Visualizing Velocity Fields from Fusion Simulations using Advected Particle Trajectories

Franz Sauer[1], Yubo Zhang[1], Weixing Wang[2], Stephane Ethier[2], Kwan-Liu Ma[1]

[1] University of California at Davis
[2] Princeton Plasma Physics Laboratory

Introduction

- Understanding velocity fields is important for studying magnetic confinement
- Particle advection is an intuitive tool
- Alone cannot highlight specific features of interest
- Develop a set of mapping, filtering, and projection methods

Overview

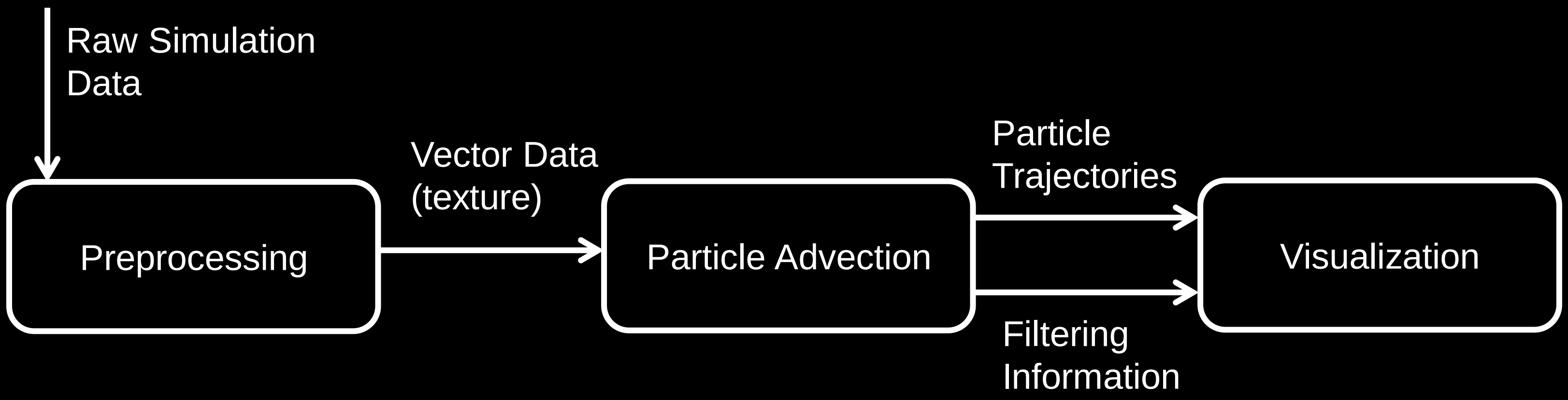
- Simulation and Data
- Implementation
- Exploration Techniques
  - Color Functions
  - Filters
  - View Projections
- Conclusion and Future Work

Simulation and Data

- Gyrokinetic Tokamak Simulation (GTS) Code
- Simulate and study turbulence and transport
- Output as a vector field on an unstructured mesh
- Particle advection as a way of reintroducing particle representation
- Time-varying field with 830 timesteps

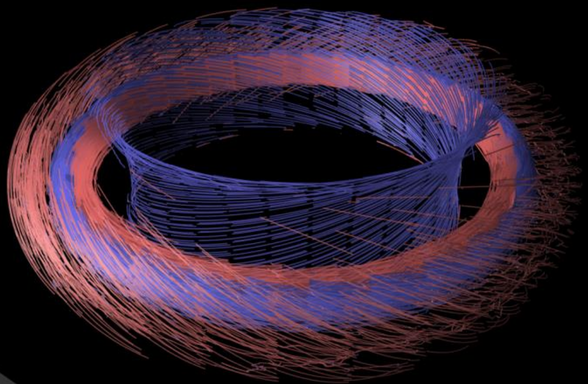
Implementation

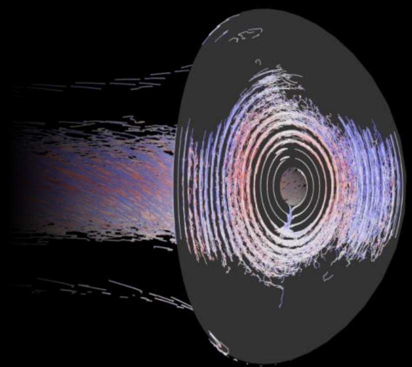
- Preprocessing
  - Convert raw data to a 3D texture
- Particle advection
  - Seed and generate trajectories/calculate filter info
- Visualization
  - Draw illuminated pathlines/realtime interactivity

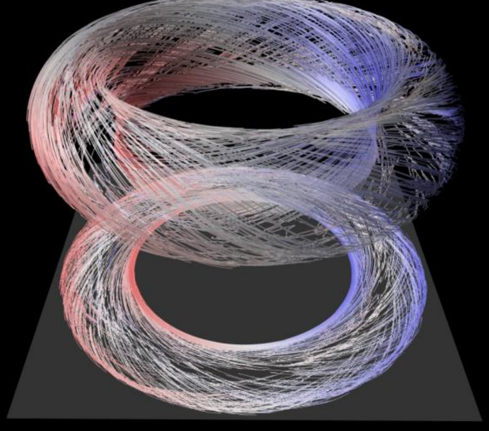


Exploration Techniques

- Color Functions
  - Toroidal Velocity
  - Flux Normal Velocity
  - Scalar Field Value
- Filters
  - Turns
  - Radial Displacement
  - Entropy
- View Projections
  - Poloidal Cutting Slice
  - Floor Projection
  - Expanded View

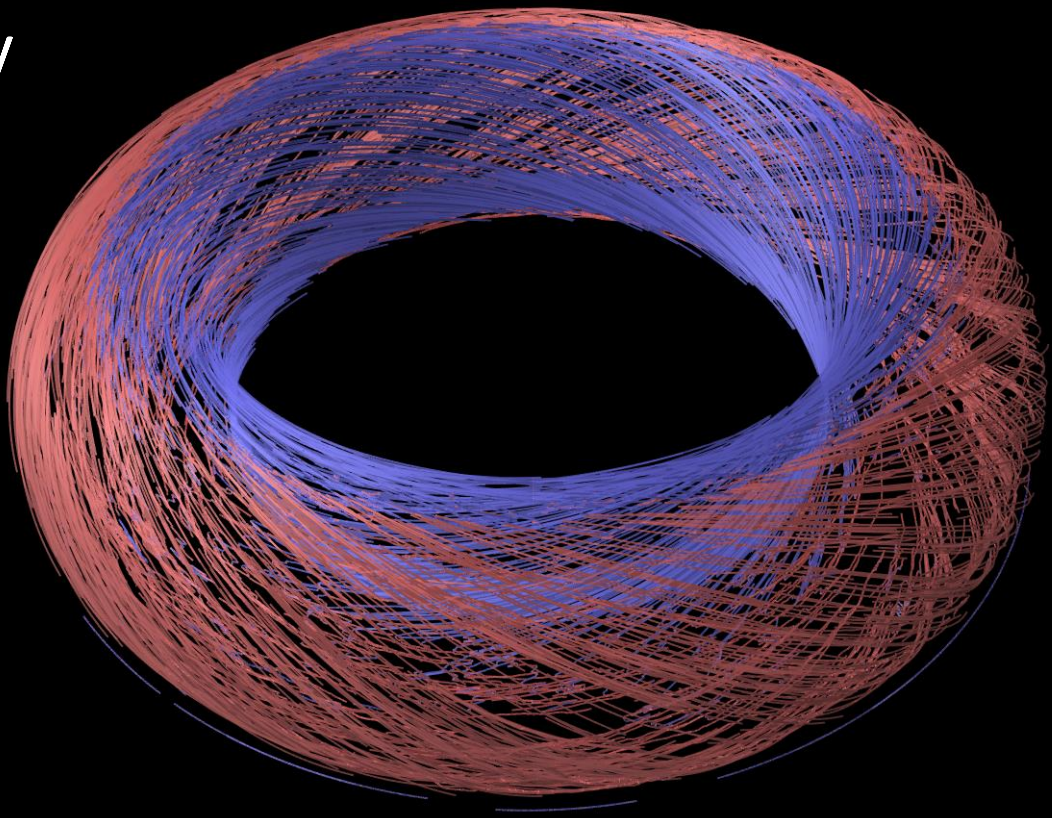


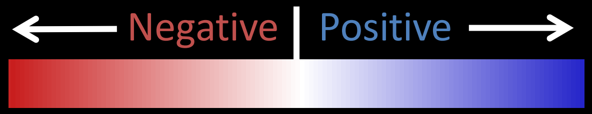




Color Functions – Toroidal Velocity

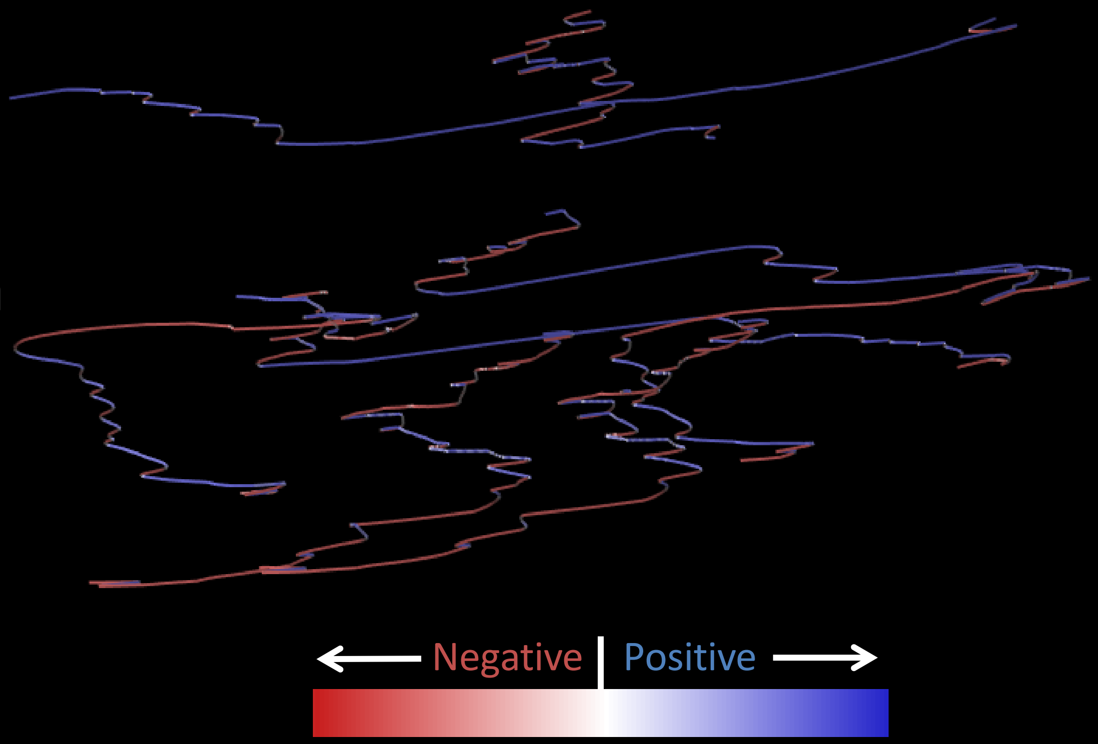
- Velocity projection onto the toroidal direction
- Blue – positive toroidal velocity (counter-clockwise)
- White – low velocity or perpendicular motion
- Red – negative toroidal velocity (clockwise)





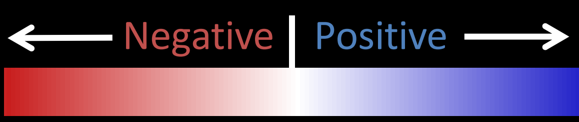
Color Functions – Toroidal Velocity

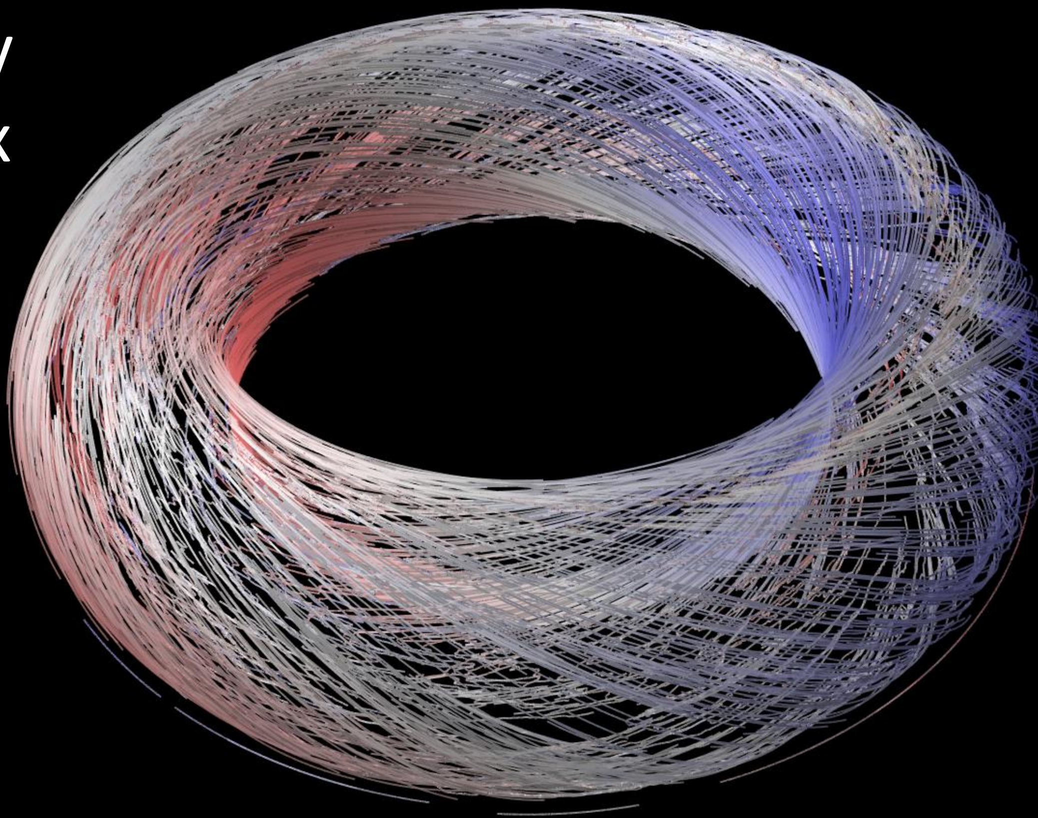
- Variation of color along trajectory
- Insights into acceleration/deceleration of particle
- Trajectories fade rapidly between red and blue
- Quick acceleration and deceleration when changing direction



Color Functions – Flux Normal Velocity

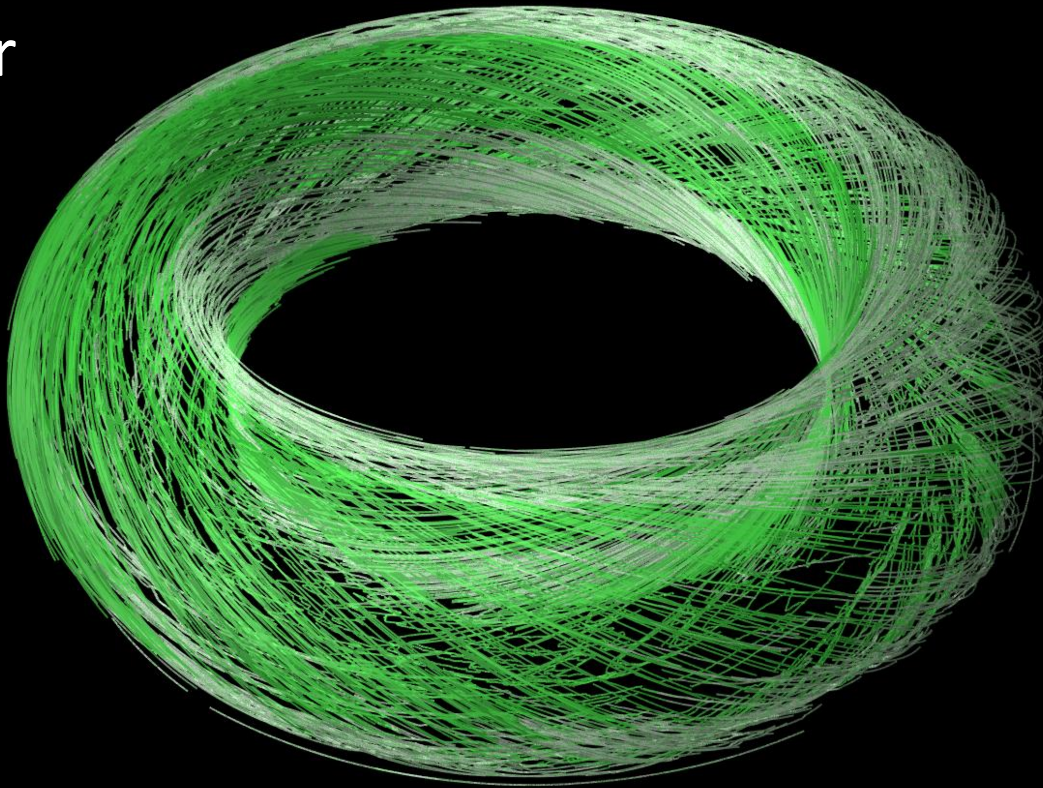
- Velocity projection onto flux surface normals
- Blue – positive flux normal velocity (towards walls)
- White – low velocity or motion along flux surface
- Red – negative flux normal velocity (away from walls)



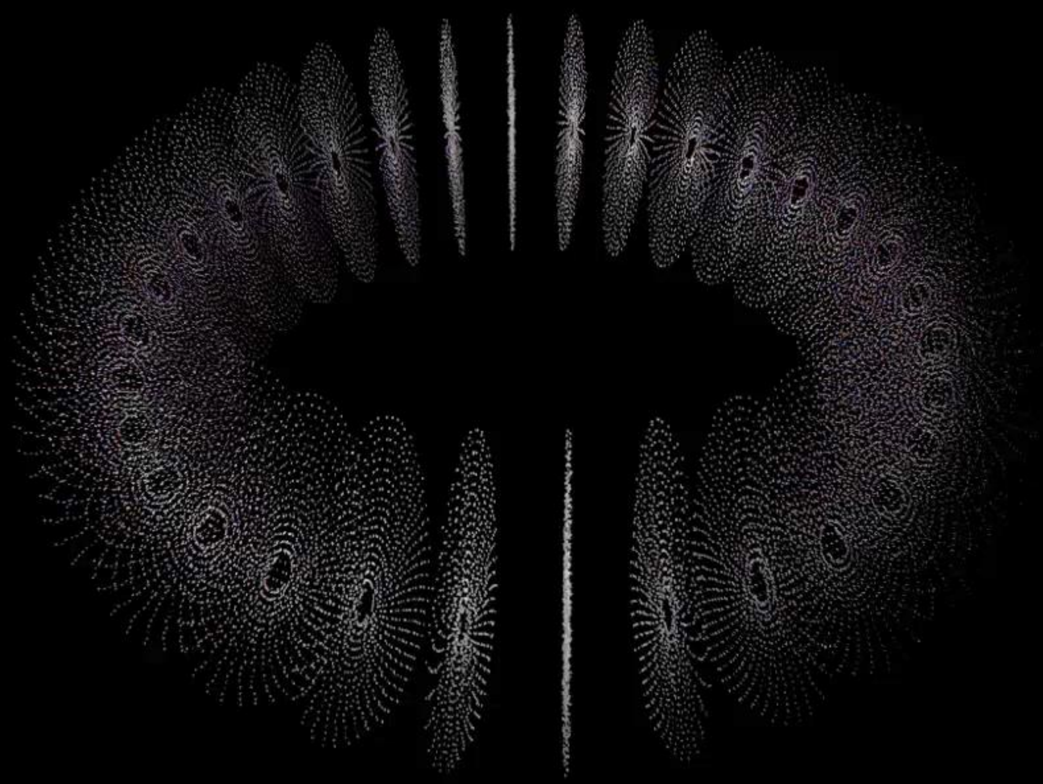


Color Functions – Scalar Field Value

- Color trajectories according to a scalar field value
- Green – higher scalar values
- White – lower scalar values
- Potential or density fields



Video

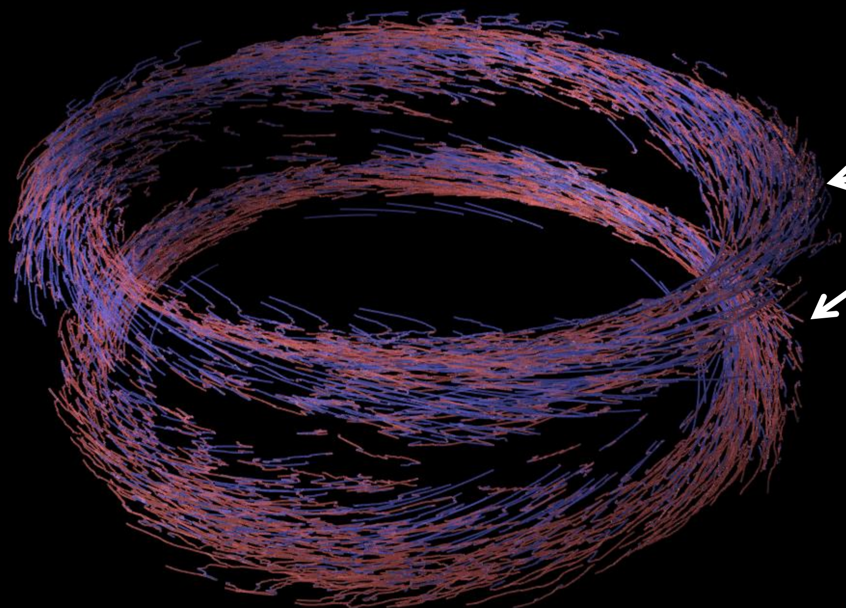


Full Torus View – All Trajectories

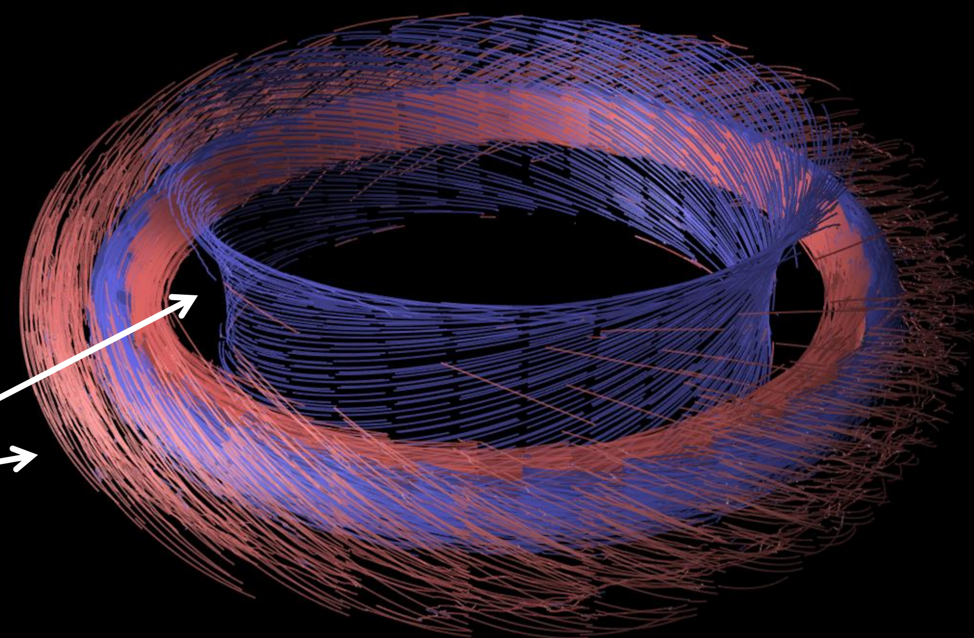
Filters - Turns

- A measurement of the number of directional changes within a trajectory
- Accumulate the number of “turns” along each trajectory
- One “turn” is a directional change greater than 90 degrees
- Both sudden and gradual directional changes
- Good at highlighting turbulence

Filters - Turns



High Number of Turns



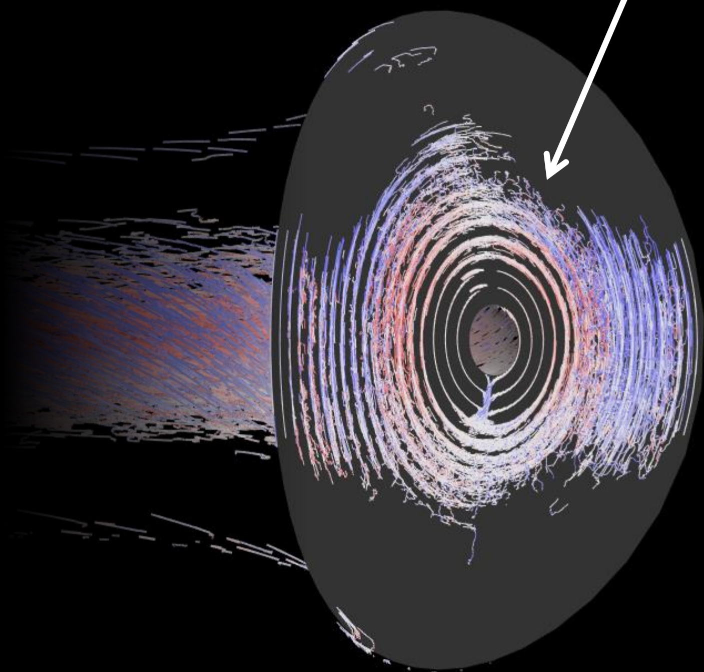
Low Number of Turns

Filters – Radial Displacement

- A measurement of motion towards or away from the magnetic axis
- Project the displacement vector in the radial direction
- Accumulate the magnitude of the displacement along each trajectory
- Good at highlighting transport into and out of the plasma core

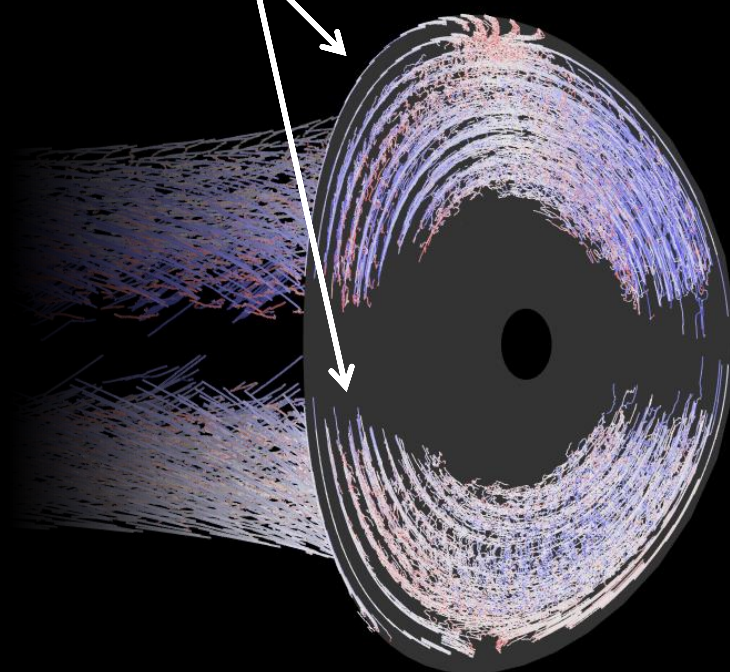
Filters – Radial Displacement

Little radial motion near the magnetic axis



Low Radial Displacement

A lot of radial motion near the top and bottom of the torus

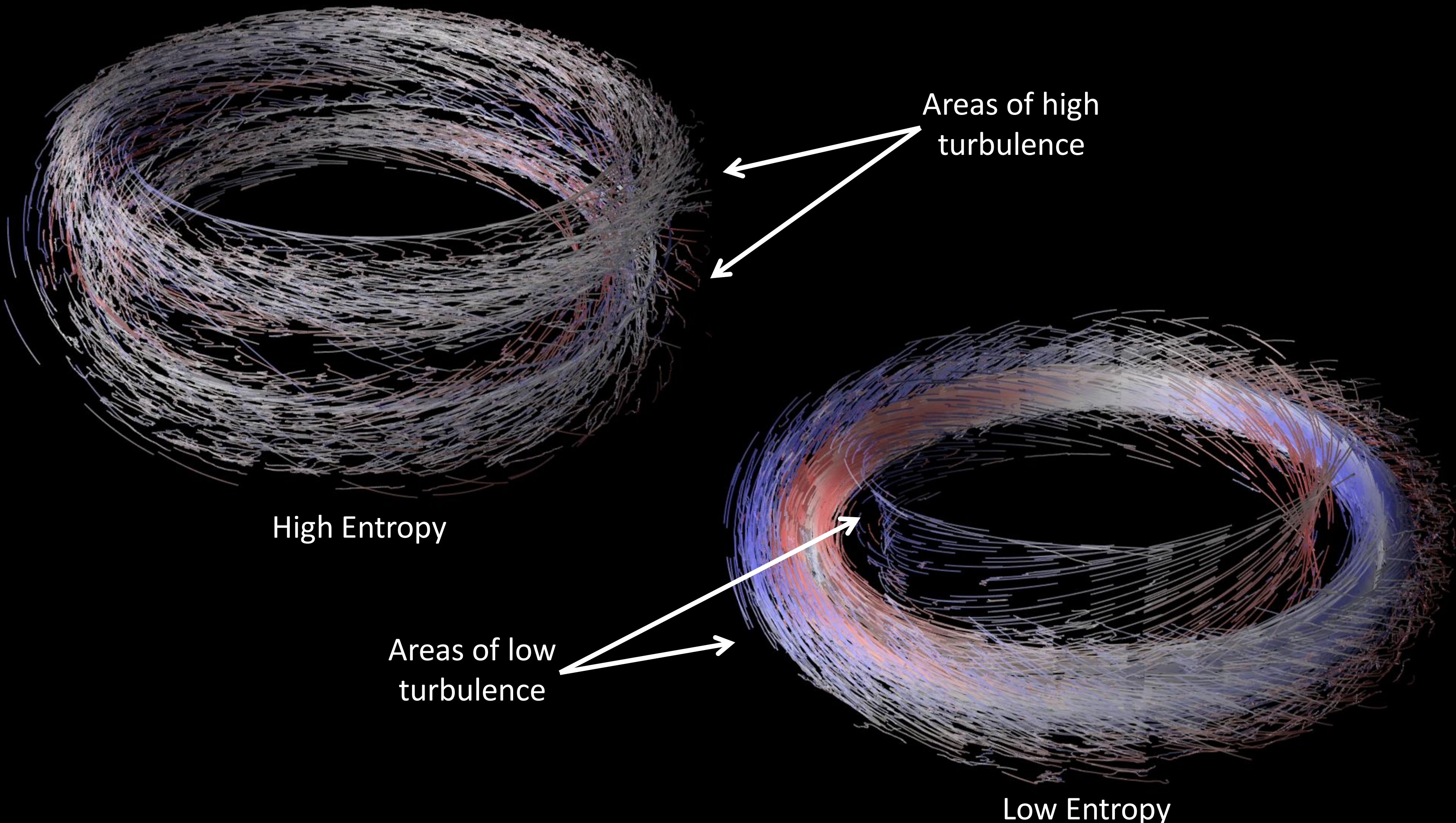


High Radial Displacement

Filters - Entropy

- A measurement of angular variation along the trajectory
- $E_A = -\frac{1}{\log_2(m)} \sum_{j=0}^{m-1} \frac{A_j}{L_A} \log_2 \frac{A_j}{L_A}$
- Perfect circles or straight lines have a low entropy
- Trajectories with a varying angle will have a high entropy
- A different way of highlighting turbulence

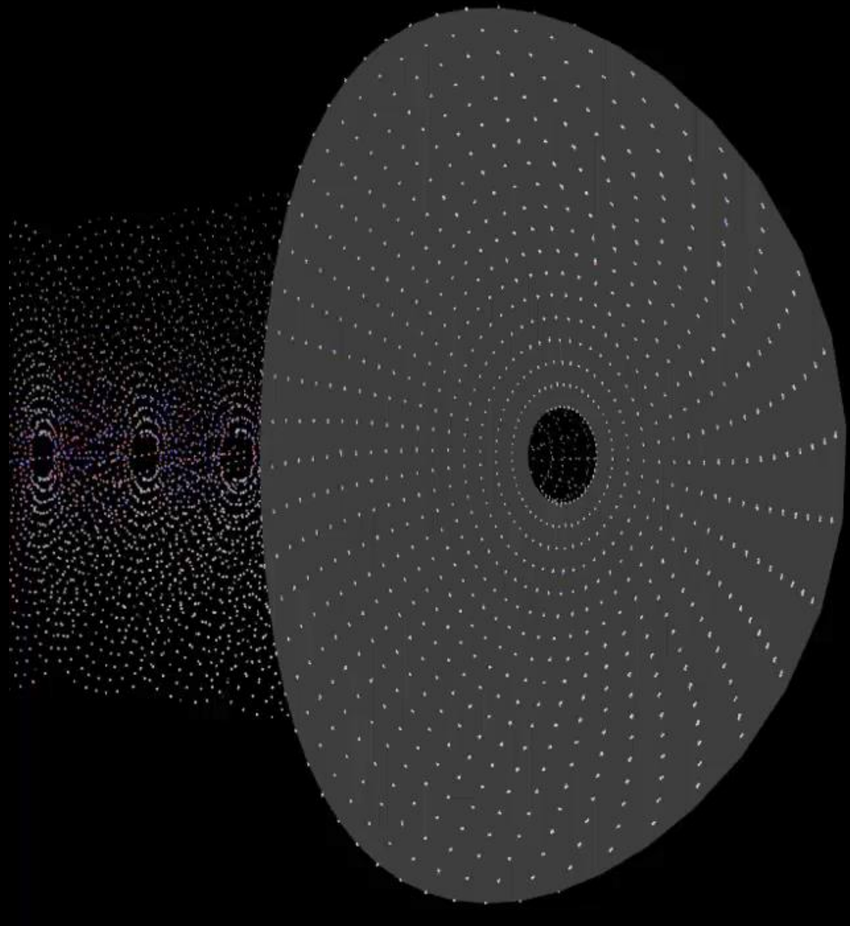
Filters - Entropy



View Projections – Poloidal Cutting Slice

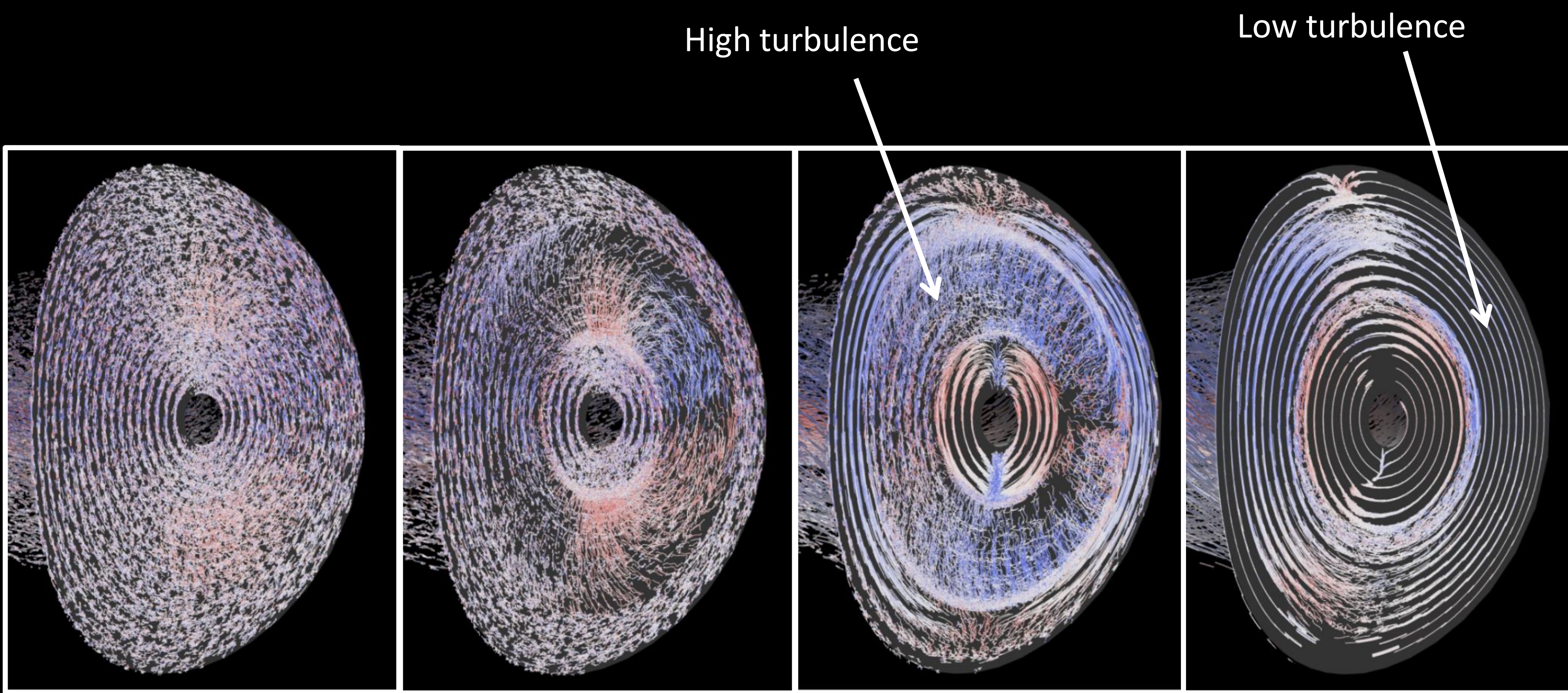
- Project trajectories onto a poloidal cutting slice
- Allows user to look along the toroidal direction
- Choose to project from specific toroidal positions
- Highlights radial and poloidal motion

Video



Poloidal Cutting Slice– All Trajectories

View Projections – Poloidal Cutting Slice



Phase 1: Small initial turbulence

Phase 2: Exponential growth in turbulence

Phase 3: Turbulence becomes saturated

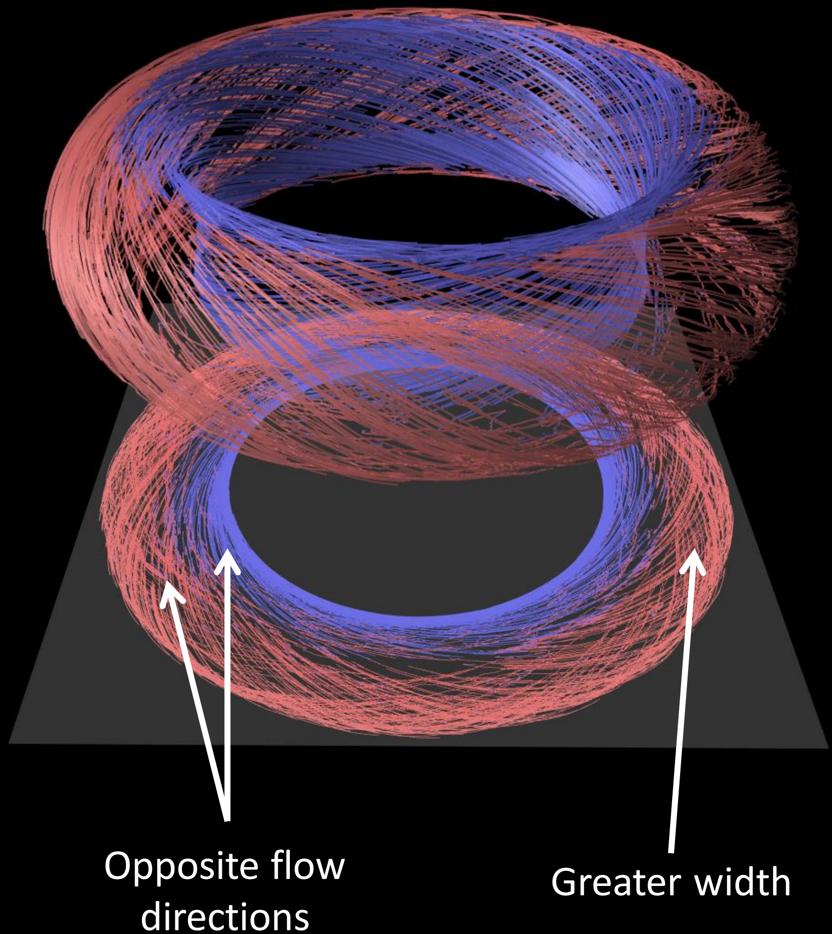
Phase 4: Turbulence decreases

View Projections – Drop Projection

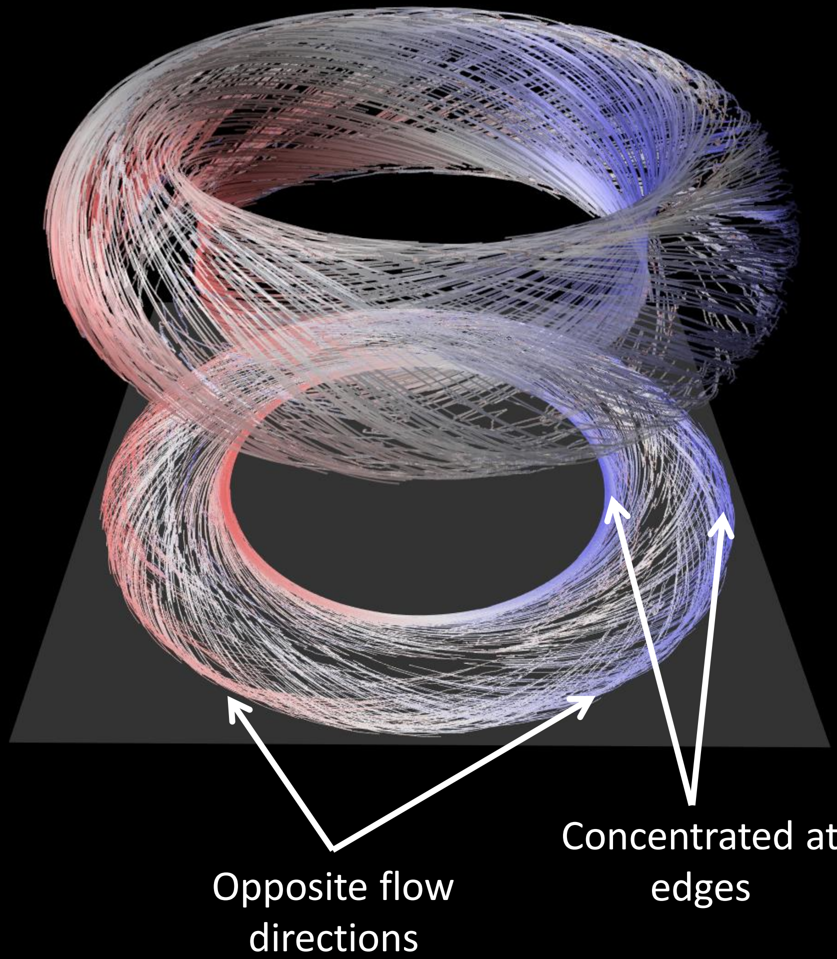
- Project trajectories onto a plane below the torus
- Highlights toroidal differences and differences between the high and low field sides
- New insights that are difficult to see in the full torus view

View Projections – Drop Projection

Toroidal Coloring

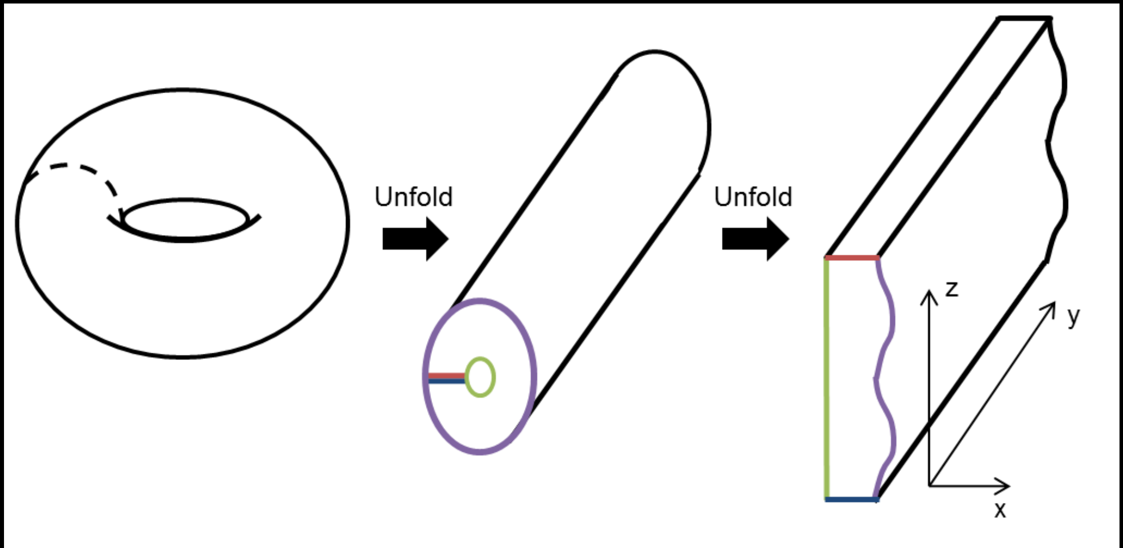


Flux Normal Coloring



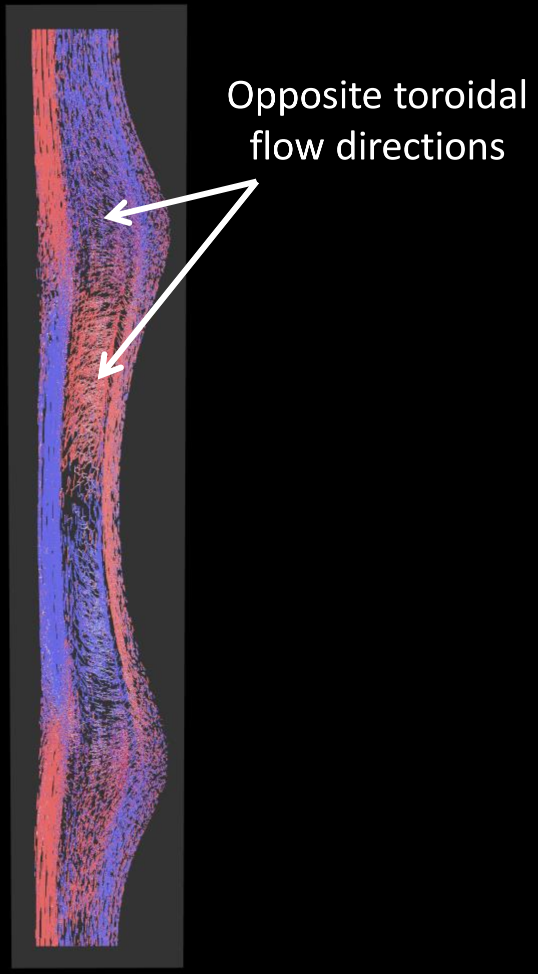
View Projections – Expanded View

- Unfold the torus into a 3D rectangular volume
- Project trajectories accordingly
- Toroidal, radial, and poloidal directions lie along flat axes
- Reduces occlusion

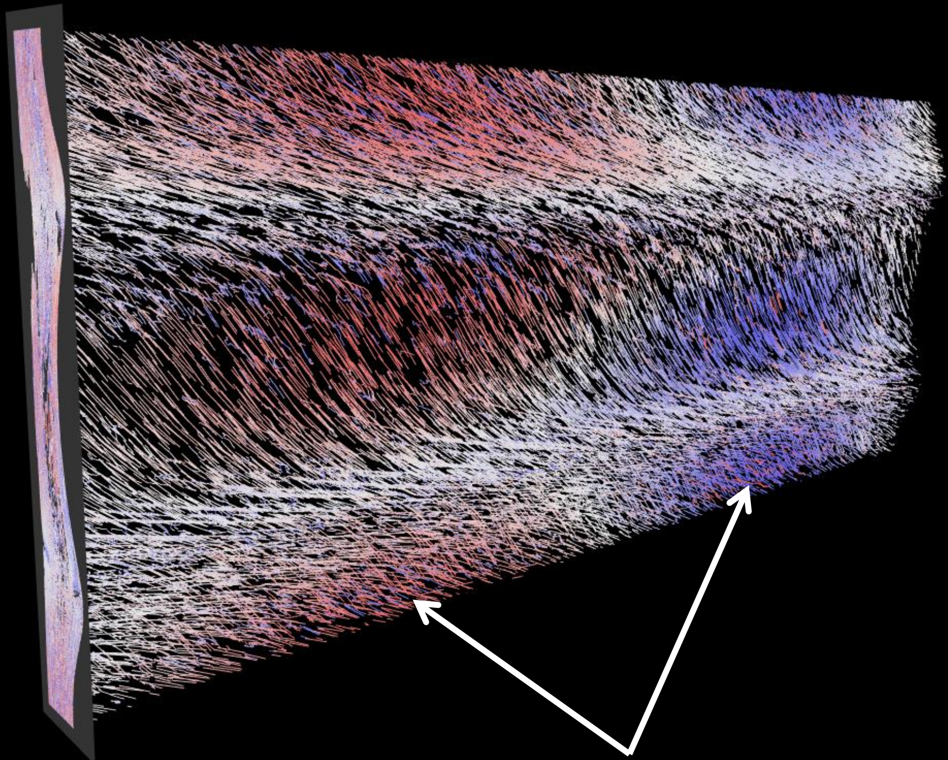


View Projections – Expanded View

Toroidal Coloring - Slice



Flux Normal Coloring - Volume



Conclusions and Future Work

- We develop a number of visualization tools to help understand features in flow fields
  - Color functions
  - Filters
  - View projections
- In situ implementations
  - Construct high resolution flow lines
  - Apply filtering techniques
- Better incorporate other data types (scalar data)

Thank you for your time