

New Insights from Supercomputing Simulations of Transport in Toroidal Plasmas

One of the key issues in fusion energy research is to understand how plasma energy and particles are lost from a magnetically confined system such as a tokamak. Such information could provide the basis for new methods to better control the losses and improve plasma confinement in a fusion reactor. At the microscopic level, the plasma transport is caused by binary collisions between charged particles and by plasma turbulence caused by fluctuating electric and magnetic fields. The collisions-induced transport sets up an irreducible minimum line for the transport level. The plasma turbulence, which is driven by the “free energy” associated with the non-uniformity within the plasma, generally causes a larger level of transport. This non-uniformity is relaxed (i.e., the free energy is released) as a result of the energy and particle transport.

In the past decade as computer resources have rapidly increased and advanced numerical algorithms have been developed, our knowledge on this long-standing complicated physics issue has been significantly advanced through supercomputer simulations. First-principle-based global large-scale particle simulations have been one of most successful and productive examples of how we have been enabled to gain new insights into the complexity of toroidal plasma systems. A prominent example is that of non-local physics, which is found to play a critical role in determining the global transport level. In the NSTX experiment, where the size of ion orbits is large compared to either the plasma gradient scale length or the local plasma minor radius, these non-local effects become important. Our global simulation of the NSTX plasma has revealed that the collisional ion heat transport rate is clearly decoupled from the local ion temperature gradient, showing a typical non-local and non-diffusive nature. In particular, the ion heat flux shows extra "non-local smoothing" in its profile and is found to be in the outward direction even for a reversed local ion temperature gradient. This generally brings the simulated ion thermal transport closer to the experimental measurements. Compared to small-orbit local theory, the radial electric field from these simulations also shows significant differences in the region of the internal transport barrier in NSTX plasmas.

With regard to turbulent transport, our global particle simulation of a DIII-D-size shaped plasma, employing a newly developed general geometry capability, has demonstrated that ion temperature gradient (ITG) driven turbulence, which grows initially in the linearly unstable zone, spreads in both the inward and outward radial directions into the stable zones. This leads to radially global turbulence and transport non-locality. The global phenomenon of turbulence spreading appears quite generic, independent of the presence of zonal flow. The zonal flow, however, may significantly change the nonlinear dynamics of the spreading process (see the figures below).

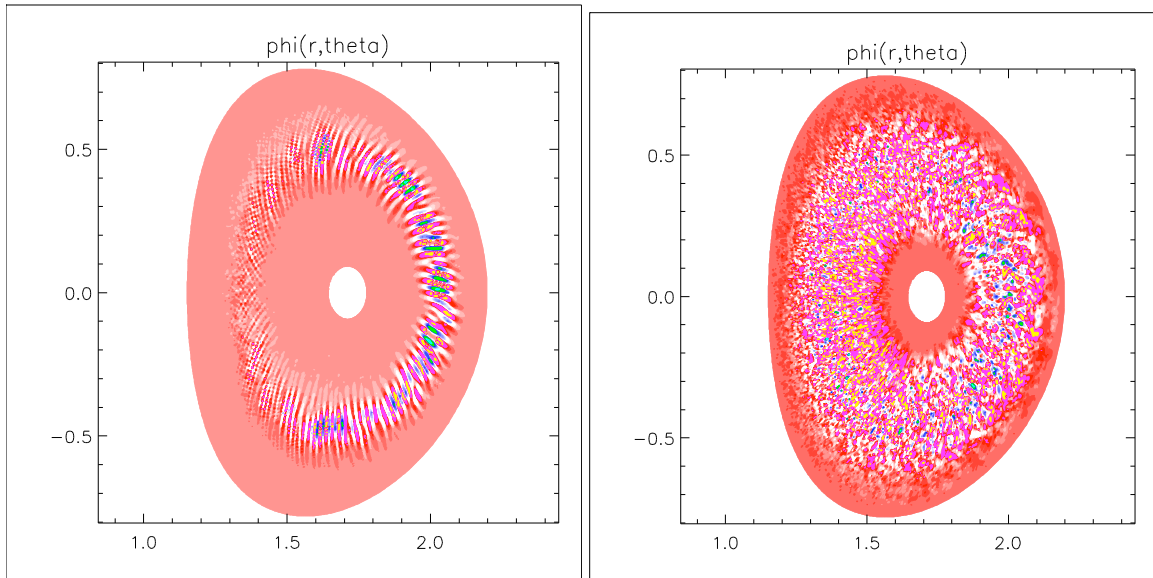


FIGURE: “Snap-shots” of the contours of the electric potential plotted on a poloidal plane, which illustrate the dynamic process of turbulence development. In the early phase (left), the elongated radial streamer structure of the eigenmode is linearly driven in the localized unstable zone ($0.42 < r < 0.76$, with r the normalized minor radius). In the later phase (right), the streamer structure breaks up as self-generated zonal flow (a radially sheared poloidal flow) is established, and eventually evolves into widely spread global turbulence.

Contact: Weixing Wang, 609-243-2609, wwang@pppl.gov

Reference:

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<http://meetings.aps.org/Meeting/DPP05/Event/35313>