# Rapid Analysis of Plasma Instabilities in Fusion Science

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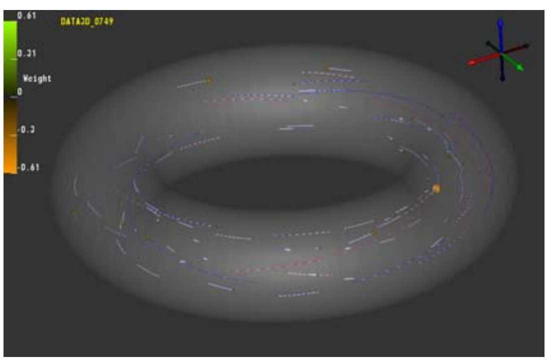
## Summary

Developing a reliable energy system that is economically and environmentally sustainable is the long-term goal of Fusion Energy Science (FES) research and is a worldwide effort. As fusion experiments have increased in size and complexity (too expensive to duplicate), there has been concurrent growth in the importance of simulation and visualization. Scientists from the SciDAC Visualization and Analytics Center for Enabling Technology (VACET) working closely with fusion scientists have developed new capabilities for visually exploring and, ultimately, understanding fusion simulation data sets. These new techniques leverage DOE's parallel computing platforms enabling the: (1) rapid exploration of datasets containing millions to billions of values, (2) rapid extraction of features of interest within a large simulation, and (3) interactive visualization of the analysis results. These techniques have helped fusion scientists reduce the time spent in analysis and further the utility of fusion reactor simulations.




Output from microturbulence simulation of a fusion plasma showing 22 of the 400 million plasma particles simulated. Petascale-class machines help fusion scientists model their simulations with higher fidelity and physical accuracy then previously possible. Particles are displayed based on the number of times that they were magnetically trapped (red line) and de-trapped (blue line) in relation the confining magnetic field. Data courtesy S. Ethier, PPPL.

A critical characteristic of a typical fusion reactor is the growth of instabilities in the plasma due to the large gradients of density and temperature, the field geometry, and the inherent self-consistent interactions between charged particles and electromagnetic waves. Identifying and understanding these plasma instabilities is critical in the design of fusion reactors such as the International Thermonuclear Experimental Reactor (ITER), a Tokomak reactor scheduled for completion in 2018. Plasma instabilities occur on very different spatial and temporal scales and can represent highly unique phenomena.

For instance, fusion scientists are actively exploring the micro-scale instabilities created by microturbulence within the plasma. The waves generated by this turbulence can trap particles within the electric field, resulting in a radial diffusion of plasma particles across the confining magnetic field. On the macro scale fusion scientists are interested in "magnetic island" formation due to anisotropic plasma equilibration relative to the magnetic field. As with microtrubulence, magnetic island formation allows plasma particles to escape from the confining magnetic field. Understanding these two phenomena is necessary in the ultimate understanding and control of the rate of energy loss and plasma deposition on the wall of the fusion reactor.

The SciDAC VACET team has developed new technologies that are currently in use in the fusion community. The software deployed enables; (1) the rapid finding and tracking of a plasma particle within a given simulation (previously this task required hours to complete and now requires only seconds); (2) the replacement of a manual particle search process with one that is automated and based upon state-of-the-art machine learning, and (3) the rapid identification of “magnetic islands” within the magnetic field.

Working with researchers from the SciDAC *Scientific Data Management Center*, the VACET team developed a method for the rapid visual exploration of very large, multivariate, time-varying datasets. Initially developed for analyzing particles in laser wakefield simulations, this method was expanded to meet the needs of fusion scientists. This expanded capability includes the ability to perform explorations and track particles on a cumulative basis as well as utilizing derived data.

The VACET team, in collaboration with the SciDAC Center for Extended Magnetohydrodynamic (MHD) Modeling, has developed analysis tools for automatically identifying and extracting magnetic islands. This analysis tool, which has its foundation in time–frequency techniques, allows fusion scientists to either work directly within their simulation codes using portable libraries or work offline after a simulation has completed.

The new capabilities provided by the VACET team to the fusion research community are implemented in production-quality, parallel-capable, visual data exploration software that runs on virtually all modern platforms, ranging from desktop-class machines to DOE’s petascale computer systems.

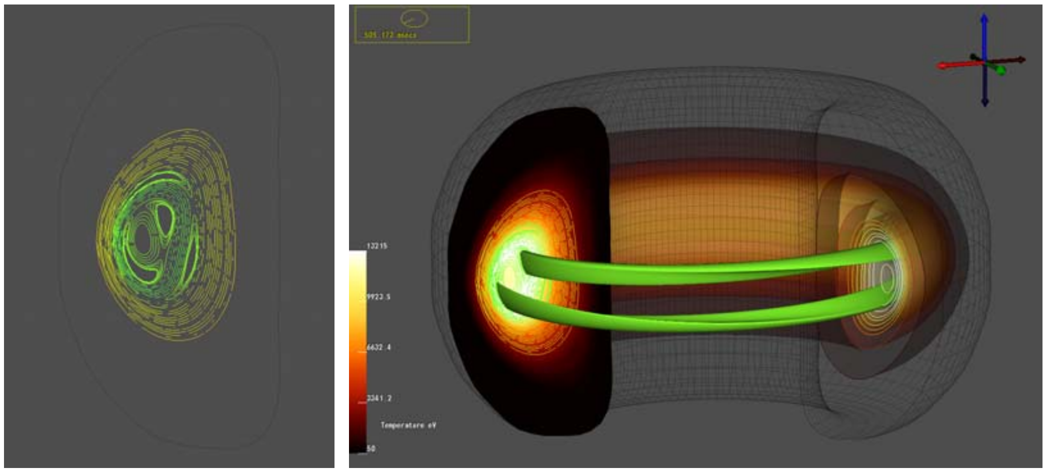



**Figure 2:** The topology of the magnetic field is visualized using an analysis tool that produces a Poincaré map, left. Of particular interest in the analysis of the magnetic field topology is the break up of the magnetic flux surfaces into a series of “magnetic island” chains. The image on the right shows an island chain that dominates the inner core of the simulation. As the field becomes more stochastic, the plasma will cool rapidly. This cooling is highlighted by a series of transparent iso-temperature surfaces. Though the temperature profile remains as a series on nested contours they have deformed based on the topology of the magnetic field. This visualization enables scientists to quickly gain insight into the relationship between statistical-space and physical-space features. This tool, developed as part of VACET’s research and development portfolio, is being deployed within a widely distributed, production-quality, parallel capable visual data exploration software infrastructure (VisIt).

**Recent Publications**

Allen R. Sanderson, Xavier Tricoche, Christoph Garth, Scott Kruger, Carl Sovinec, Eric Held, and Joshua Breslau, “Detection of Magnetic Nulls in Toroidal Geometry”, 48th Annual Meeting of the Division of Plasma Physics, 2006.

Allen R. Sanderson, Xavier Tricoche, Christoph Garth, Scott Kruger, Carl Sovinec, Eric Held, and Joshua Breslau, “Visualizing Patterns in the Poincare Plot of a Magnetic Field”, IEEE Visualization Conference Compendium 2006.

**For further information on this subject contact:**

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