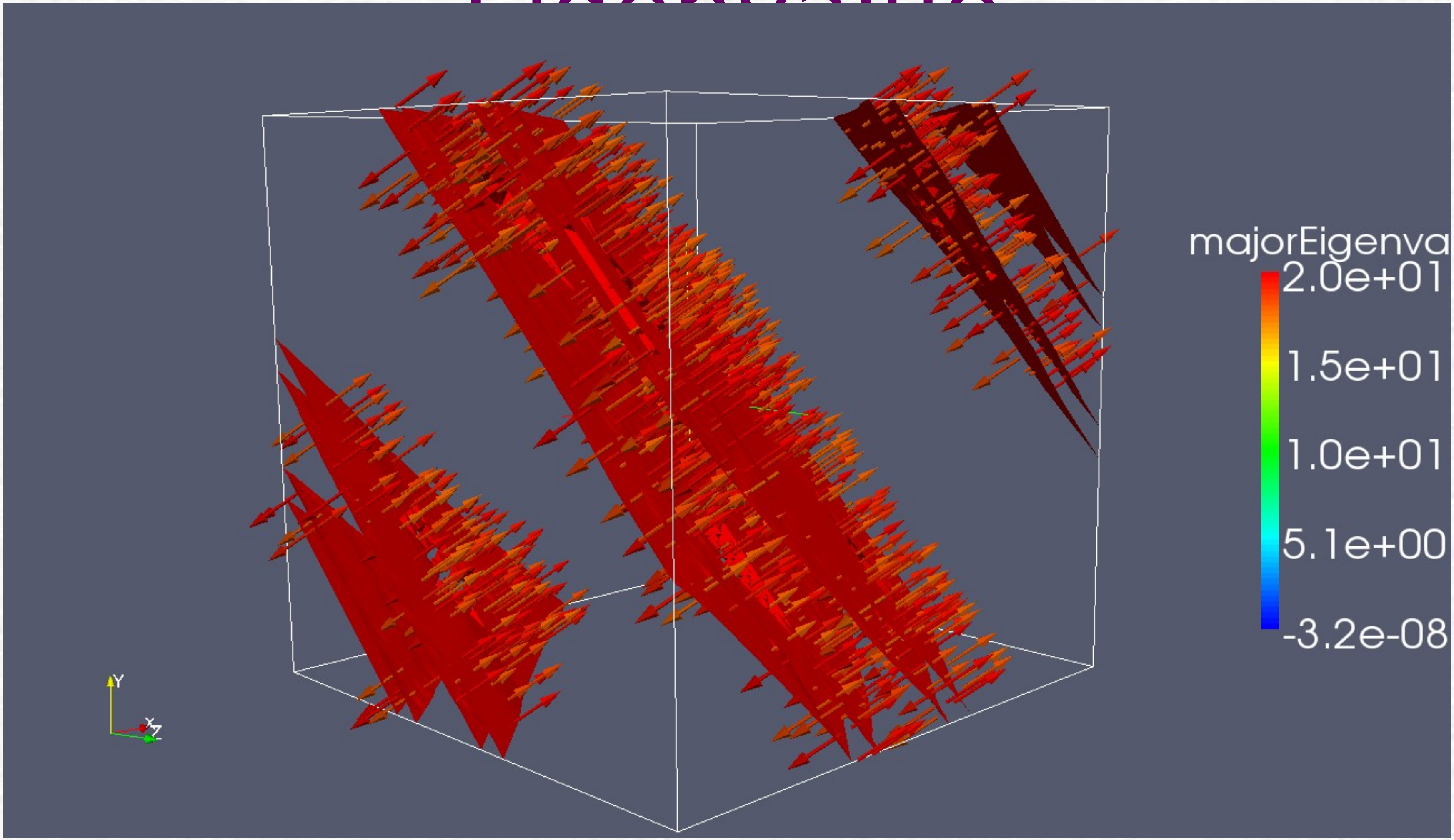


MC^2: Dot Product

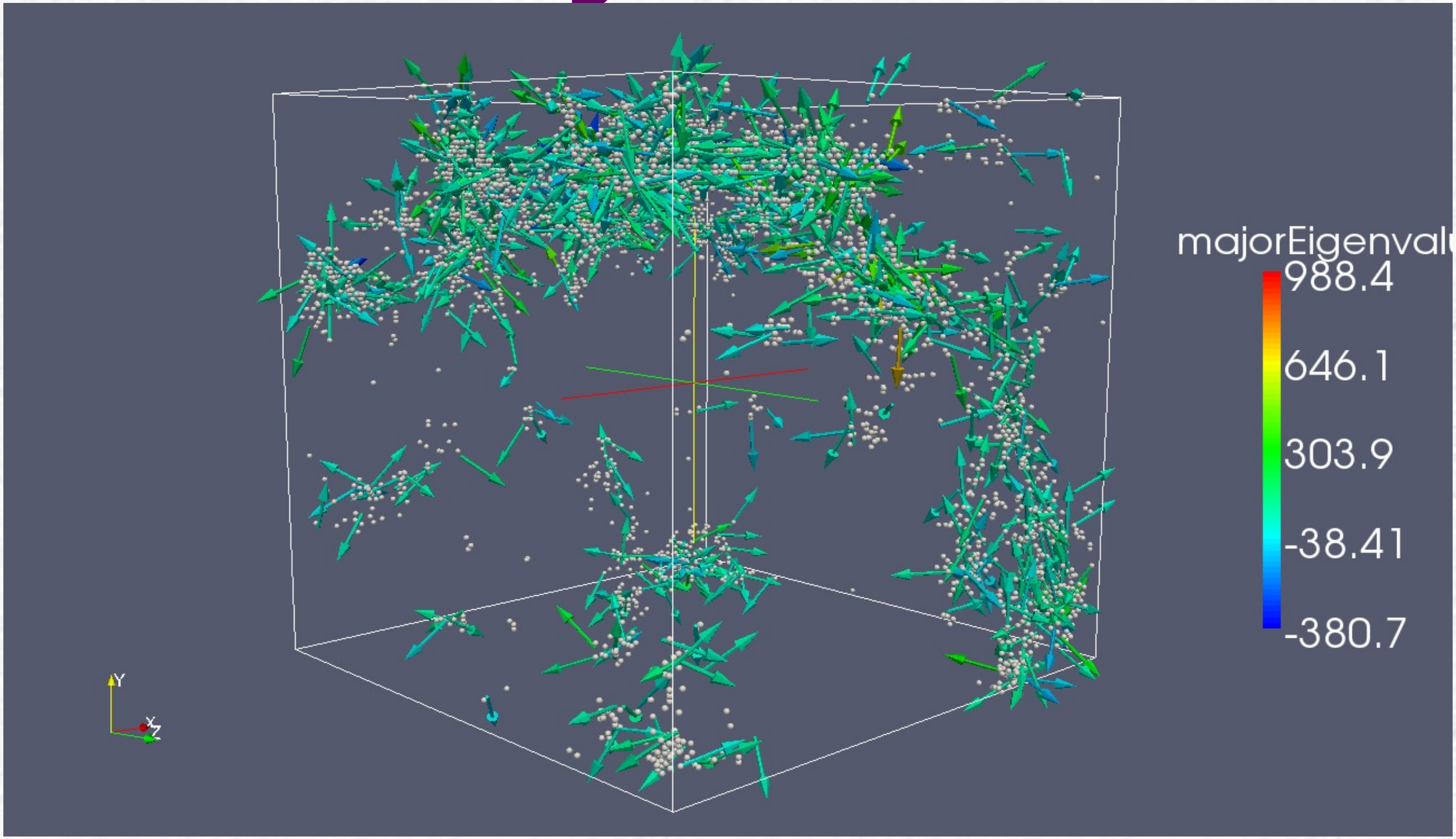
- The threshold is set between -0.05 and 0.05.



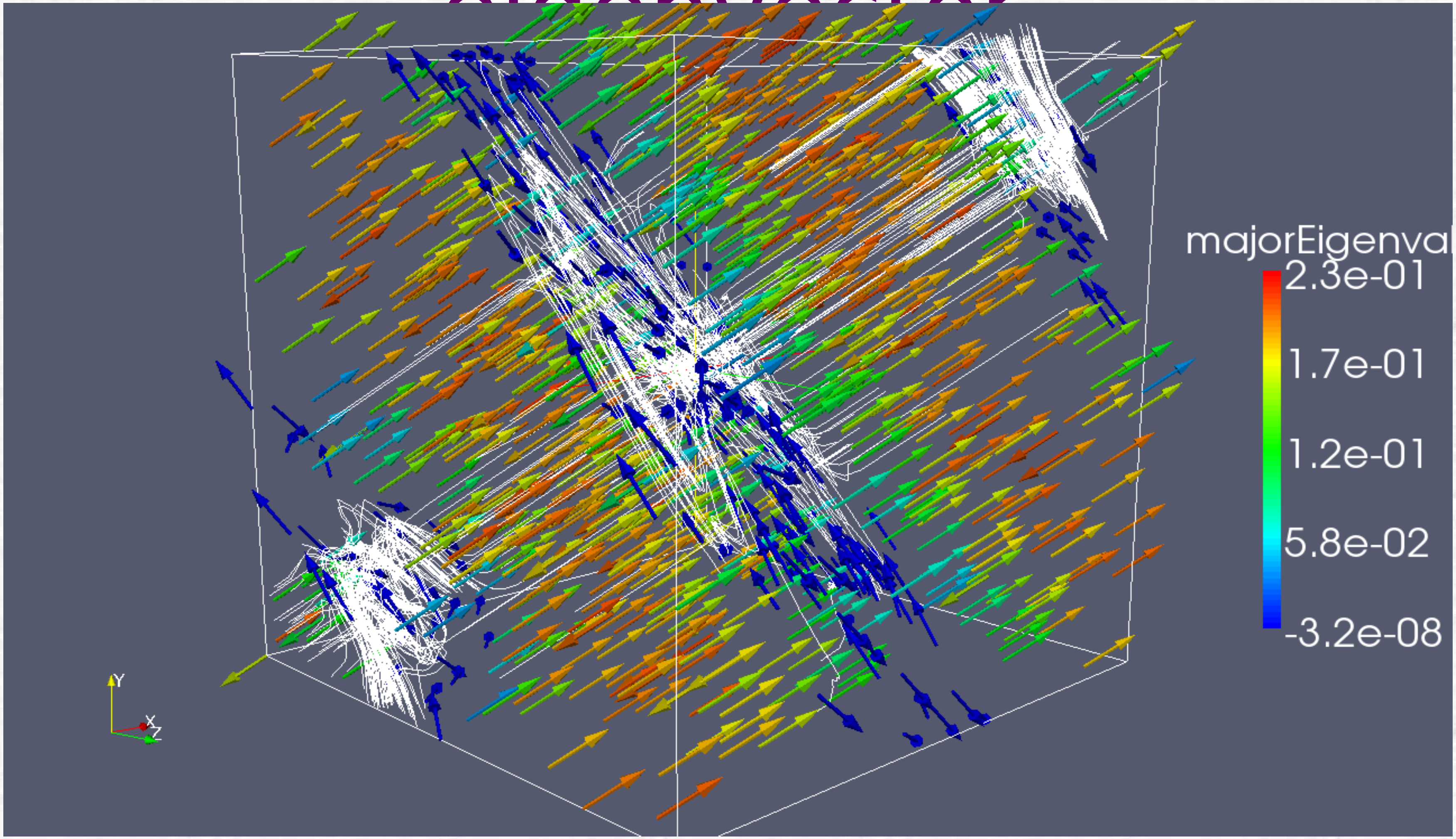
Pancake: Max-Min Eigenvalue



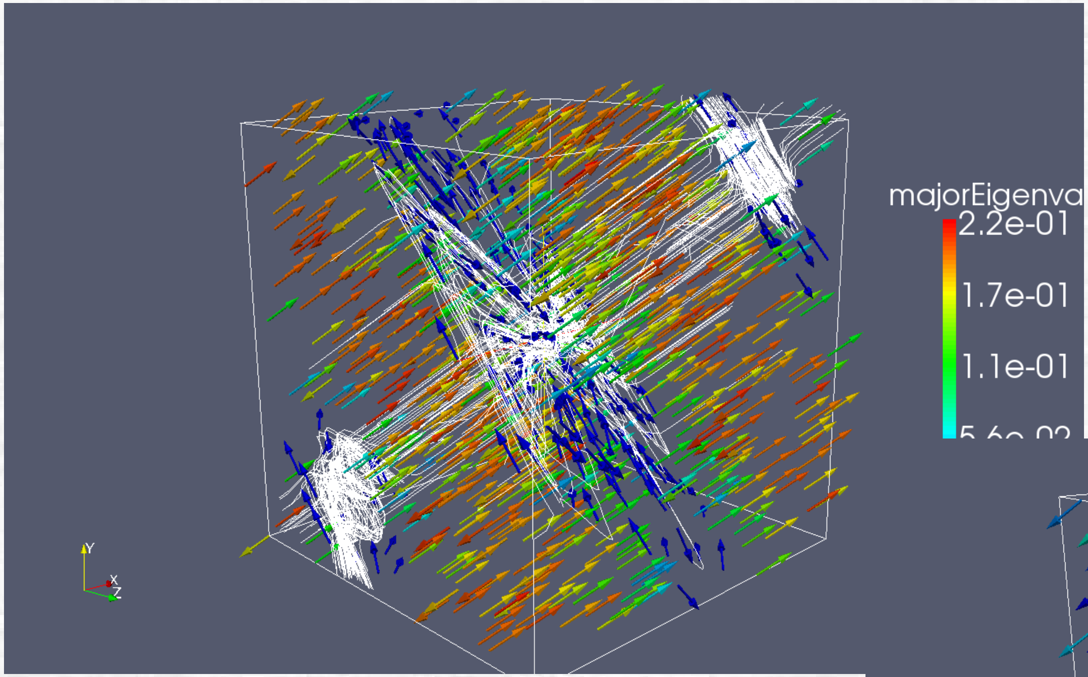
MC²: High Shear Flow



Pancake: major eigenvector

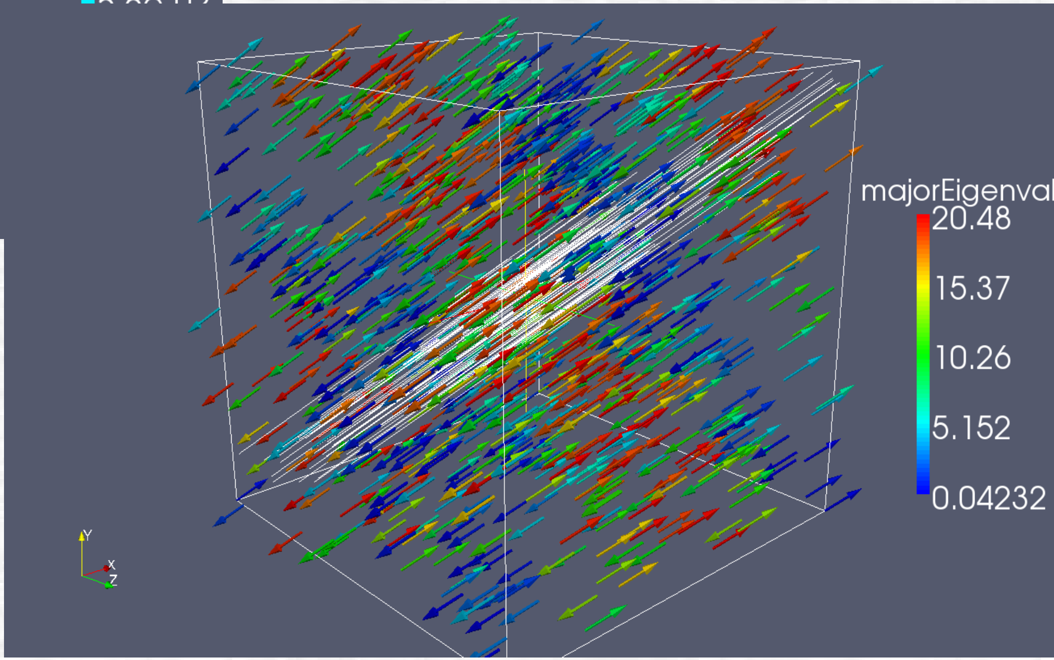


Pancake Data: Major Eigenvector Field

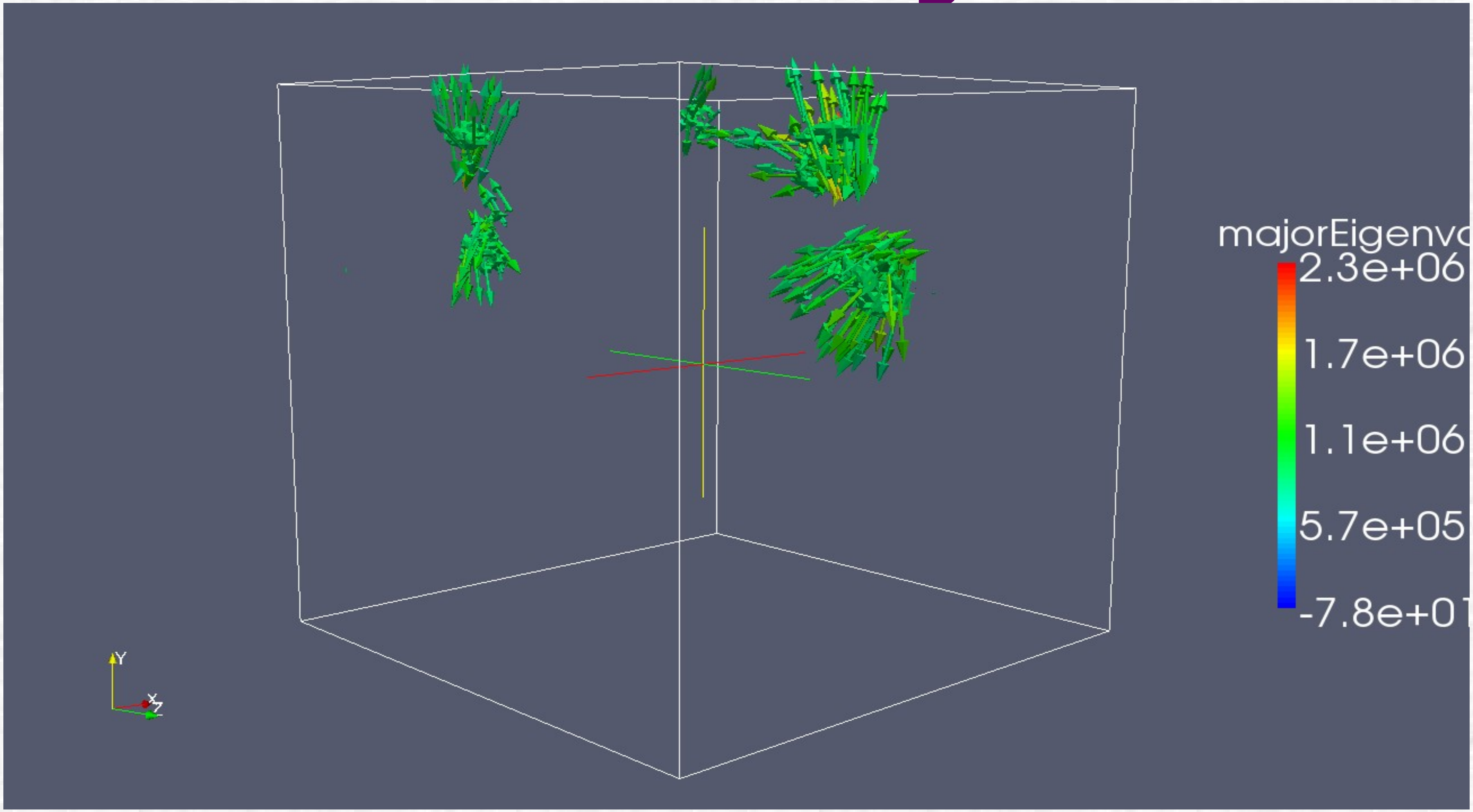


Method 1

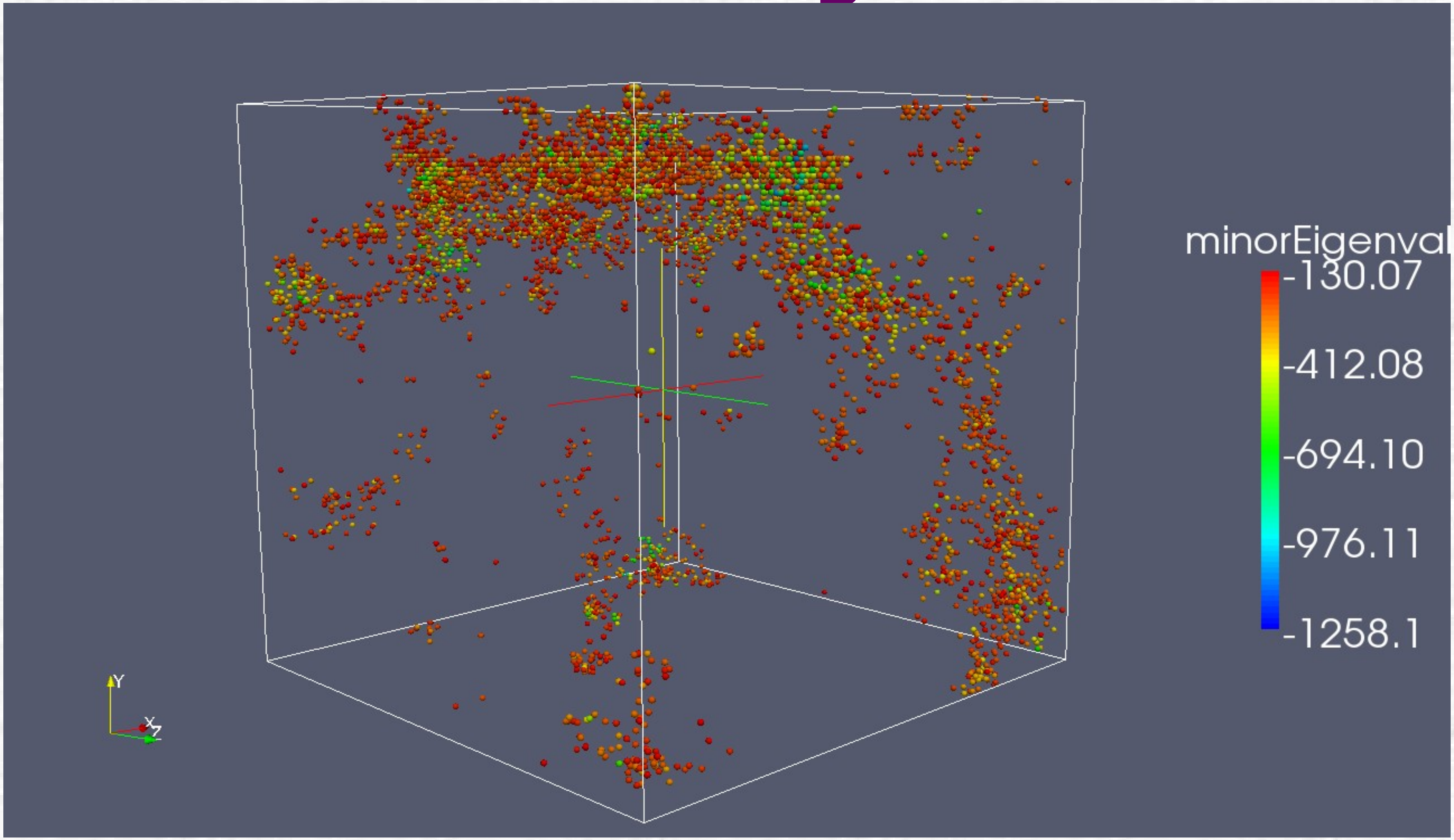
Method 2



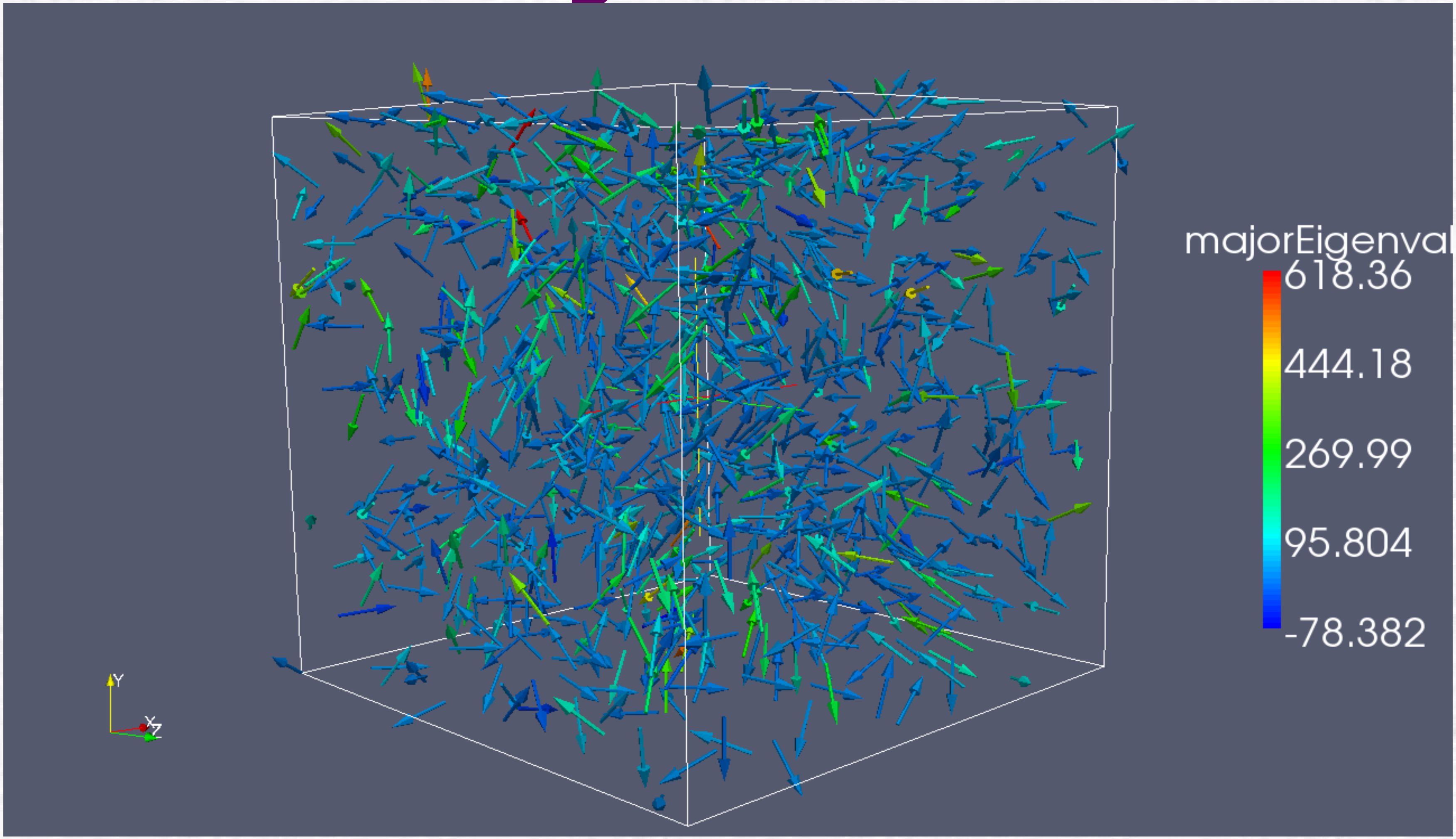
MC²: Max-Min Eigenvalue

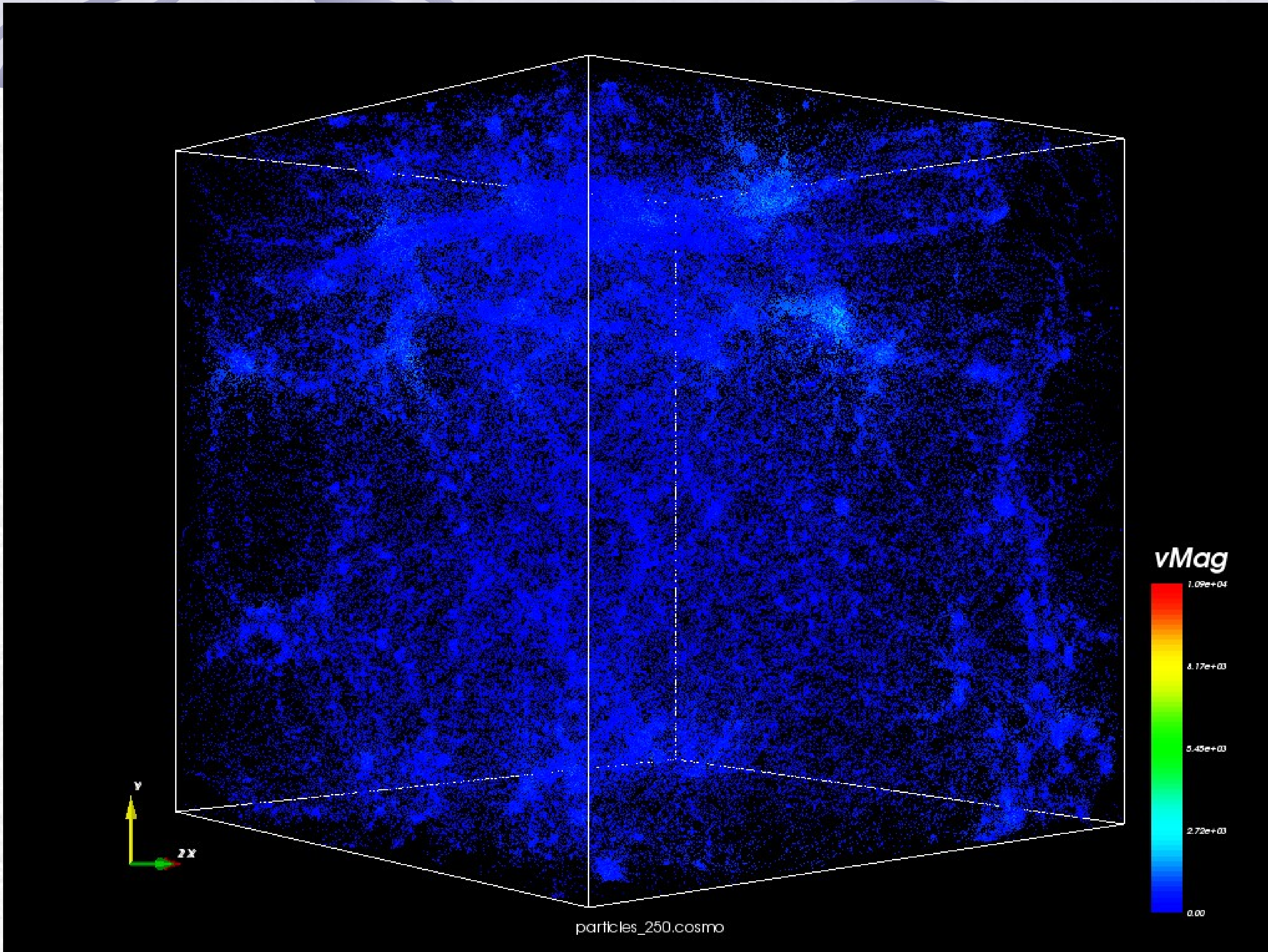


MC^2: Minor Eigenvalue



MC²: High Shear Flow





vMag
1.09e+04
8.17e+03
5.45e+03
2.72e+03
0.00
Y
Z X
particles_250.cosmo