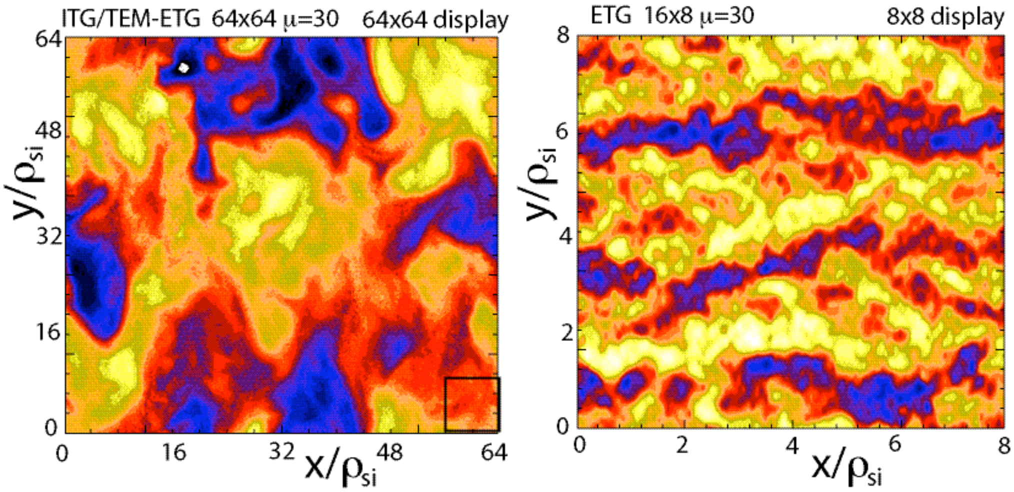
Tokamak turbulent transport coupling large and small eddies*

Production of fusion energy from a tokamak reactor requires that the heating energy stay confined long enough to heat the plasma to fusion temperatures. The energy containment time increases with the size of the tokamak and determines the large size required of practical fusion power reactors. The energy leaks from a tokamak across the confining magnetic field by turbulent eddy motions which becomes smaller the higher the magnetic field. The eddies on the scale of tens of ion gyroradii account for most of the energy loss in a tokamak reactor which will have about a thousand ion gyroradii across it's minor confining radius. However some energy is lost by even smaller eddies on the electron gyroradius scale. The ion scale eddies are driven mostly by ion temperature gradients of the plasma, and electron scale eddies by the electron temperature gradients. The ratio in circulation area of the large eddies over the small is called the Reynolds number. The computer time needed to simulate the turbulence increases almost like the square of the Reynolds number. Limited computer time has previously restricted simulation of tokamak plasma turbulence to either large ion scale or small electron scale eddies but not both at once.

Researchers at General Atomics won a DoE INCITE computer time award in 2006 (http://hpc.science.doe.gov/allocations/incite/) sufficient to simulate coupled ion and electron eddy scale turbulence at very high Reynolds number: more than a hundred fold larger [left figure]. The most expensive single simulation using General Atomics GYRO code (http://fusion.gat.com/comp/parallel/) required nearly the whole of the 18 teraflop Cray X1E Phoenix computer at the ORNL National Center for Computer Science running a full week. Contrary to previous speculations, the large simulations (in comparison to the small [right figure]) show that the turbulent transport at the ion and electron scales is separable and not highly coupled. Unfortunately predicting the spectrum of the small eddies does require the expensive high Reynolds number simulations. A new petaflop computer NCCS expected in 2008 would significantly shorten the time required for high Reynolds number simulations and enable systematic studies for scientific discovery. Tokamak diagnostics normally focus on the large ion scale turbulence. However experiments are in progress on the DIII-D tokamak at General Atomics to measure the spectrum of the small eddies. While the large ion scale eddies carry most of the transport, the turbulence in these large scales is sometimes quenched by high levels of electric field shear in good confinement regions of the tokamak. The small electron scale eddies then dominate the remaining small transport in good confinement layers. These good confinement layers are crucial to the efficiency of reactor scale tokamaks like the international burning plasma experiment ITER now being constructed in southern France (http://www.iter.org/) .

*Supported by US DOE under DE-FG03-95ER54309



Small electron scale eddies embedded in large scale ion eddies in a 64x64 ion gyroradius high Reynolds number simulation box (left) compared to elongated "streamer" electron scale eddies in a smaller 8x8 lower Reynolds number simulation box (right)

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Session GI2: Advances in Plasma Simulation I

9:30 AM–12:30 PM, Tuesday, October 31, 2006
Philadelphia Marriott Downtown - Grand Salon CDE

Chair: John Cary, Tech X
Abstract: GI2.00006: Coupled ITG/TEM-ETG Gyrokinetic Simulations

12:00 PM–12:30 PM

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