Advanced Visualization Techniques for Plasma Physics Simulations

Kwan-Liu Ma

SciDAC Institute for Ultrascale Visualization

Visualization & Interface Design Innovation

Introduction

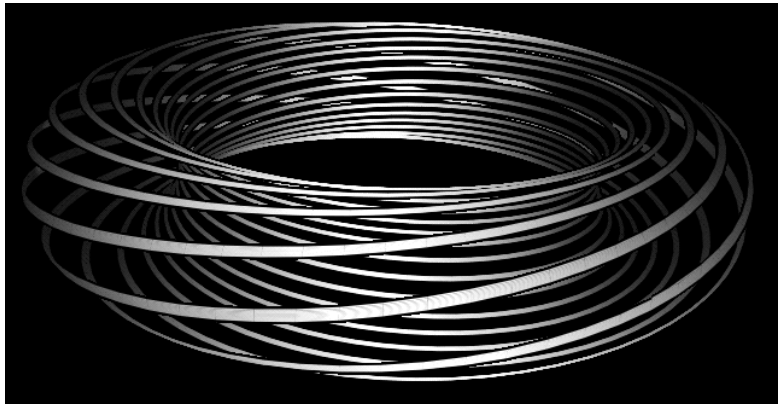
- SciDAC Institute on Ultrascale Visualization
- 5 year project sponsored by DOE's SciDAC 2
- Collaborations with fusion scientists:
  - Dr. Stephane Ethier and Dr. Wei-Li Lee (PPPL)
  - Dr. CS Chang (NYU and PPPL)
  - Professor Zhihong Lin (UC Irvine)

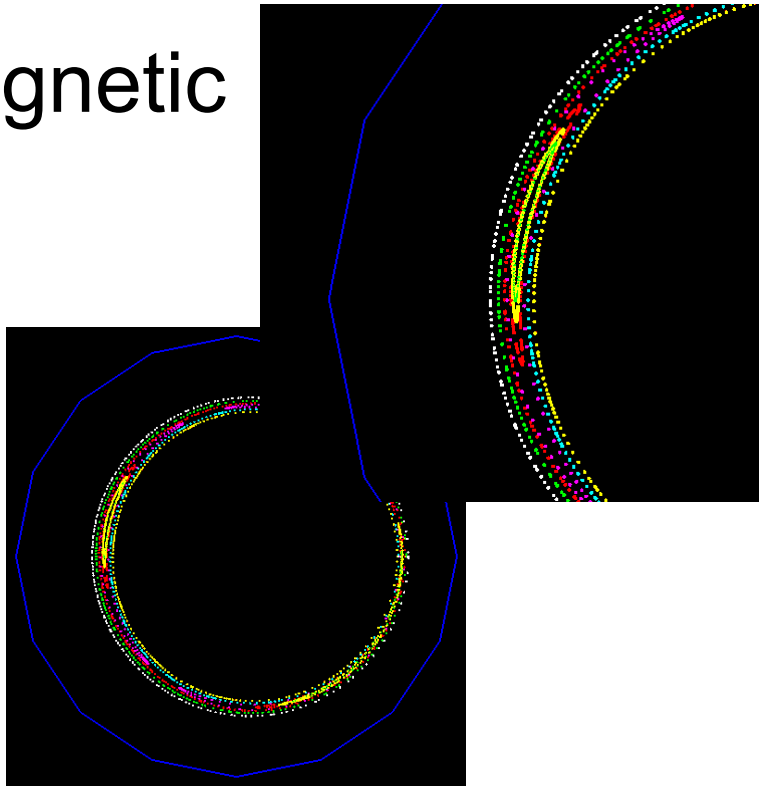
Outline

- Early Work
- Multivariate Particle Exploration
- GPU Accelerated Volume Rendering
- Multi-band Volume Visualization (New)
- Twisted Vector Field Visualization (New)
- Summary

Early Work

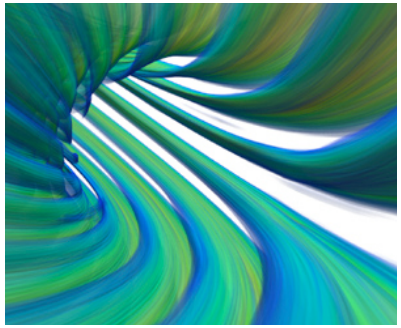
- DIII-D Tokamak (General Atomics)
- 3D field line visualization
- 2D cross sections of magnetic islands

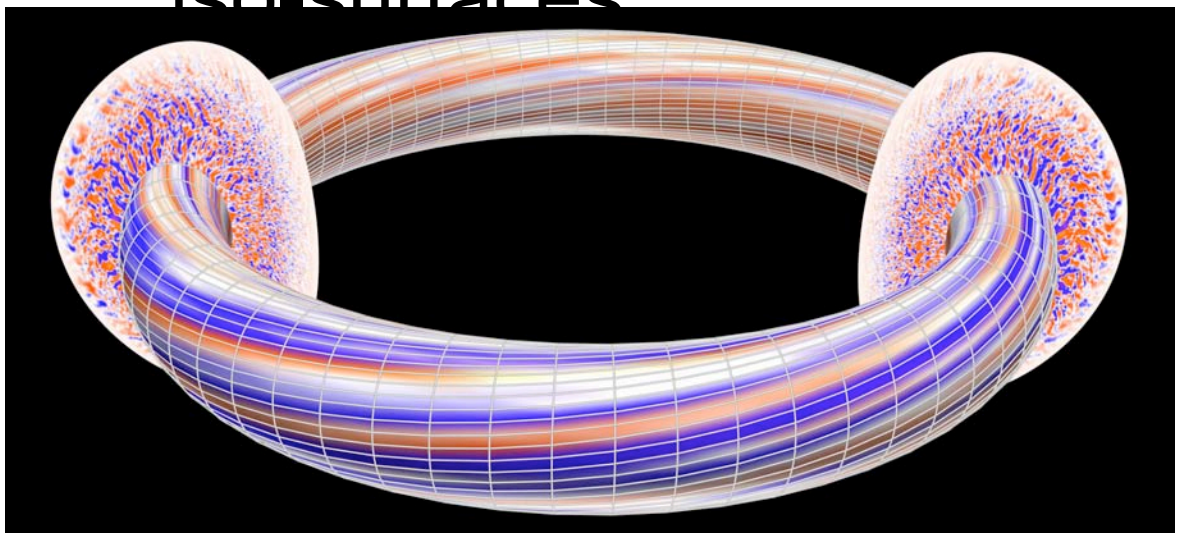


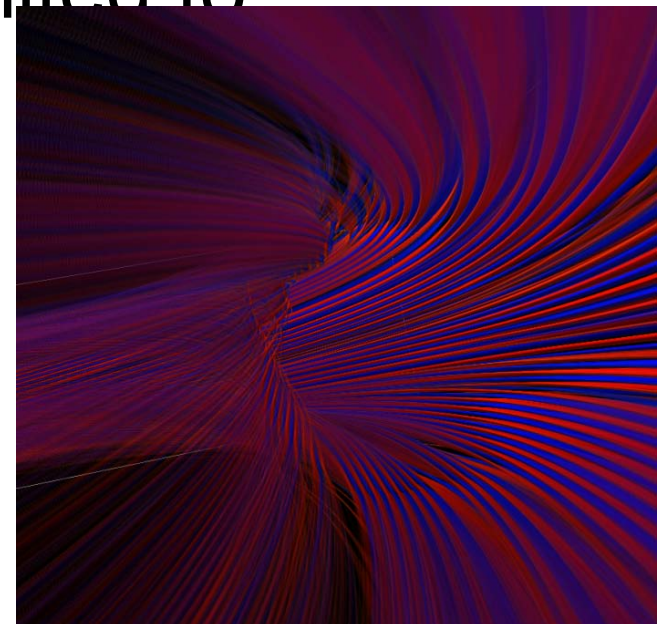


Early Work

- Scalar potential volumes
- Semi-transparent volume rendering
- Previously, 3D rendering limited to iso-surfaces

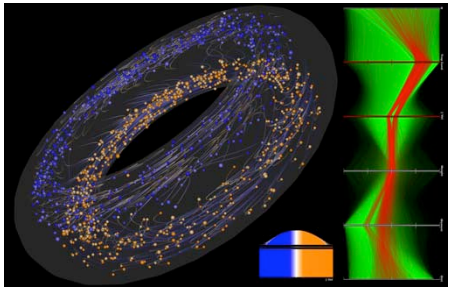






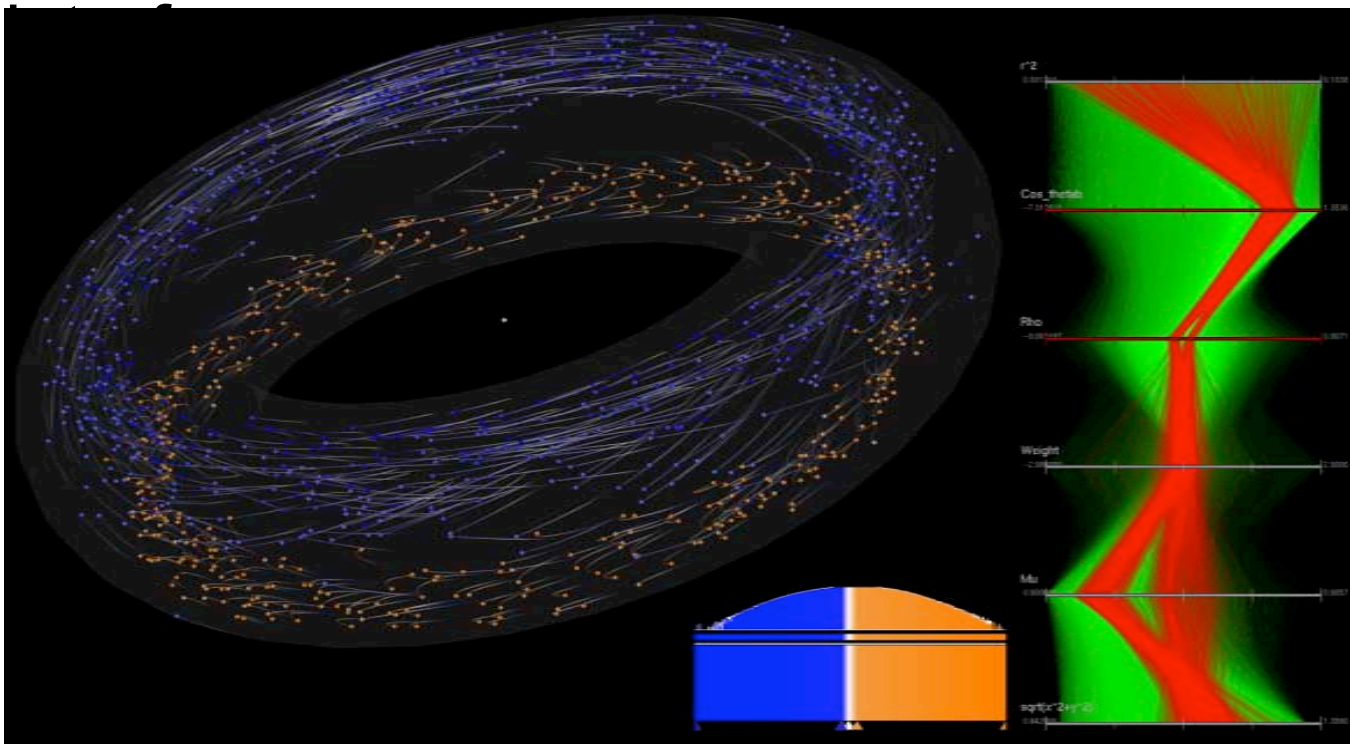
Multivariate Particle Exploration

Dual-view physical and variable space visualization tool



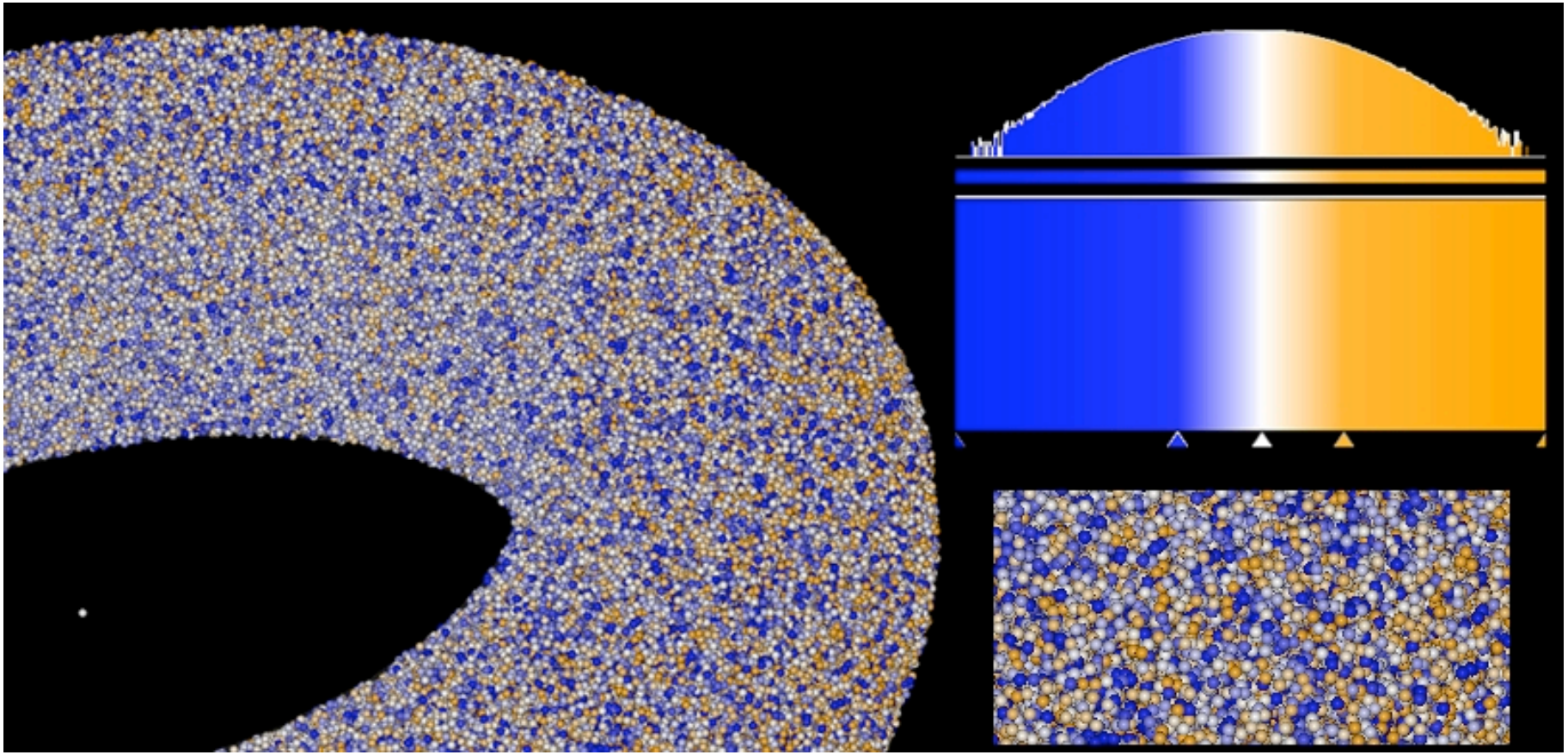
Approach

- Exploration Interface for Particle Analysis
  - Let the researcher see all variables in the data
  - Provide both visualization and filtering



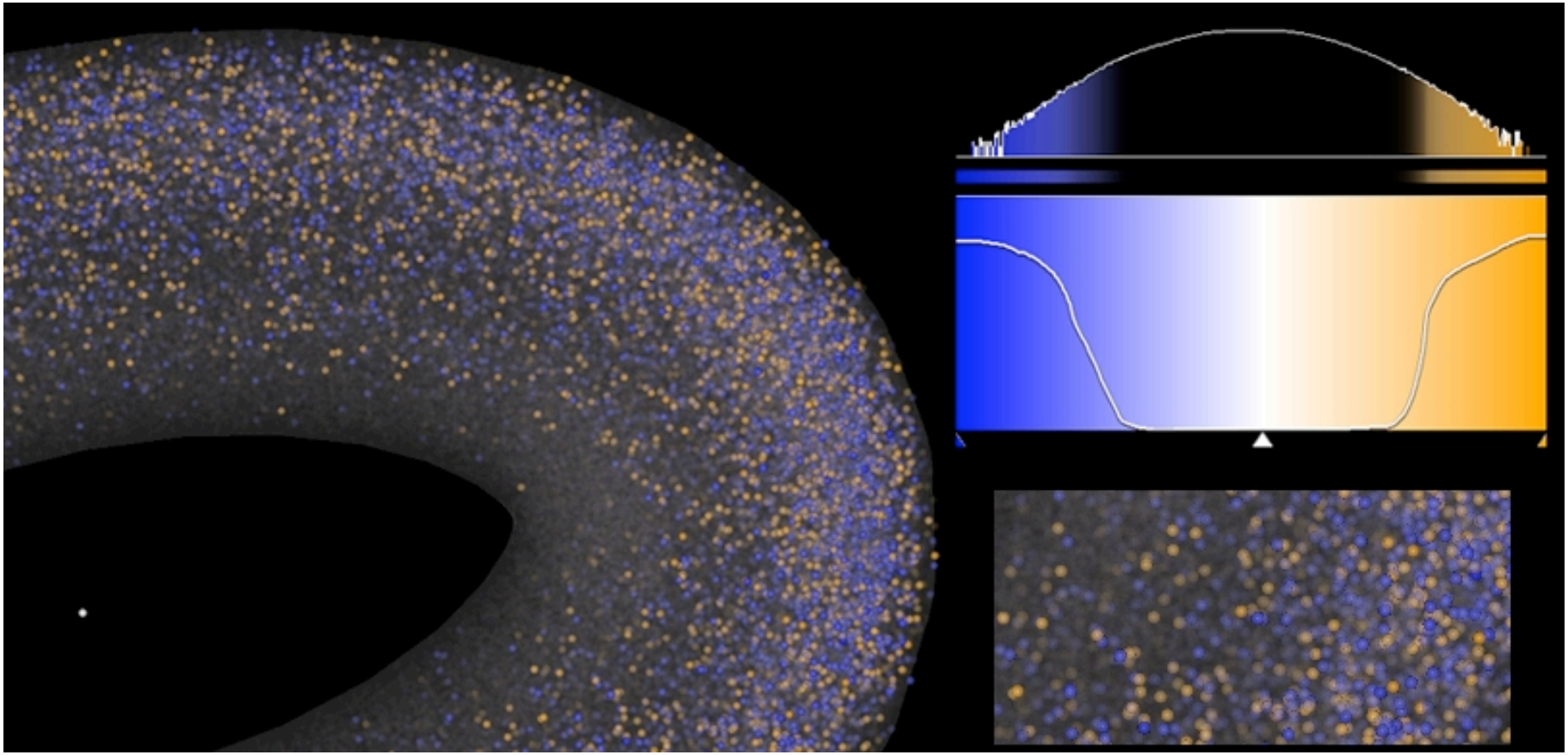
Physical Visualization

- Features hard to pick out from dense particle collections even with color



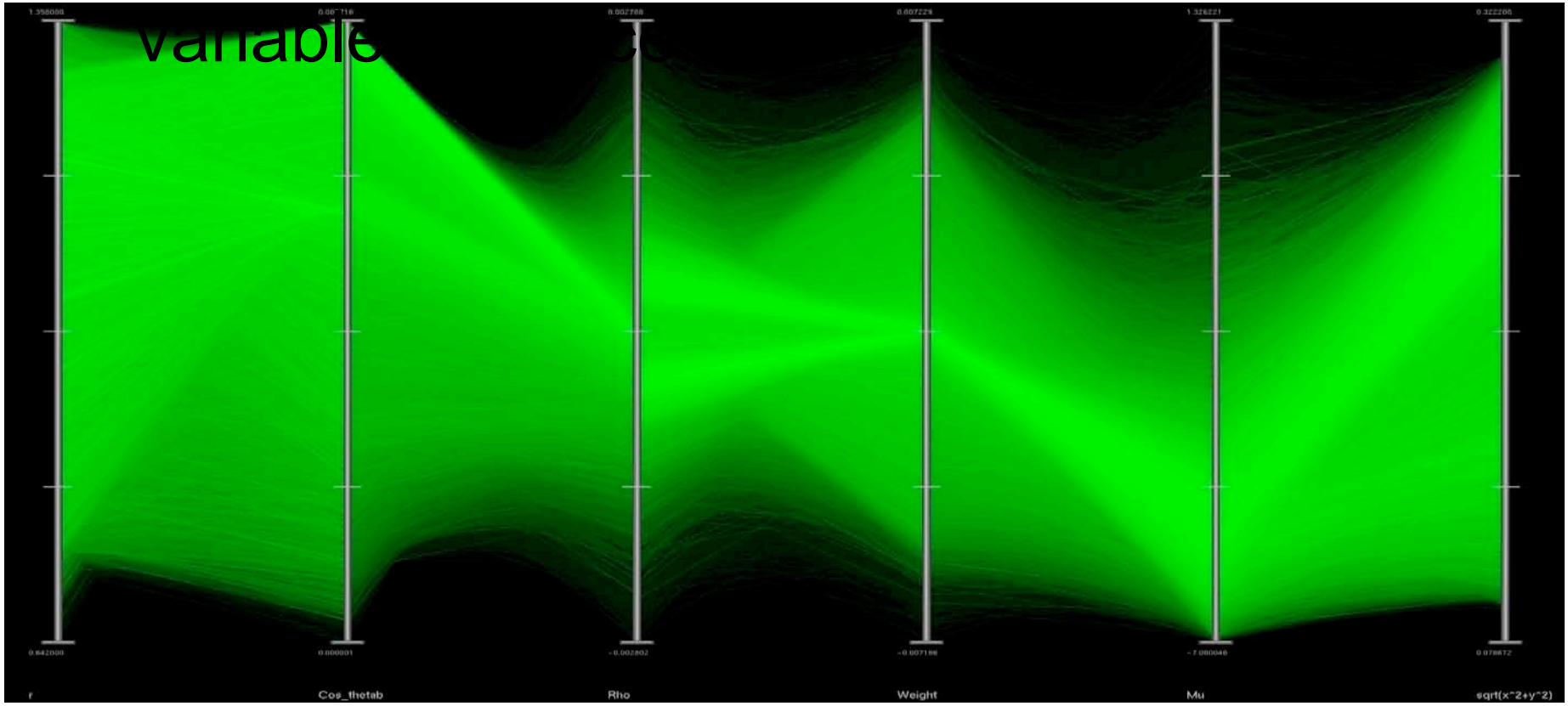
Physical Visualization

- Opacity modulation helps, but only allows a single variable to be explored



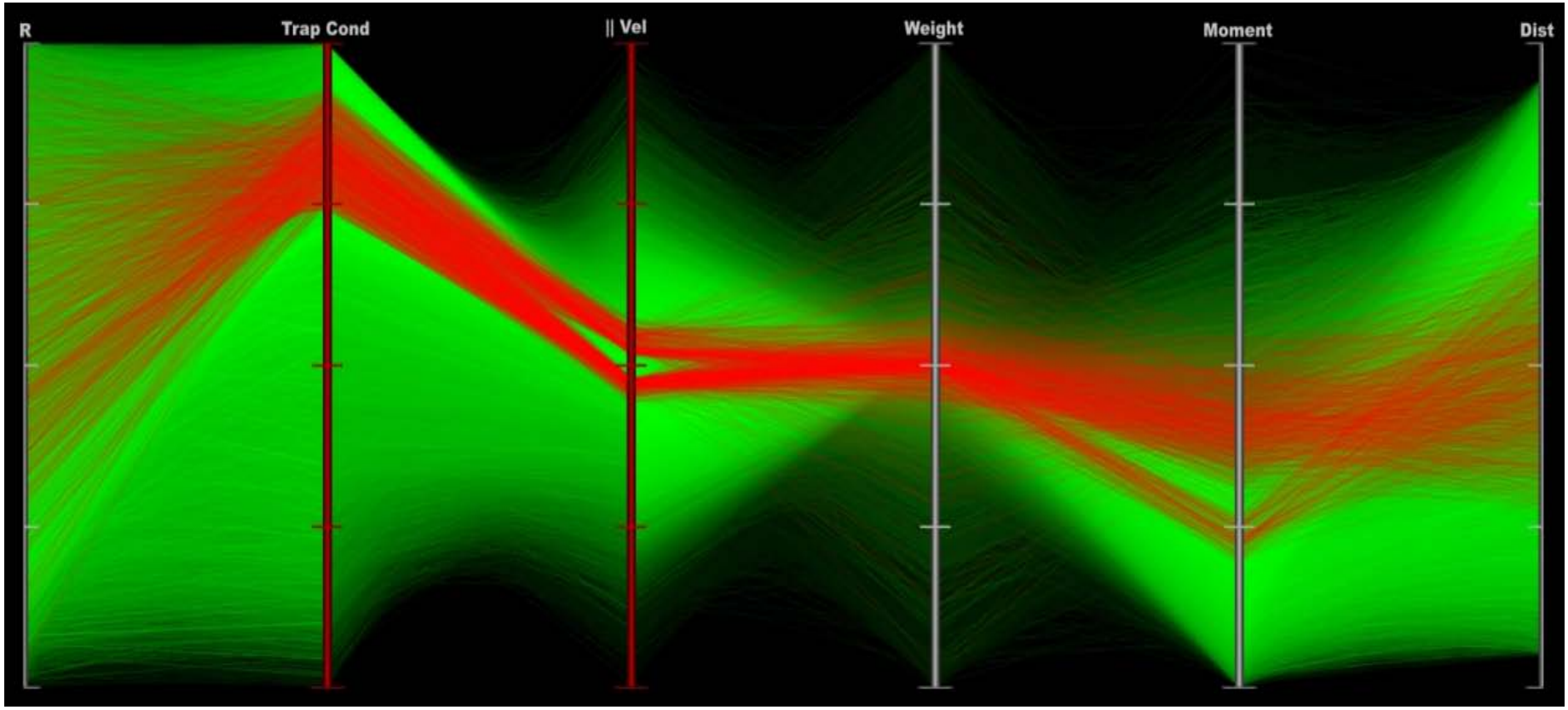
Variable Visualization

- Parallel coordinates shows value correlations between multiple pairs of variable

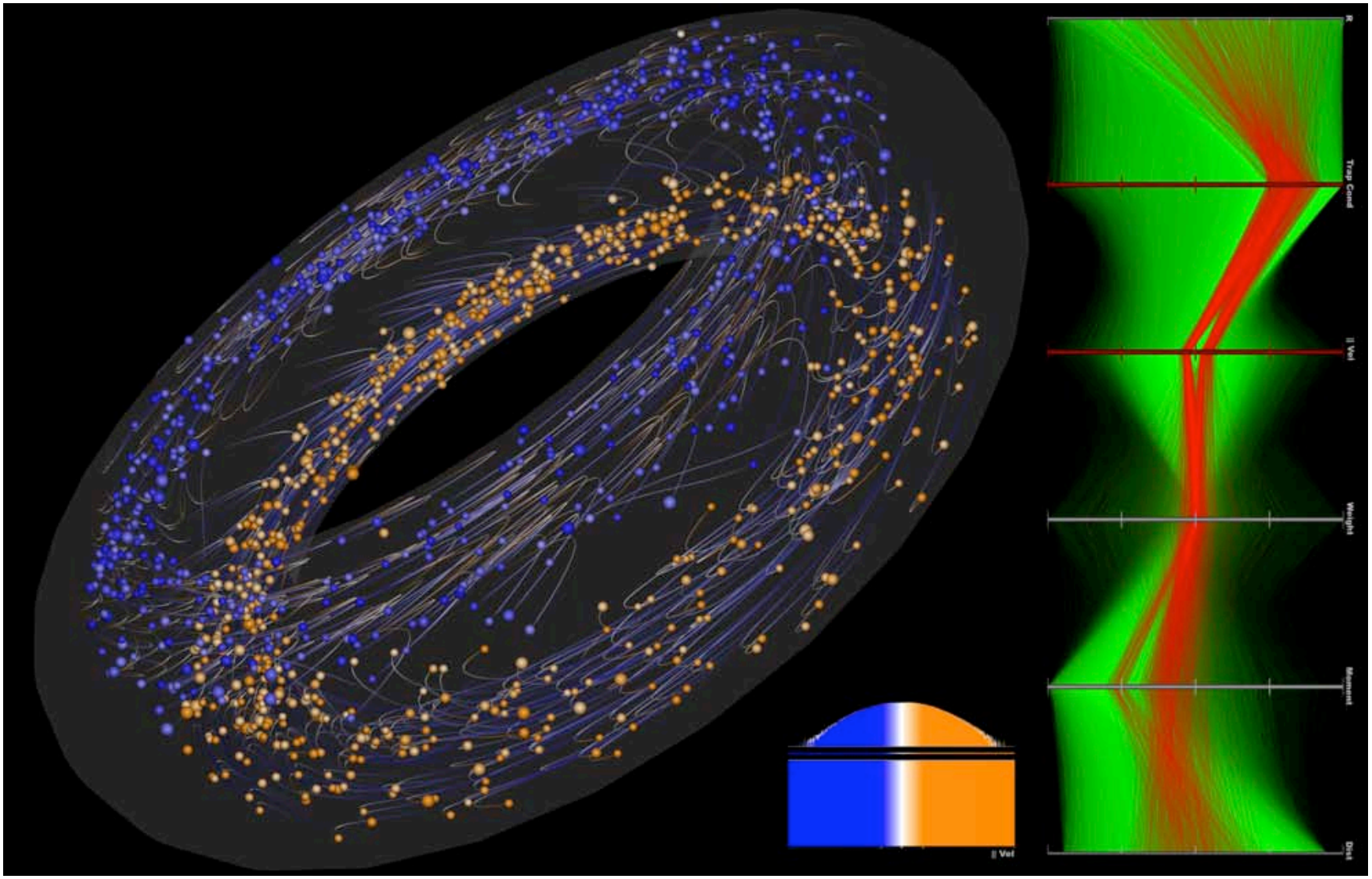


Exploration of Plasma Particles

- Ranges of values can be selected interactively, creating “focus subsets”



Trapped Particles



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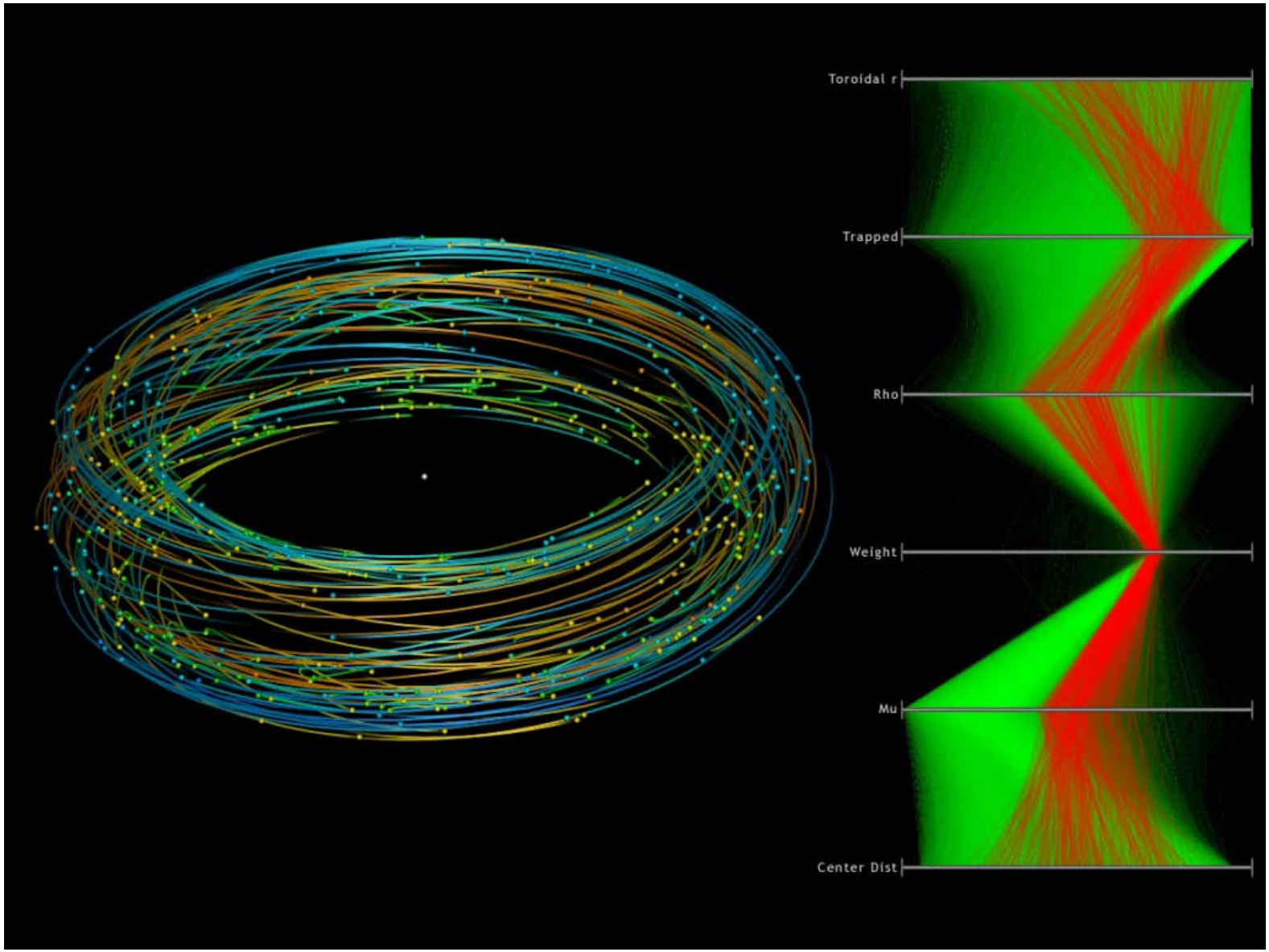

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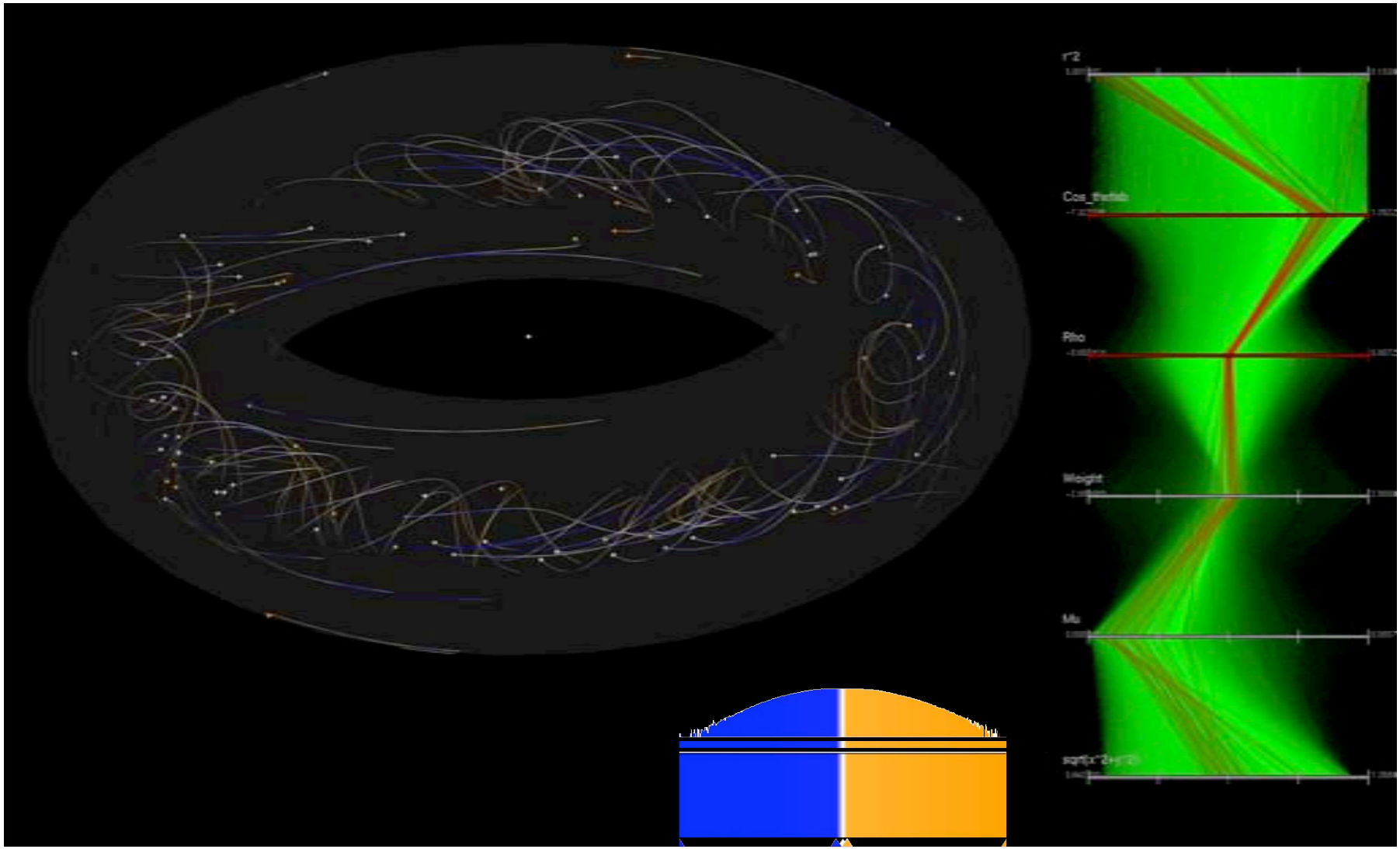

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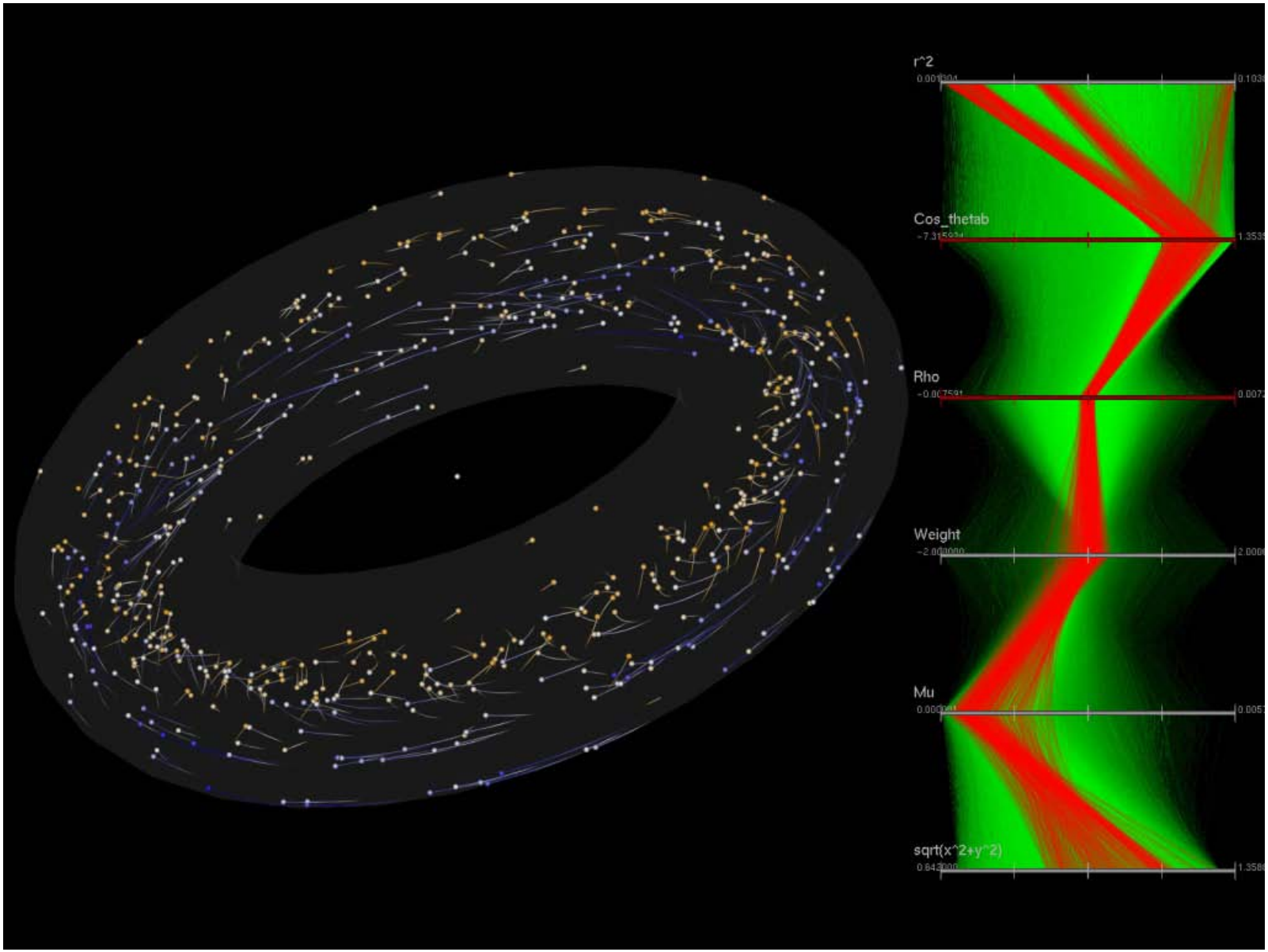
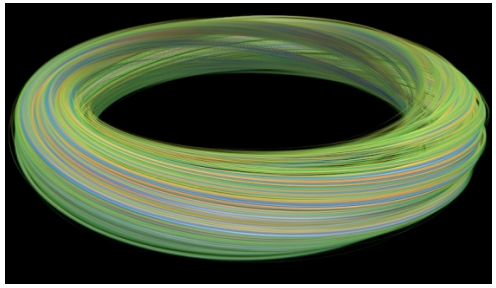


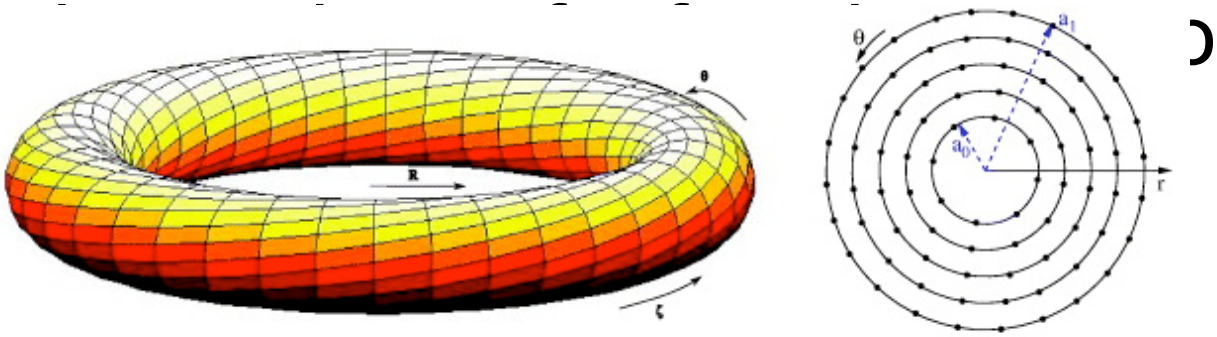
GPU Accelerated Volume Rendering

Fast, high-quality rendering of toroidal volumes



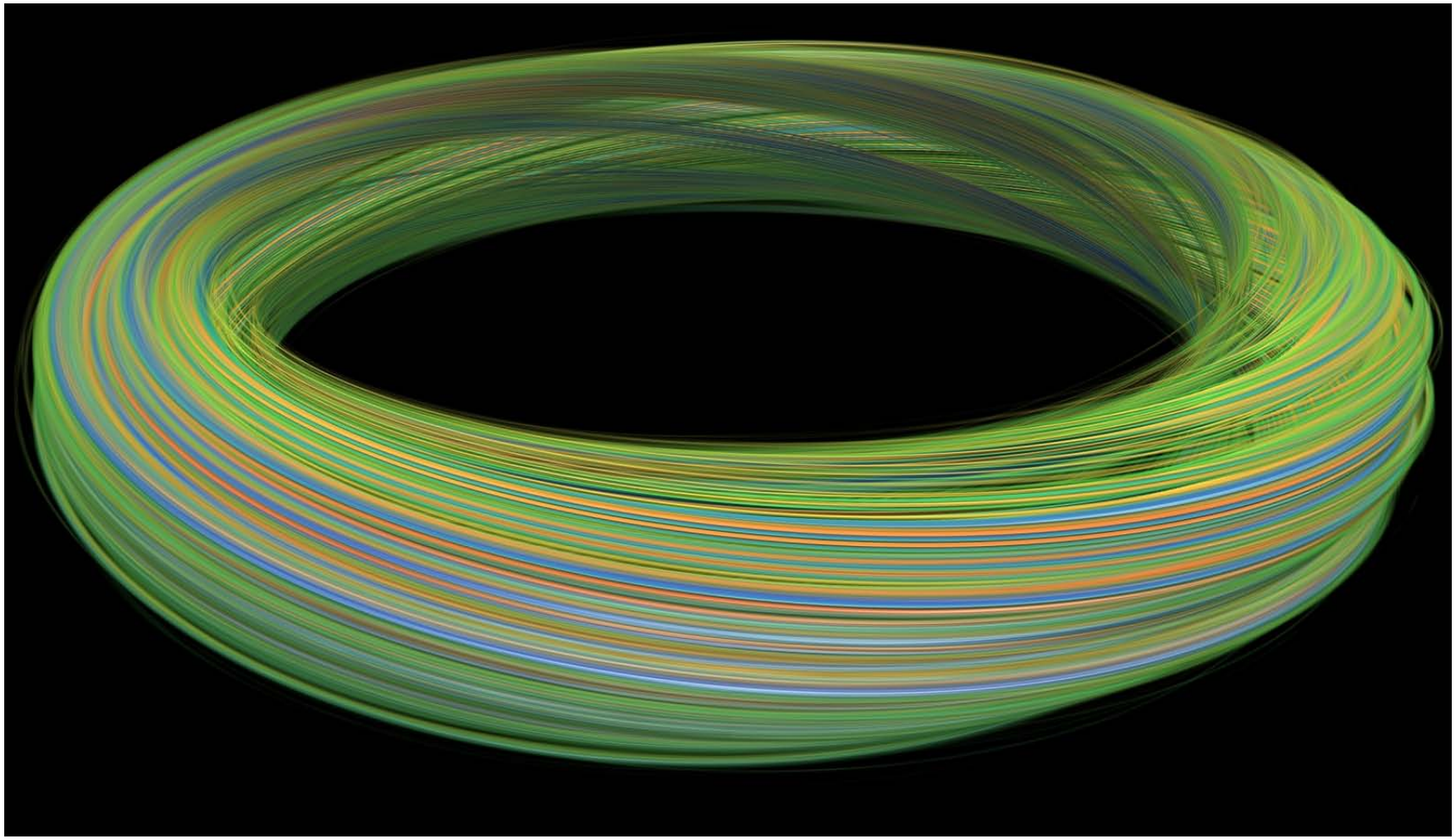
Visualizing Potential Volumes

- Full 3D Volume Raycasting:
  - Challenge: Mapping irregular toroidal system to GPU texture space
  - Preprocessing for fast interpolation on GPU
- Real-time rendering + high-quality rendering
- Lig ol

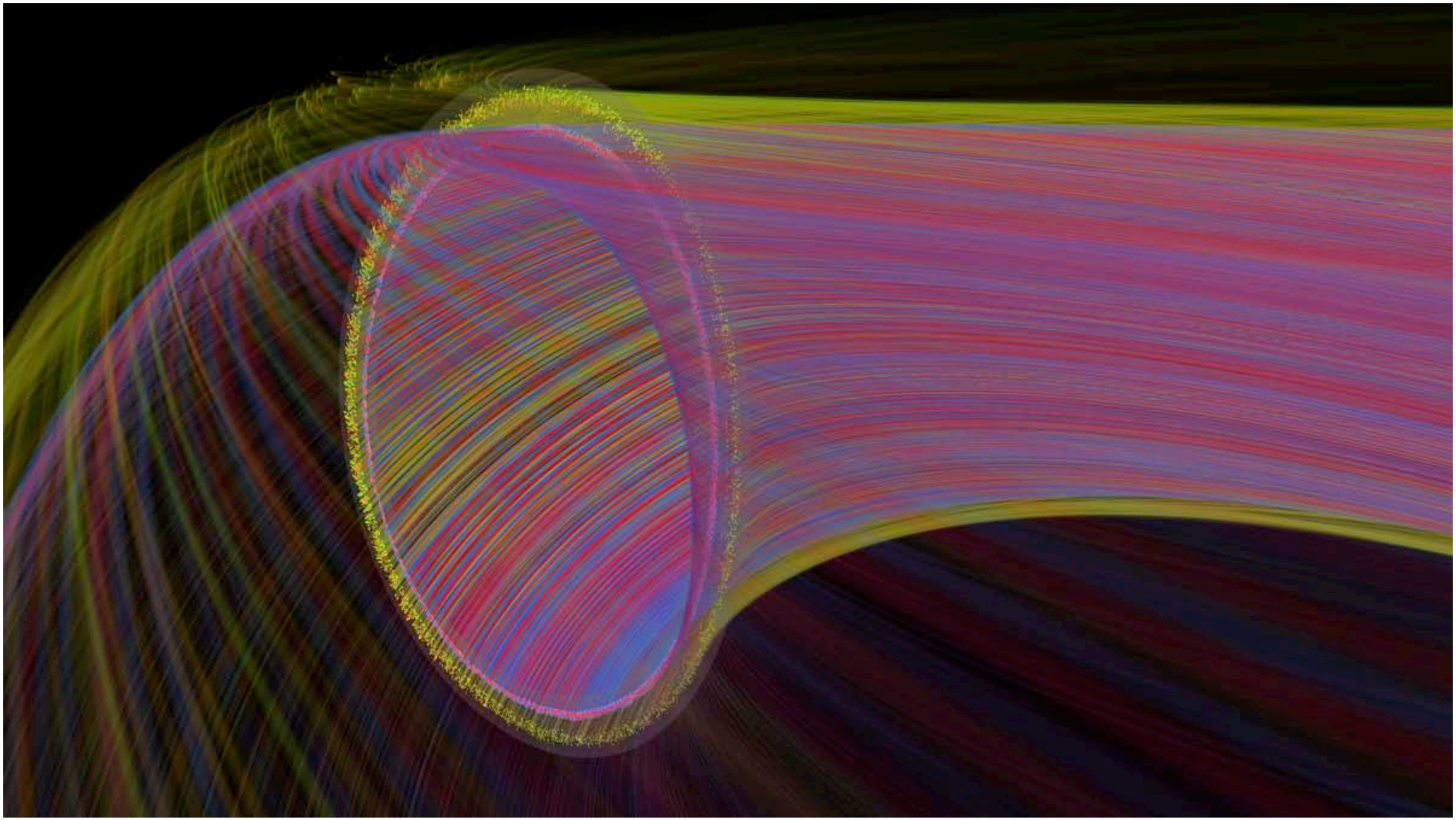


(a) field-line following mesh (b) points on a poloidal plane

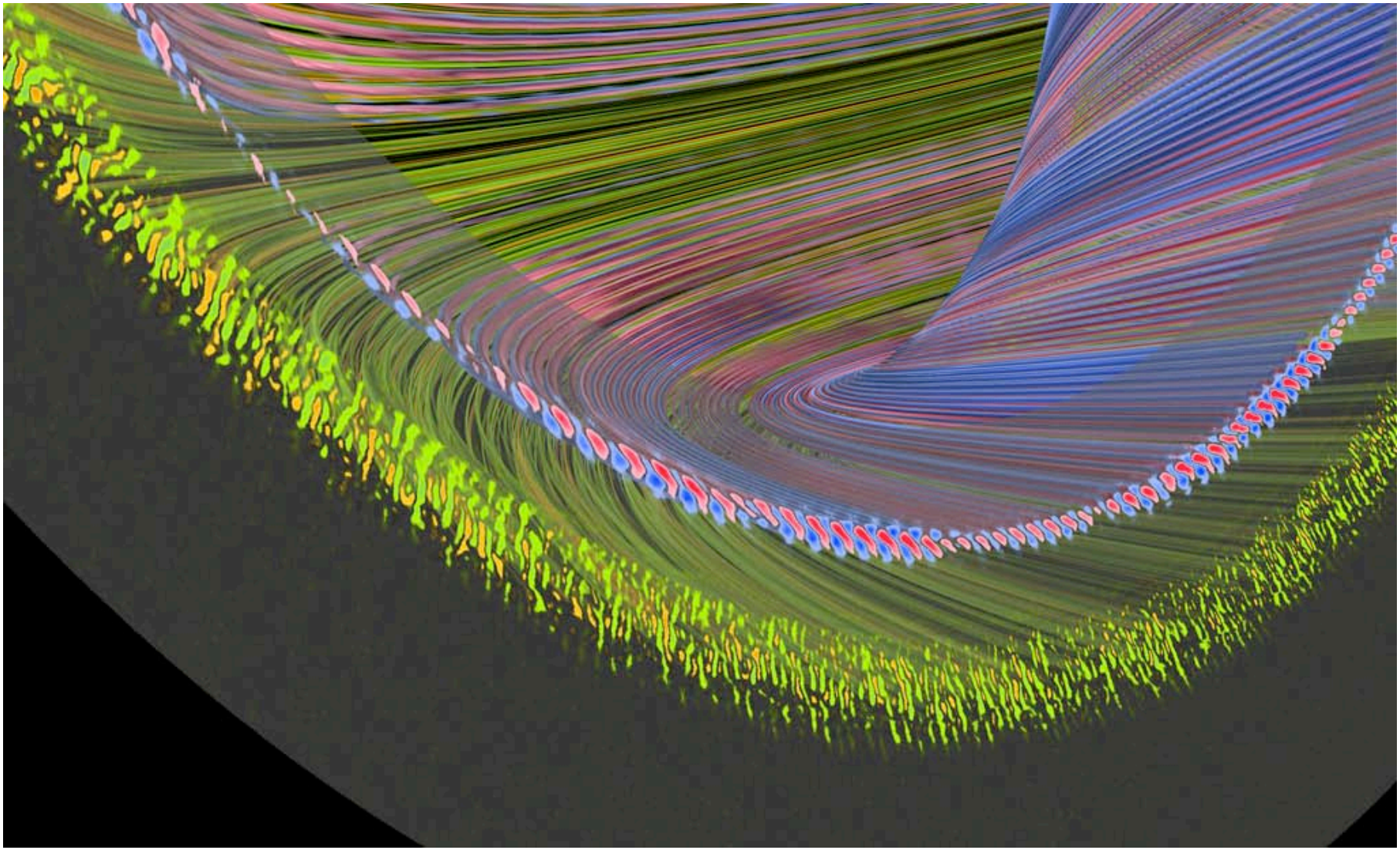
GTC Spherical Tokamak



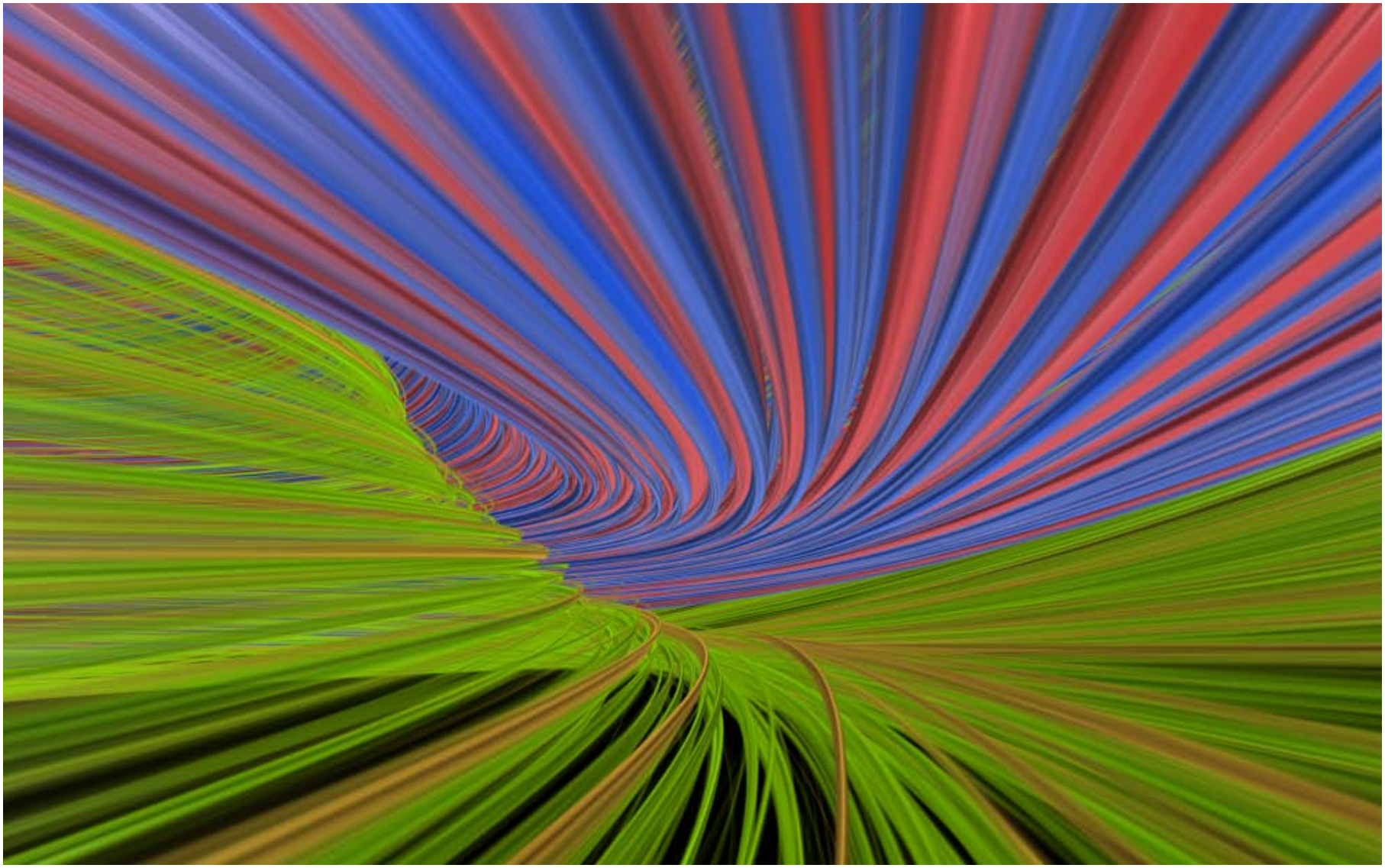
GTS ETG simulation



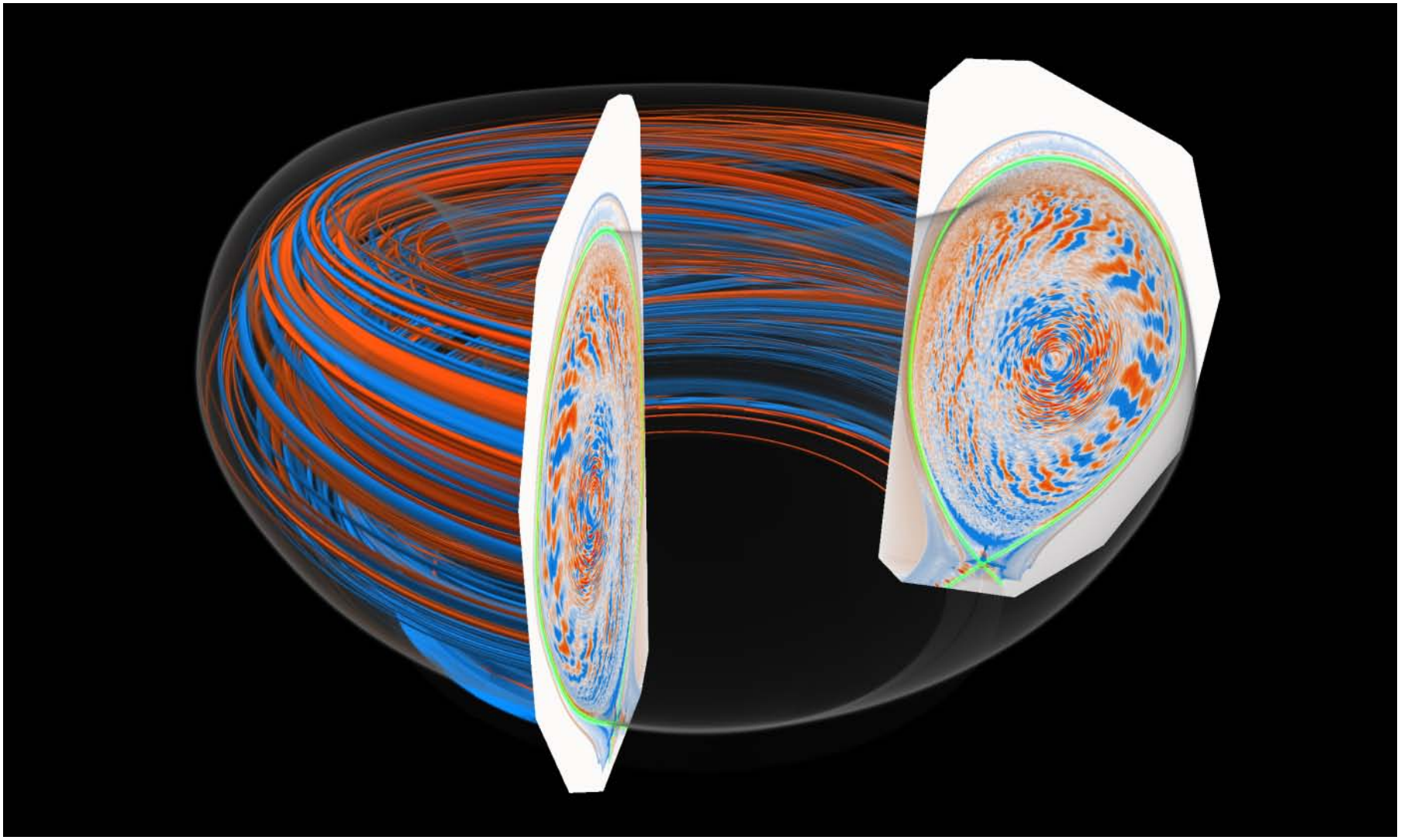
GTS ETG simulation



GTS ETG simulation

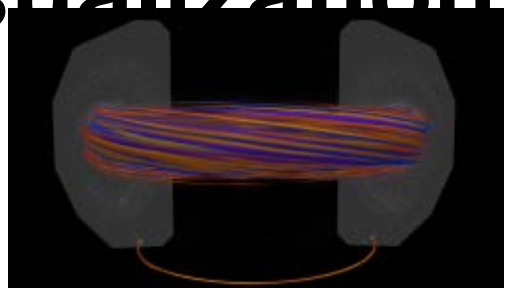


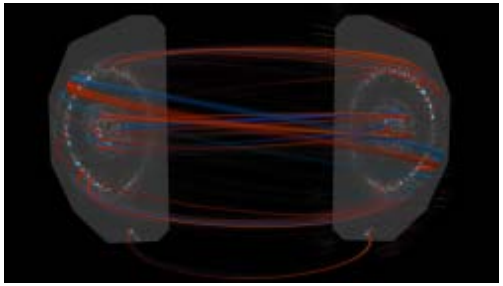
Plasma Edge Simulation

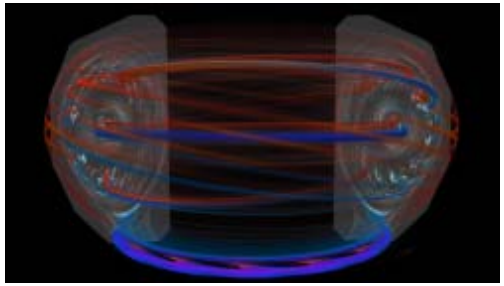


Multi-band Volume Visualization

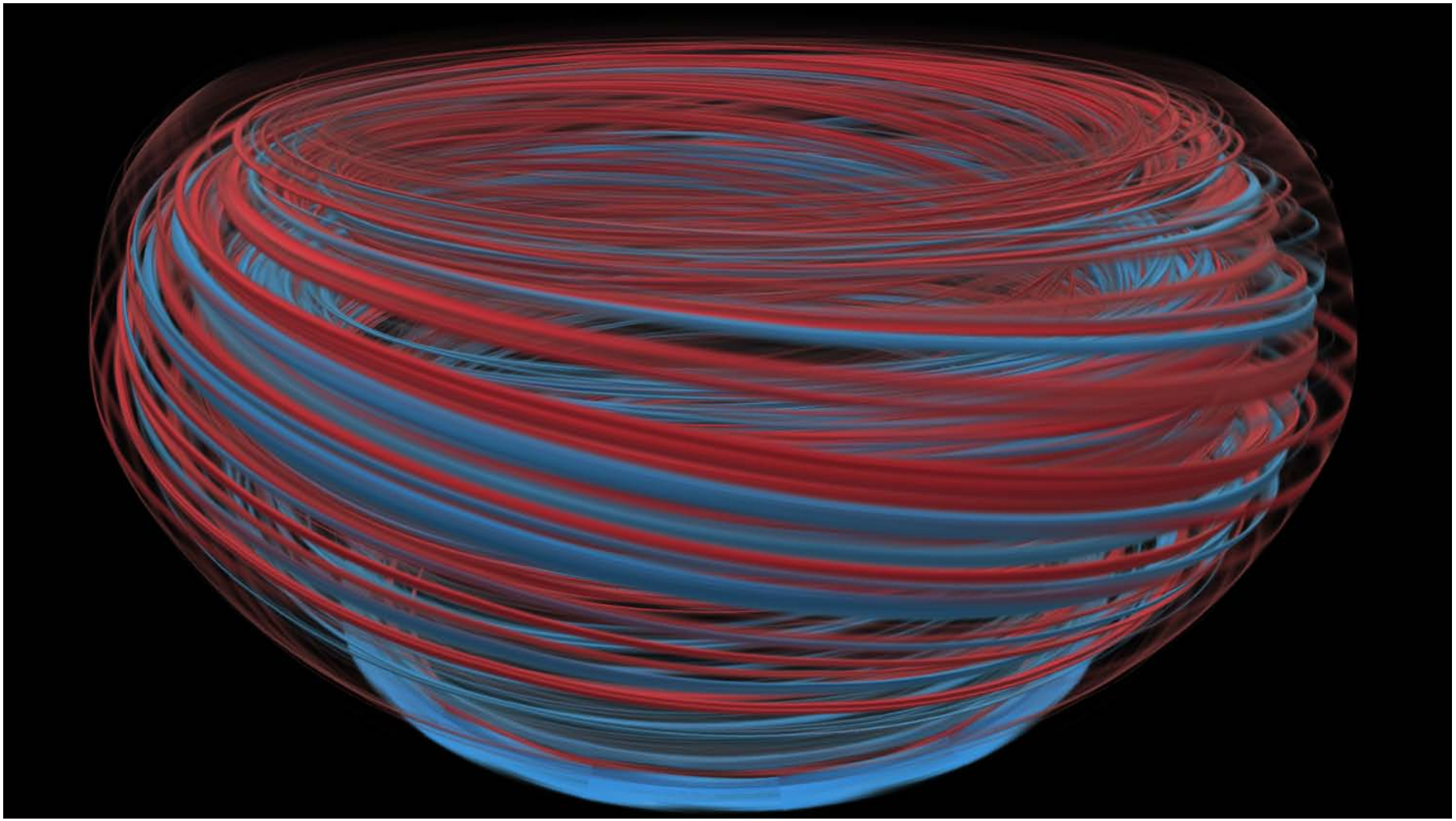
Decomposing plasma volumes using frequency analysis





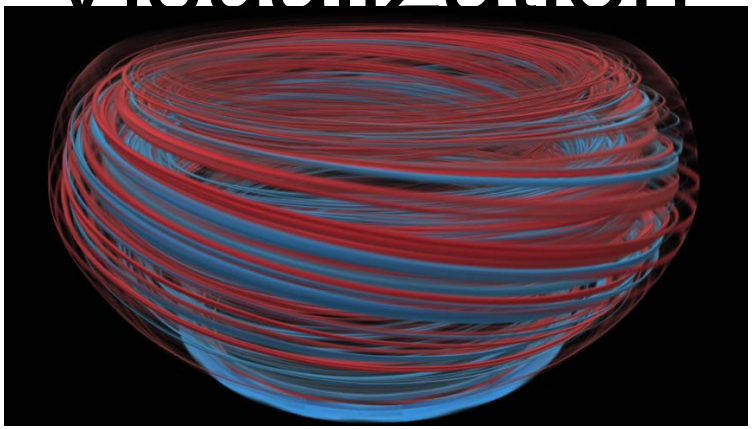


Multi-band Enhanced Visualization

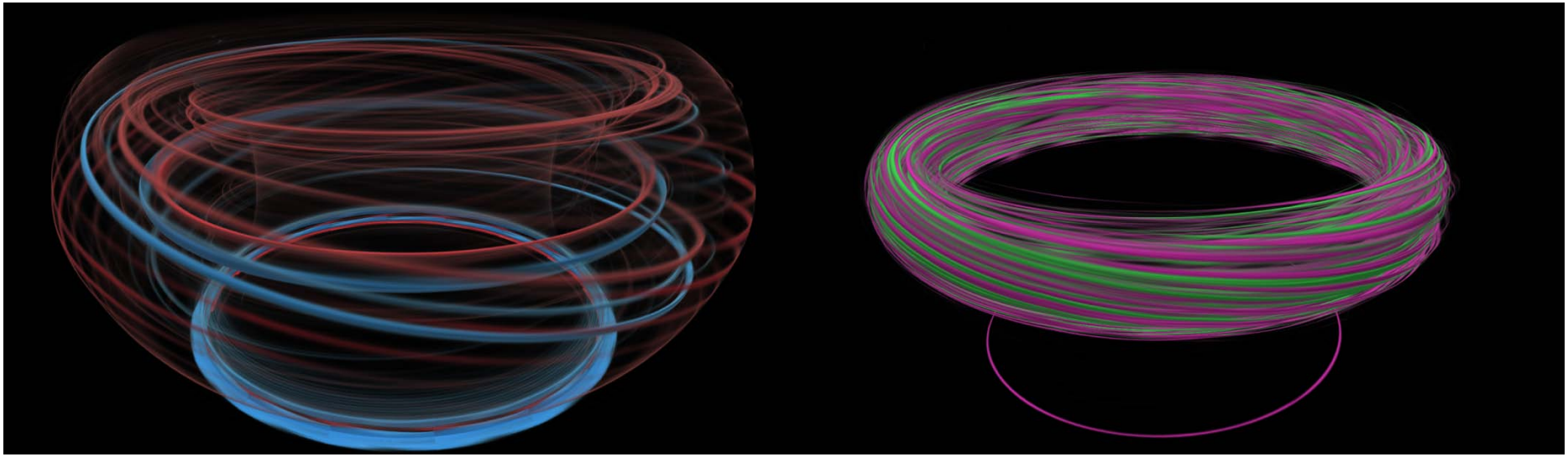


Multi-band Enhanced Visualization

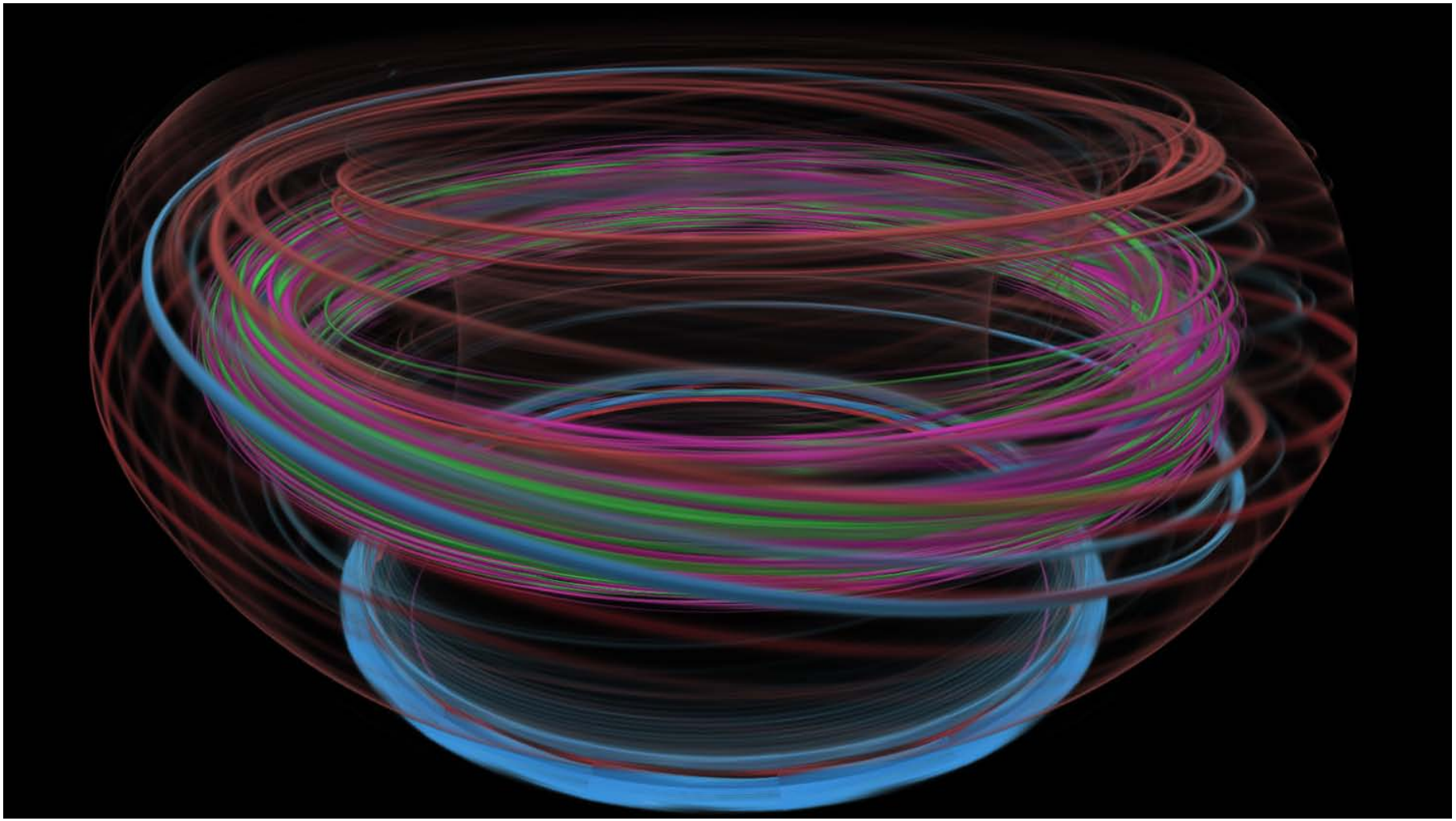
Low Pass



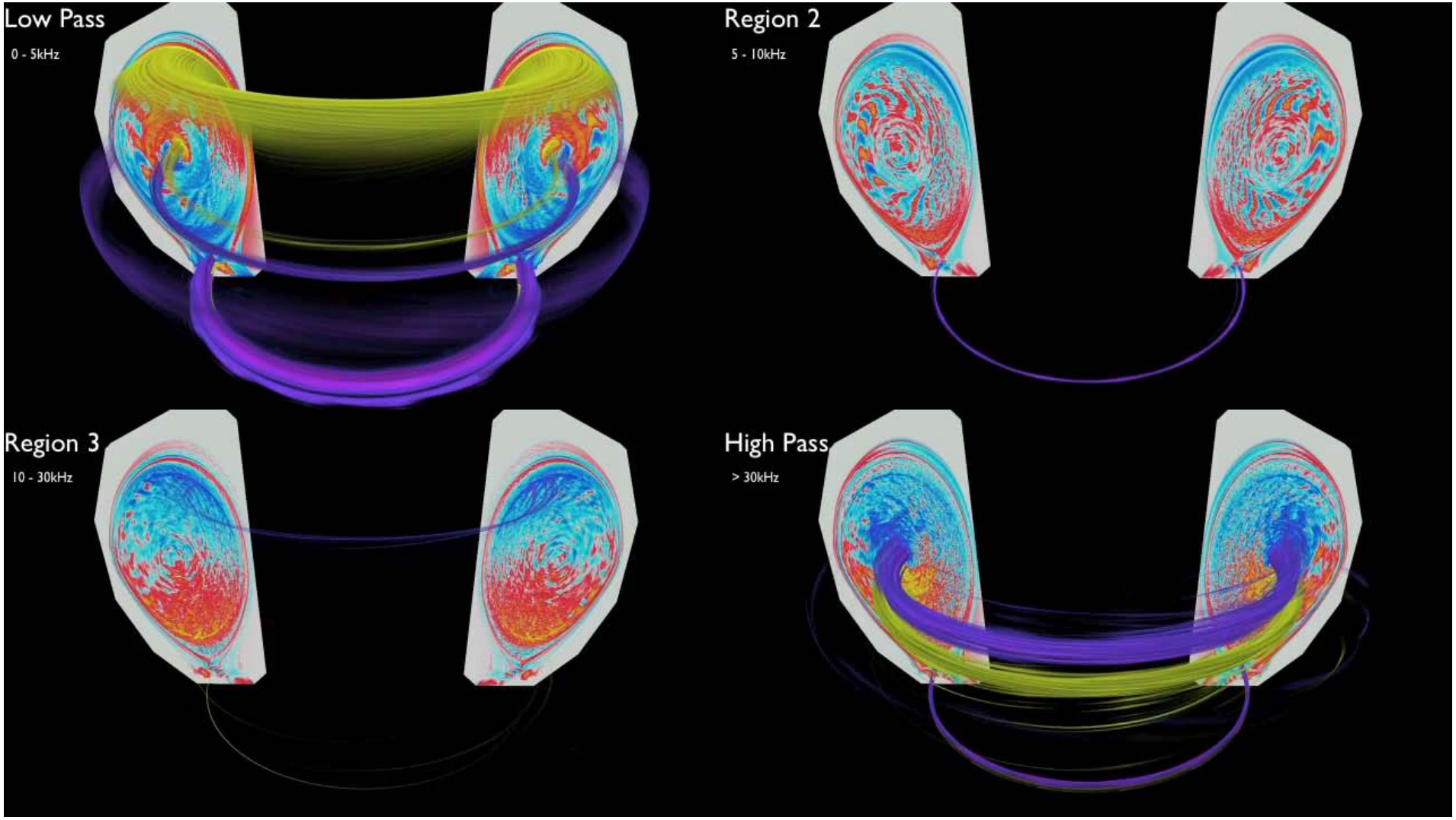
High Pass



Combined Frequency Features

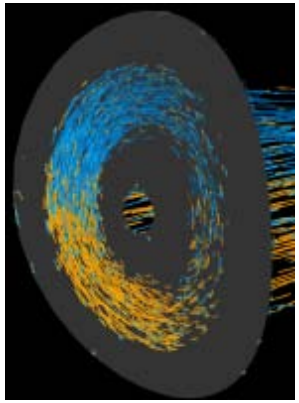


Multi-band Comparison



Vector Field Visualization

GPU particle advection and trajectory filtering

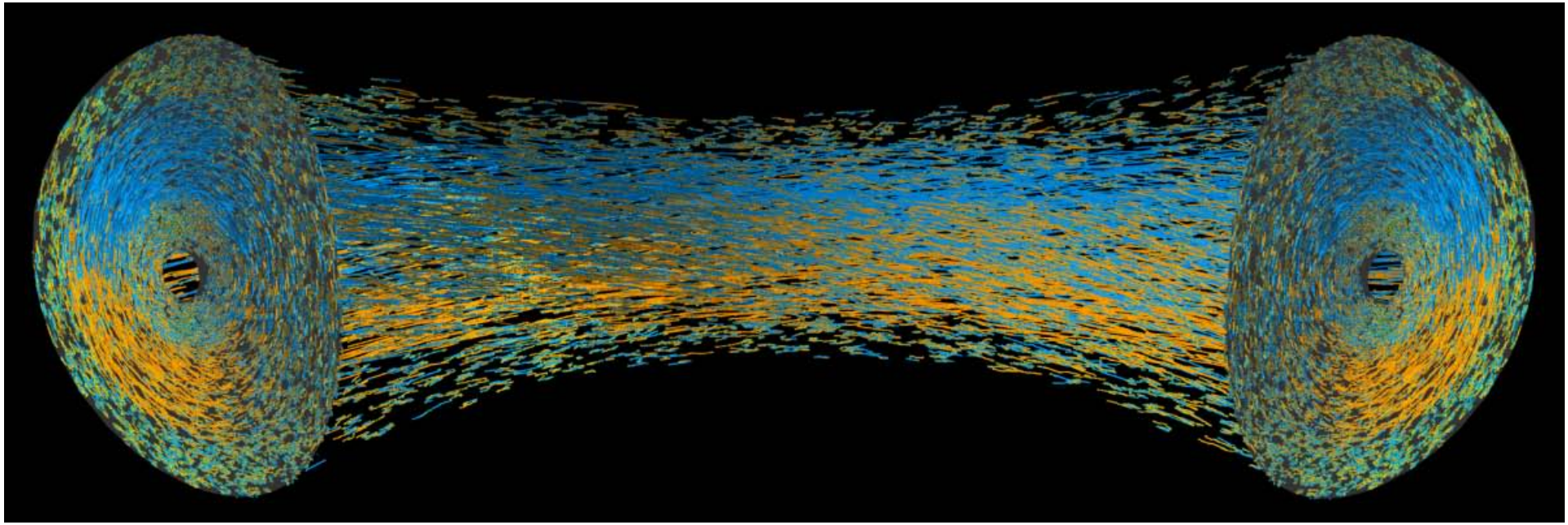


Twisted Vector Field

- Same twisted grid format as previous potential fields, such as GTS
- Volume interpolation to GPU texture
- Particle advection and rendering all done on graphics hardware
- Time variant properties used for filtering, such as length and directional variance

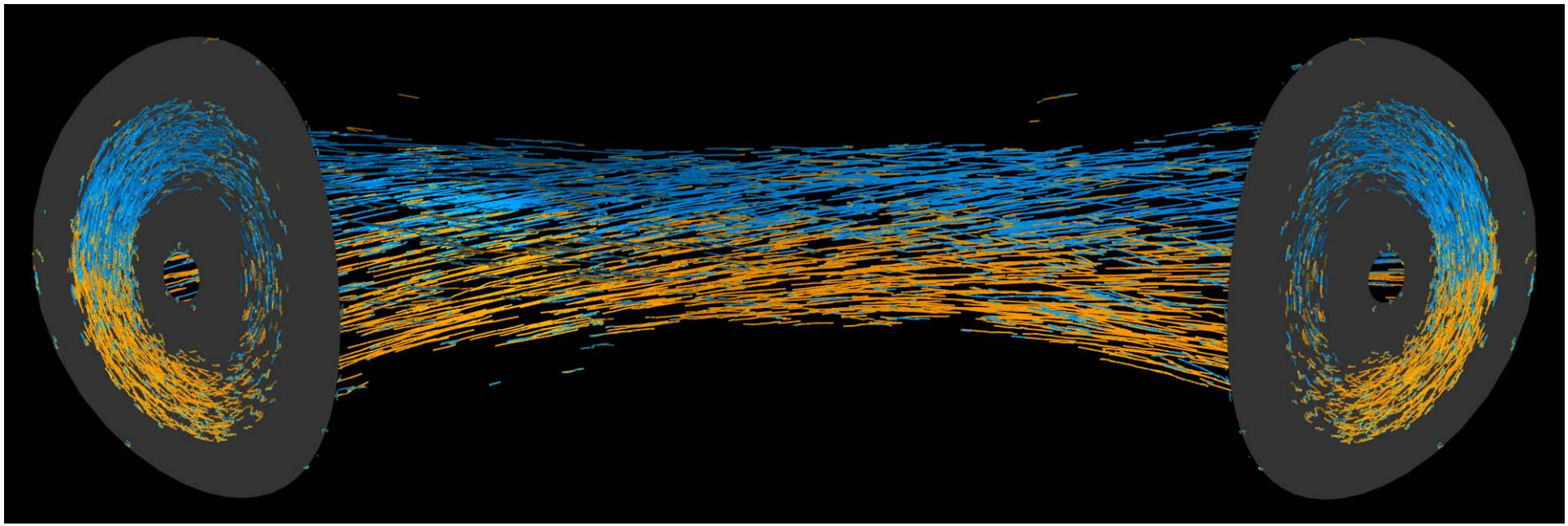
Traced Particles

- Large number of particles traced on GPU
- Rendered in 3D or onto projected planes
- Colored based on toroidal direction



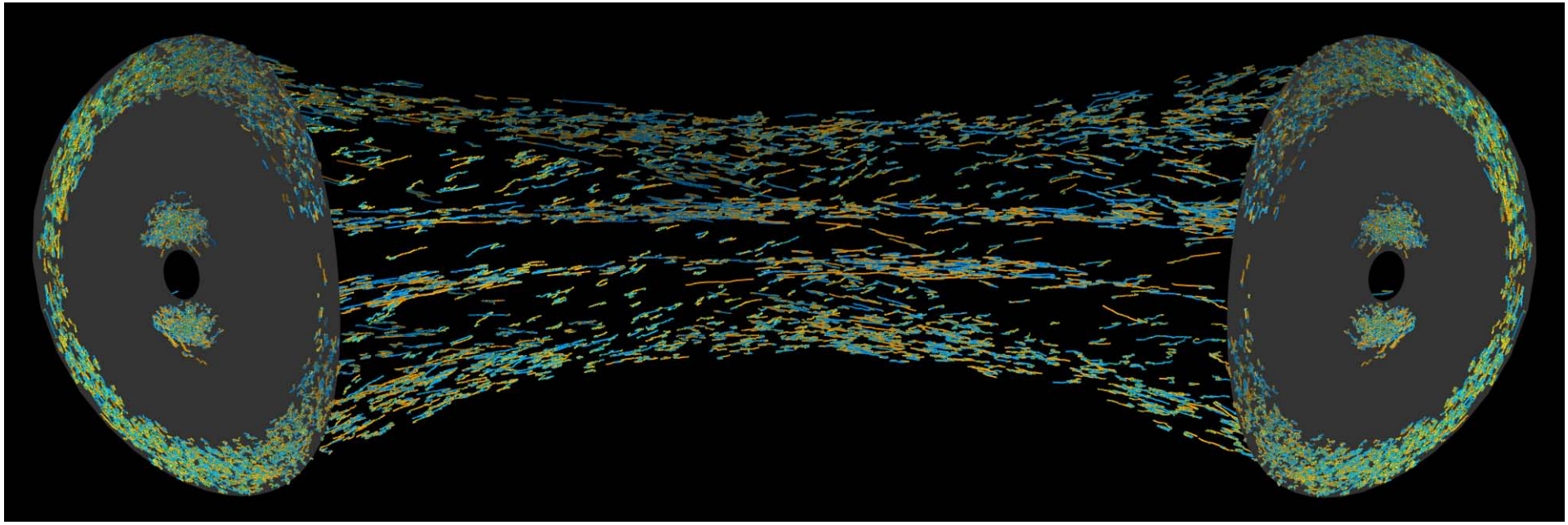
Filtered Particles

- Filter particles based on number of direction changes in lifespan
- Here, particle trajectories with few turns



Filtered Particles

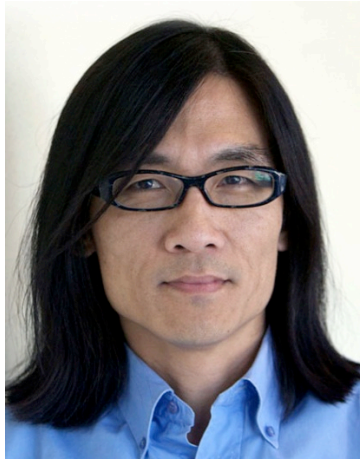
- Here, particle trajectories with many turns
- Concentrations of particle positions can be seen on poloidal planes



Summary

- Brand new visualizations for fusion data:
  - Time-varying particle rendering and selection
  - Volume rendering of twisted simulation grids
  - Multi-band decomposition of volume data
  - Vector field rendering and trajectory culling
- High-quality, single workstation systems
- Supporting latest GPUs for optimal performance
- Continue to explore new techniques based on feedback from scientists

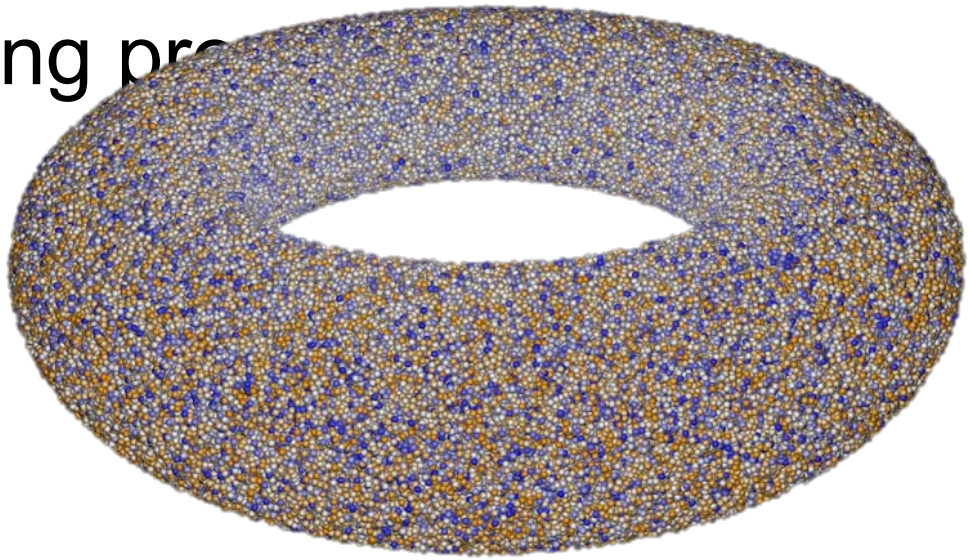
Thank You!



Contact:
Kwan-Liu Ma
ma@cs.ucdavis.edu
http://cs.ucdavis.edu/~ma

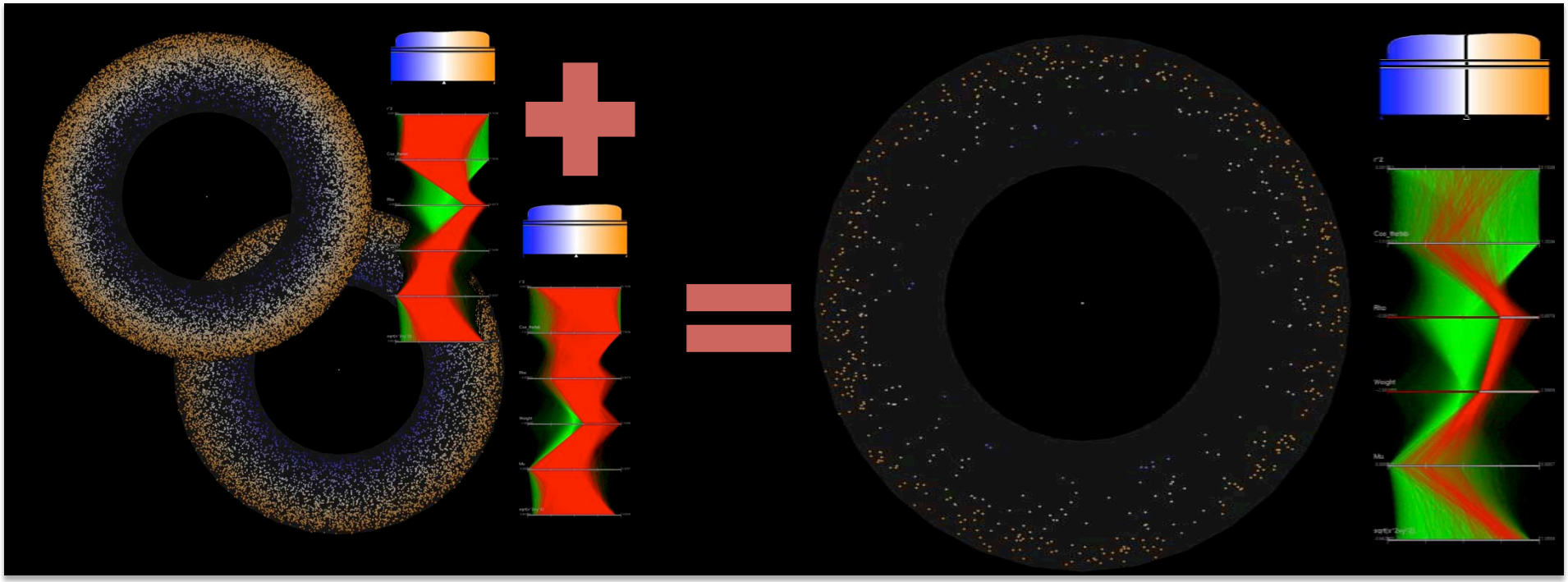
Goals

- Incorporate newest visualization techniques.
- Provide multiple views of the data.
- Reduce clutter through multivariate culling.
- Assist exploration with visual interface.
- Visualize time-varying pr



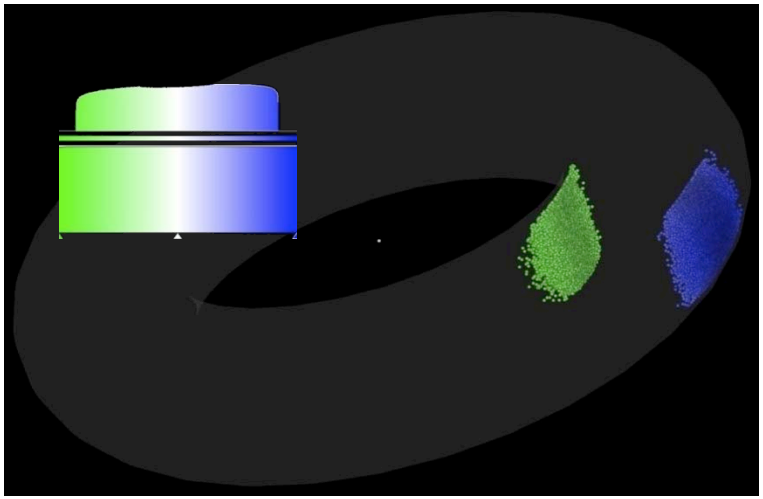
Selection Modification

- Can combine multiple selections together (union or intersection)

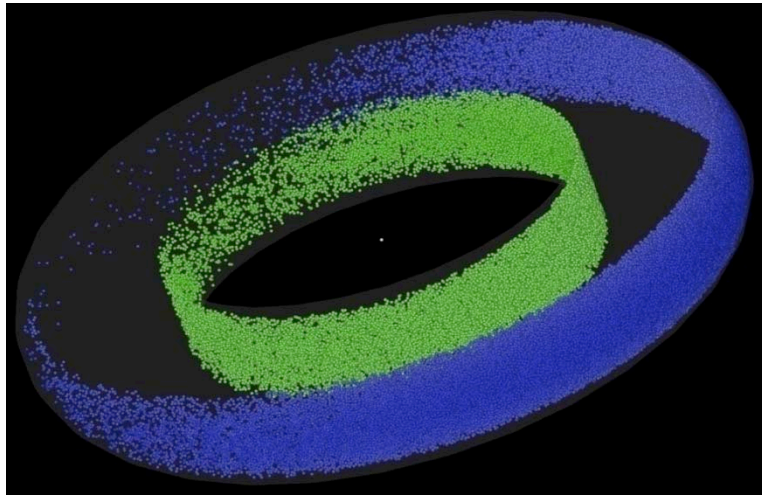


Modify Selections Over Time

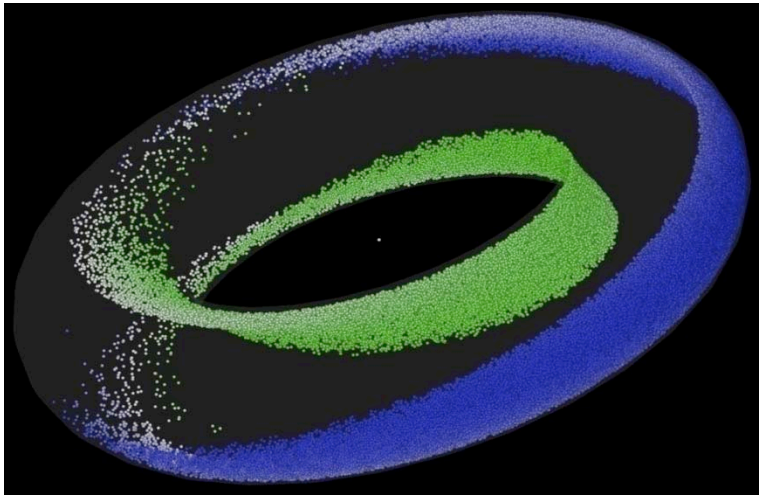
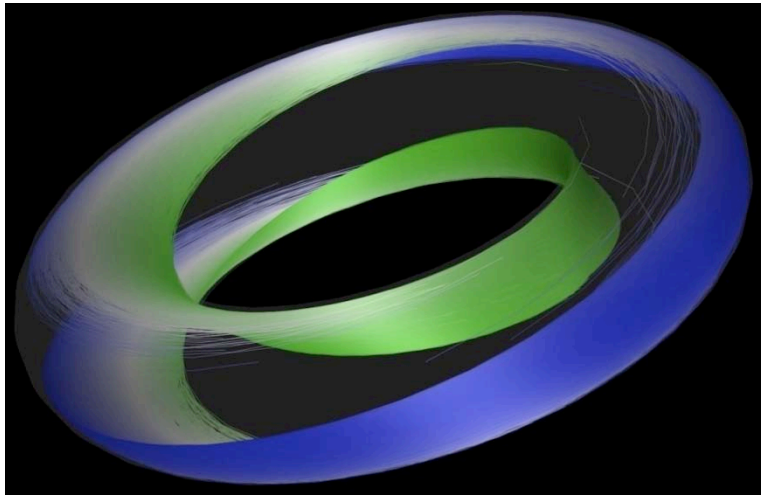
Time Step 1 Selection



Range Selection Lock



Particle Selection Lock



Pathlines