VISUALIZATION AND ANALYSIS TOOLS FOR ASSISTING IN EVALUATING FUSION SIMULATIONS

Allen R. Sanderson[1], Scott Kruger[2], Stephane Ethier[3]   [1]Scientific Computing and Imaging Institute, University of Utah; [2]Tech-X Corporation; [3]PPPL

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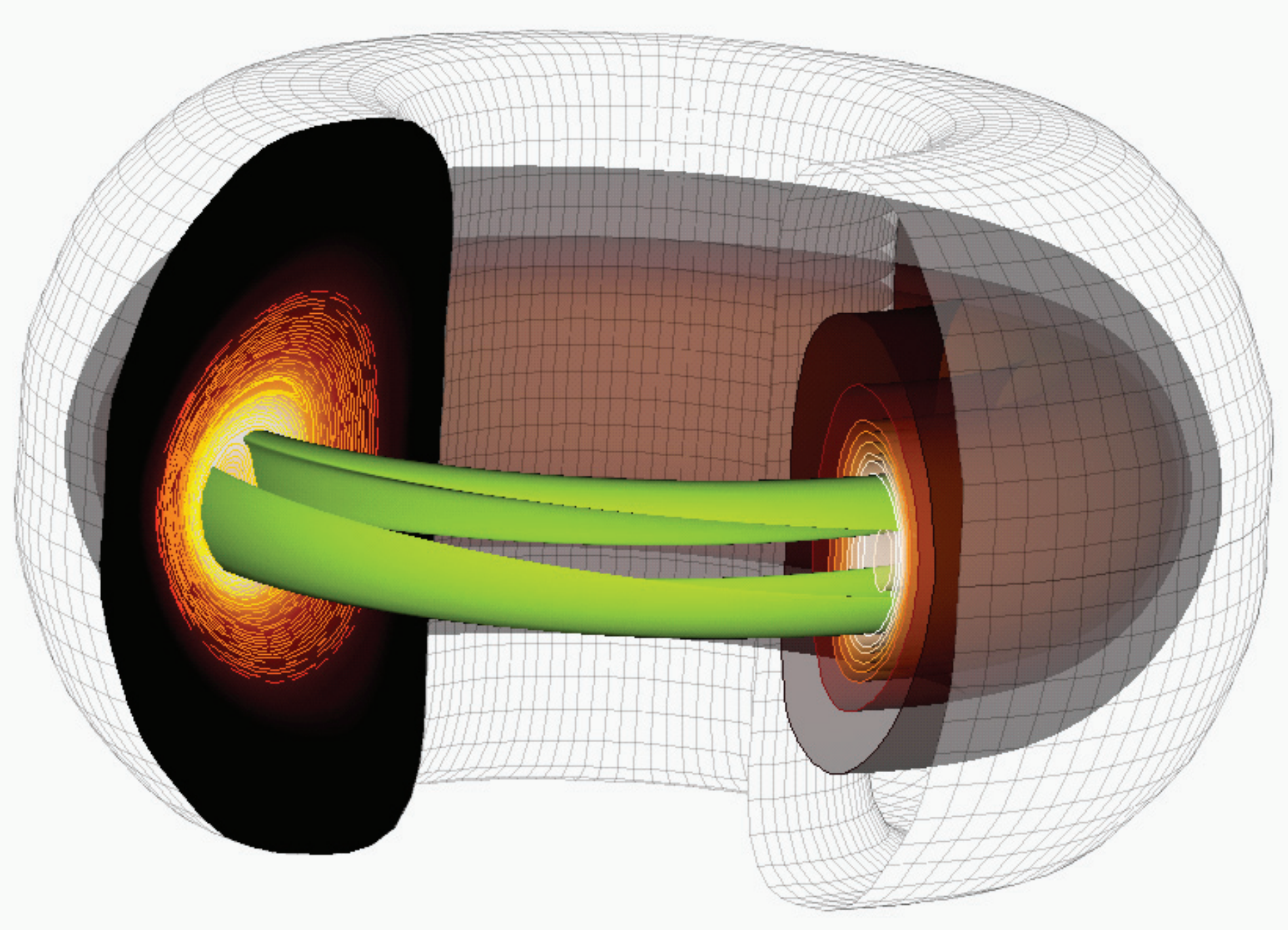

GOAL – Develop a technique to allow for the rapid construction of a Poincaré plot of the magnetic field while identifying topologically significant features such as the magnetic islands, O and X Points to better facilitate exploration and understanding of MHD simulations.

Current techniques for generating a Poincaré plot rely on a dense set of puncture points to form a continuous representation of the cross section of a magnetic surface (rational surface, flux surfaces, magnetic island, etc.) This dense set of puncture points in turn requires a large number of integration steps for each fieldline. In computing the fieldline, small local interpolation and integration errors can accumulate into a large overall error affecting the path accuracy.

Compounding the problem is that the number of integration steps is typically fixed for each fieldline which can lead to either too few or too many puncture points.

SOLUTION – We developed efficient algorithms to compute the Poincaré map of the sampled fieldlines with a near minimal number of puncture points. This efficiency is achieved by properly computing the toroidal and poloidal winding numbers (i.e. rational periods), which leads to an efficiently computed analysis. This analysis greatly reduces the number of integration steps for each fieldline and leads to a fast analysis. In addition, we show that these points are sufficient to recover the important patterns in a Poincaré plot, including “flux surfaces” and “island chains”.

Rather than rely on a dense set of discrete points to represent the pattern formed in the Poincaré plot, we present a contiguous representation by properly connecting a near minimal set of puncture points. This contiguous representation has helped the physicists identify various magnetic surfaces in an efficient manner. Other smaller features, such as “islands within islands,” which were previously undetected, can now be identified as well.

Besides characterizing different magnetic fieldlines, we also present the algorithm of extracting the critical points from the Poincaré map. They correspond to the places where the poloidal fields vanish. Together with the detected surfaces, they provide the topological information of the magnetic fields.

We have applied the techniques to multiple MHD simulations (Siesta, NIMROD, M3D) including those using higher order elements. The results demonstrate the efficacy of the proposed techniques, Figures 1 – 4.

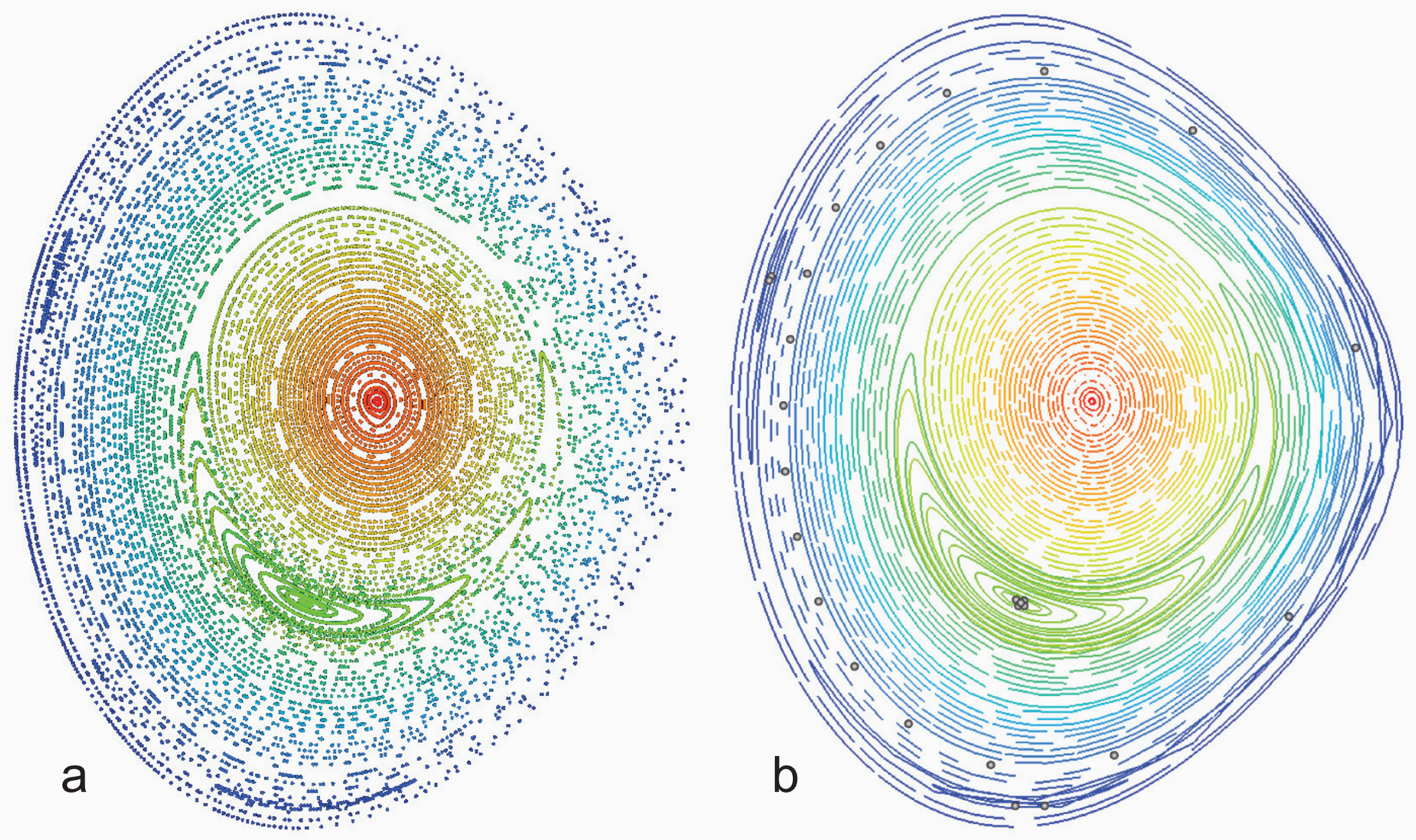

Figure 1. (a) A Poincaré plot of a Siesta MHD simulation with 75 fieldlines. Each fieldline computes 200 puncture points. (b) The same plot using a near minimal number of puncture points that have been connected. There is a small 17,10 island chain (17 grey dots) that has been identified and can not be recognized in (a). In both images, the points and lines are colored based on their safety factors.

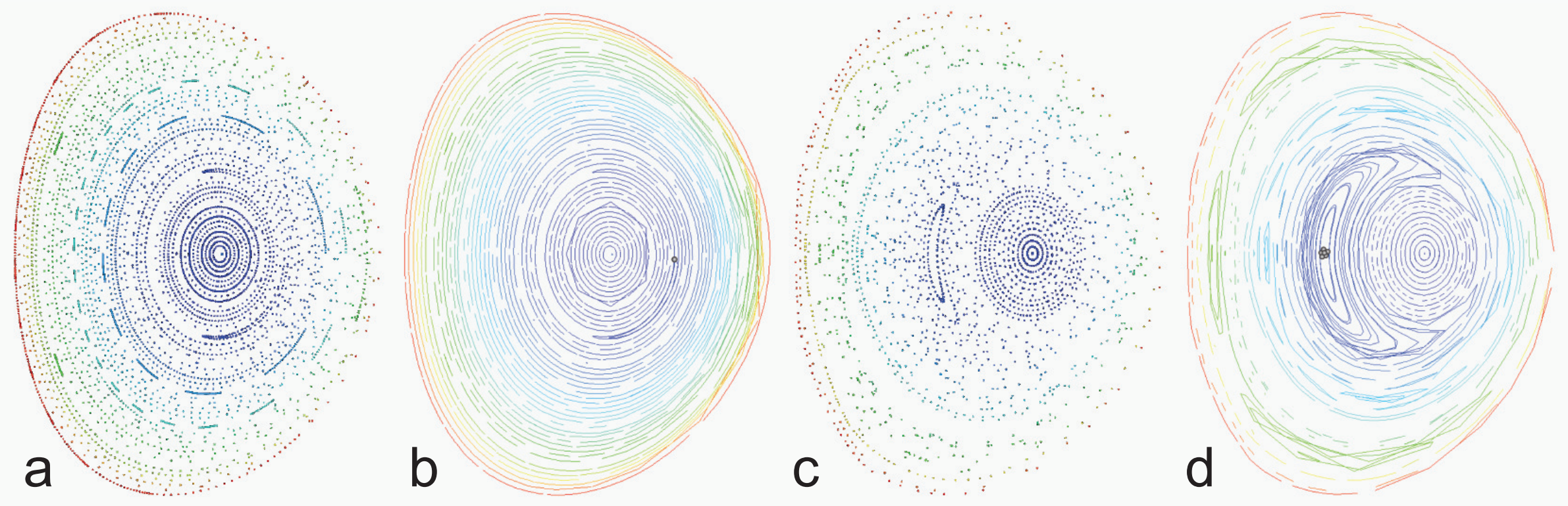

Figure 2. (a) A Poincaré plot from a M3D simulation using of 51 fieldlines. Each fieldline generates 300 puncture points. (b) The same plot using a near minimal number of puncture points that have been connected. There are two thin island chains (one green and one blue) that are partially visible without connectivity. (c) and (d) show a Poincaré plot of the same magnetic field but later in the simulation where the growth of the island chains is much more pronounced.

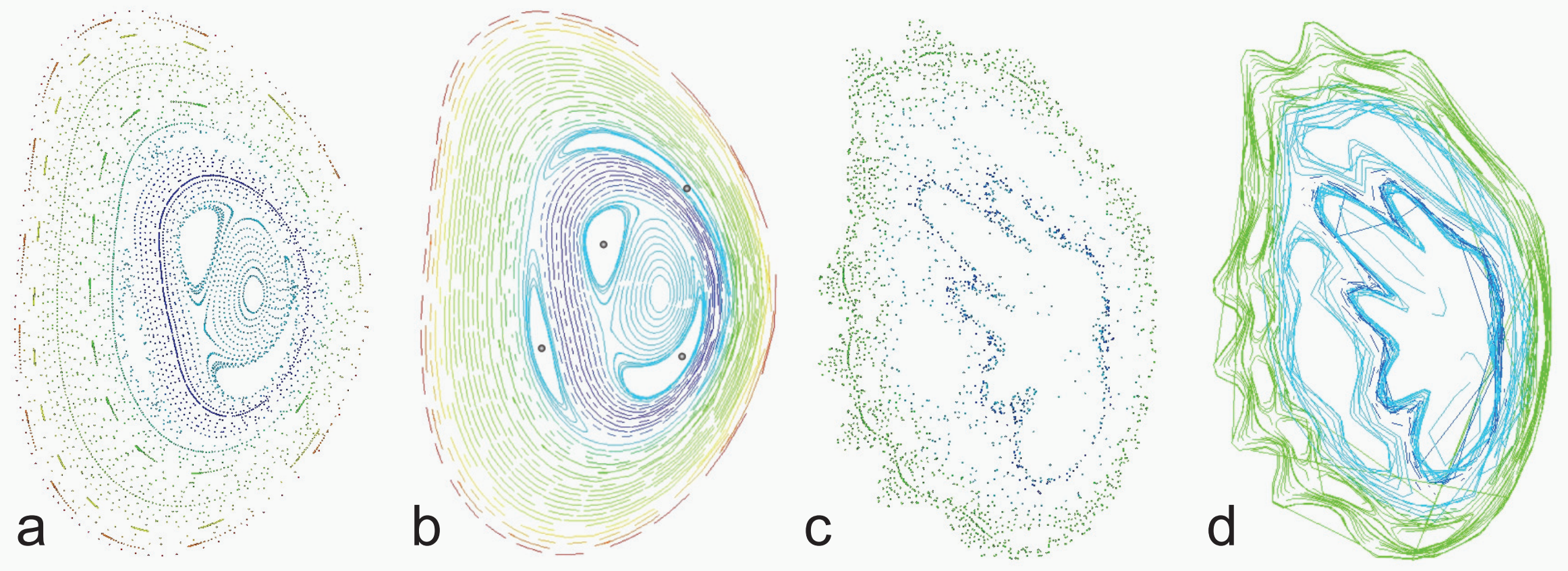

Figure 3. The Poincaré plots of a magnetic field from a NIMROD simulation. While the inner island chain can be seen on the point based plot (a), the outer island chain is not clearly visible until the points are connected in a contiguous fashion (b). (c) and (d) show a Poincaré plot of the same magnetic field but later in the simulation where the growth of the island chains is much more pronounced. It is difficult to discern the structure on the point based plot whereas once the points are connected in a contiguous fashion the structure is much more apparent.

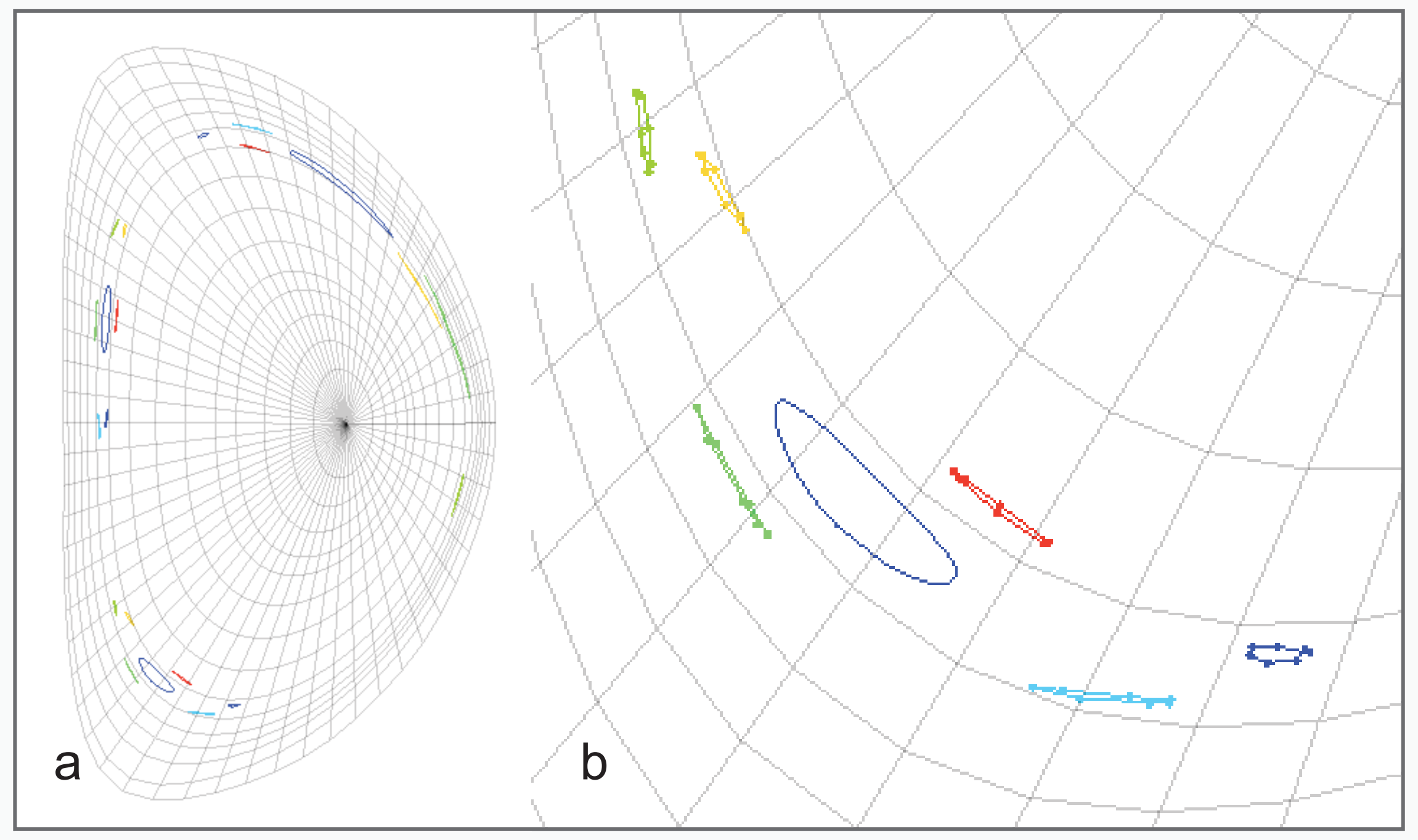

Figure 4. (a) Poincaré Plot showing a 3,1 island chain that is composed of six islands within itself - aka “islands within islands.” (b) a closeup of one set of “islands within islands.” For reference, a sibling island chain is shown (blue) nested within the six “islands within islands.”

GOAL – Develop a technique to allow for the rapid exploration of large scale multivariate particle data to better understand the mechanisms of transport with gyrokinetic simulations.

Previously, analyzing particles used in gyrokinetic simulations had to be preselected based on known particular properties and followed through the simulation. If these “tracer” particles did not exhibit the expected behavior, physicists would have to either rerun the simulation or select new particles.

What has been lacking is a tool that allows physicists to interactively explore the particle data and create “tracer” particles on the fly. This lacking has been because it is very difficult to explore multivariate data using traditional tools as they are typically limited to two or three dimensions.

Further, searching millions to billions of particles each containing multivariate data is computationally very expensive. These searches, typically in the form of range queries are key to selecting tracer particles.

SOLUTION – We used efficient query algorithms like Fastbit to rapidly perform range based queries using bitmap indexing. Bitmaps are easy to compute, efficient for querying: only bitwise logical operations, and are efficient for multi-dimensional queries. The draw back is that there is one bit per distinct value with in each variable. Further, each variable must be indexed and stored before a query is preformed.

To explore multivariate data we have utilized parallel coordinates. Parallel coordinates is a common way of visualizing high-dimensional geometry and analyze multivariate data. To visualize a set of variables each one is drawn on as a series of parallel axis. A multivariate value is represented as a polyline drawn between each parallel axis where the position along the i-th axis corresponds to the value of the i-th variable.

Parallel coordinates is an efficient way to visualize trends in multivariate data, Figure 5. However, selecting the correct parameters for observing the trends can be difficult as it is dependent on the ordering and scaling of each axis. However, because of the use of fastbit, users can quickly form new queries and test hypothesis.

Once a trend has been found, users can then select those particles and observe them as they progress through the simulation, Figure 6.

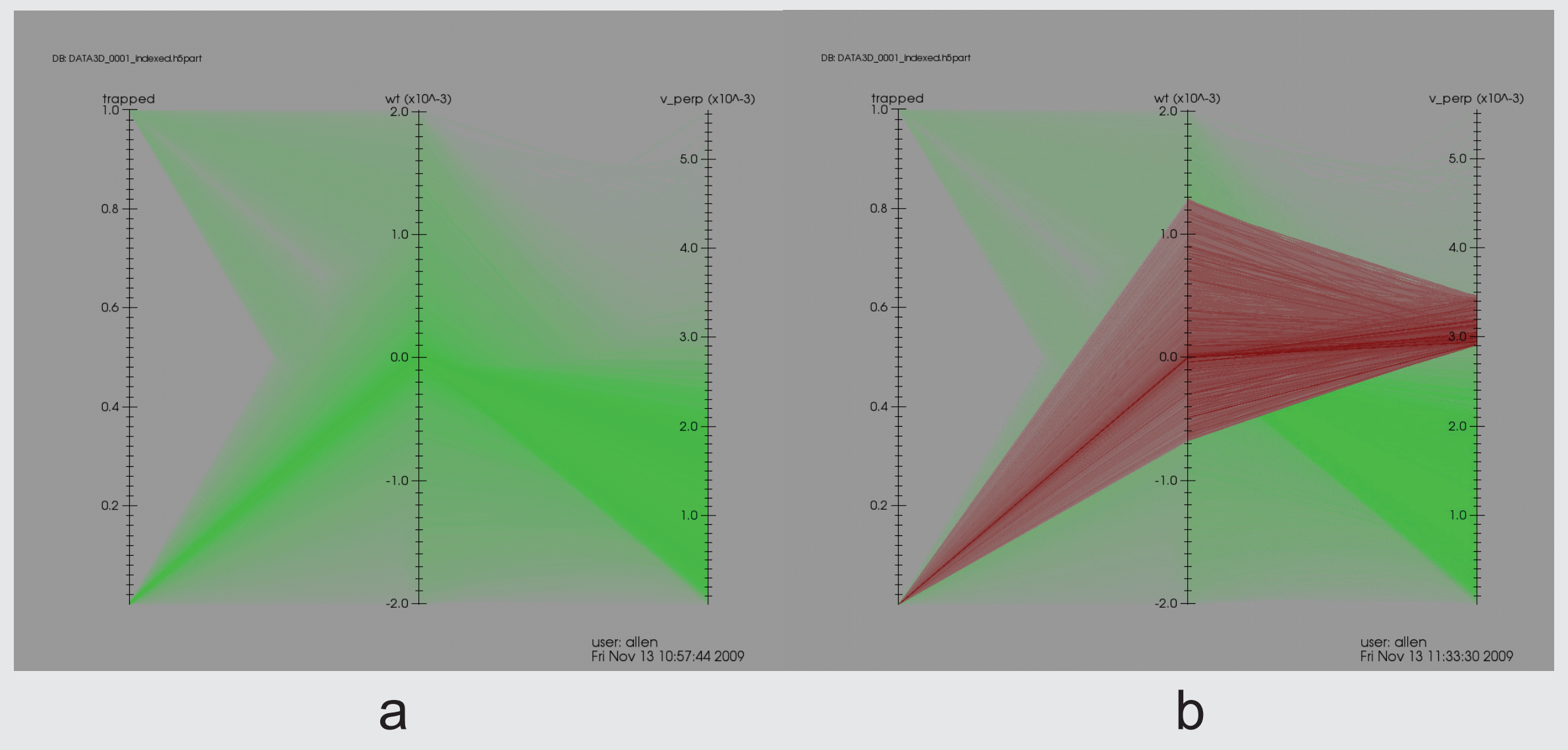

Figure 5. (a) Parallel coordinates plot showing three variables. The opacity of the polyline connecting each multivariate tupple is based on the frequency of tupples with similar values. (b) the same parallel coordinates plot but with a range query applied.

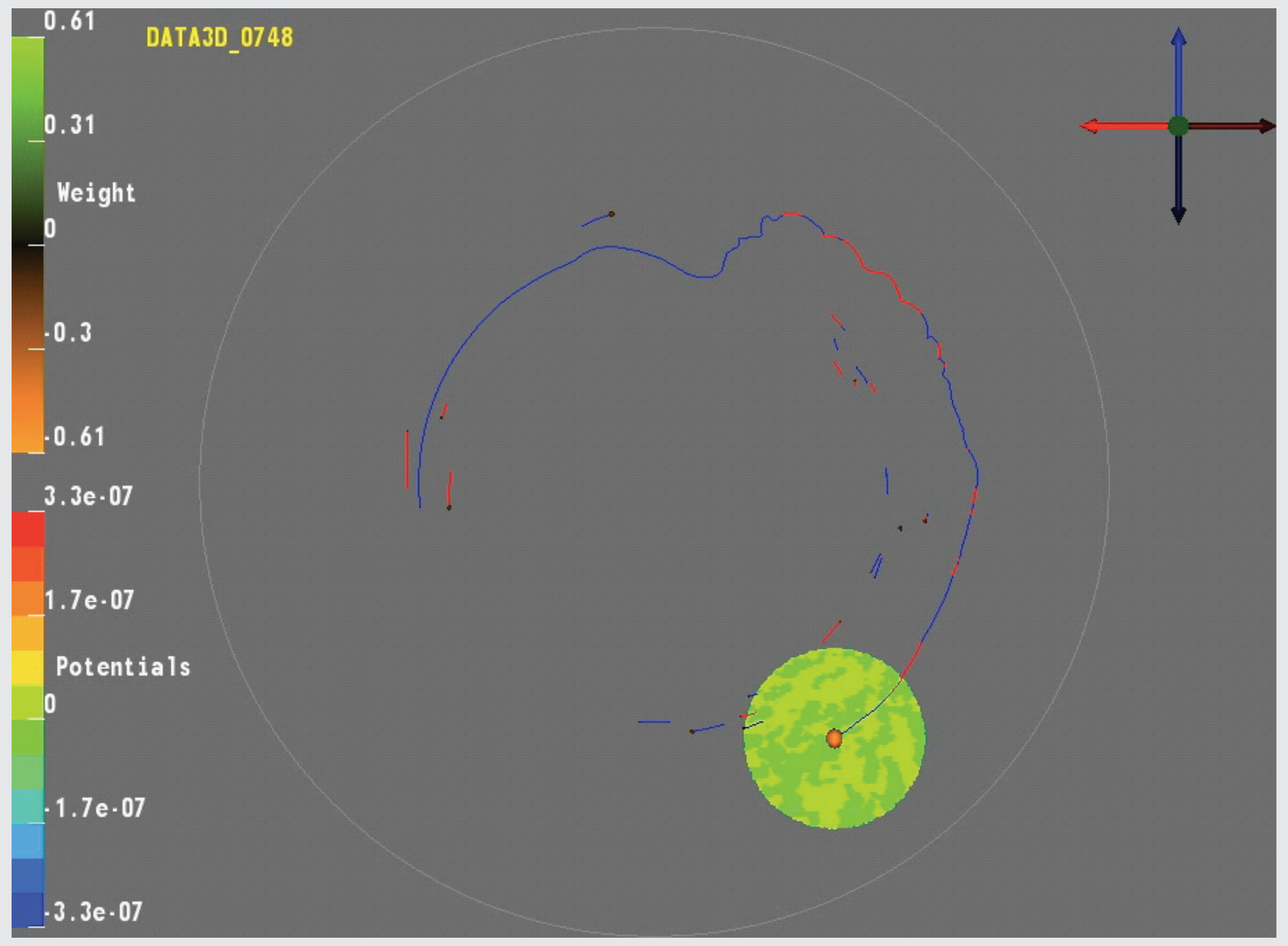

Figure 6. Particle tracking visualization of a global, gyrokinetic 3D particle-in-cell simulation of plasma microtubulence in a tokamak toroidal fusion device. Only 22 of the 400 million particles in the simulation are being displayed based on the number of times that they were magnetically trapped (red line) and de-trapped (blue line) in relation to the externally imposed magnetic field. One particle is highlighted that interacts with the potential field wave through a different kind of trapping and detrapping process, resulting in a large radial diffusion, the amount of which is represented by the size of the particle.

Both techniques have been deployed in the VisIt visualization Package and is publically available at :

https://wci.llnl.gov/codes/visit

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