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Plasma Turbulence and Flows at Conditions of Transport Transients

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Outline

I. Why it is important to simulate transport transients in fusion plasmas

II. The ELMFIRE code, a gyrokinetic full *f* plasma PIC code

III. Resources and DEISA experiences

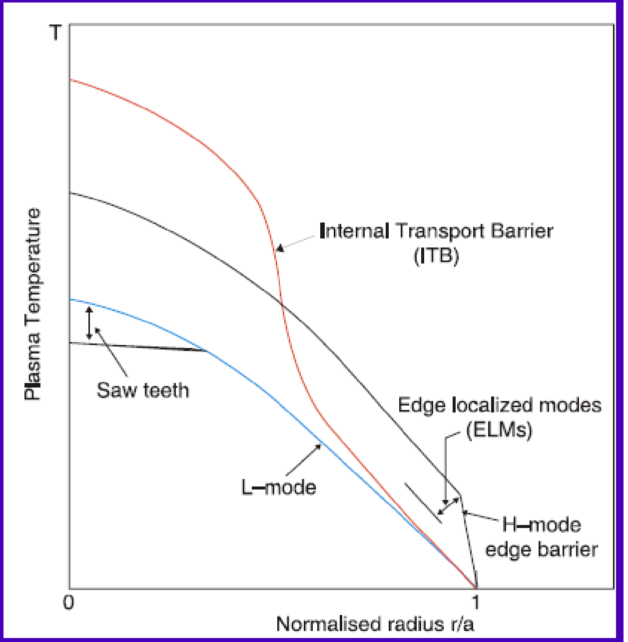
IV. Transport simulations

Conclusions

Section I
Why it is important to simulate transport transients in fusion plasmas

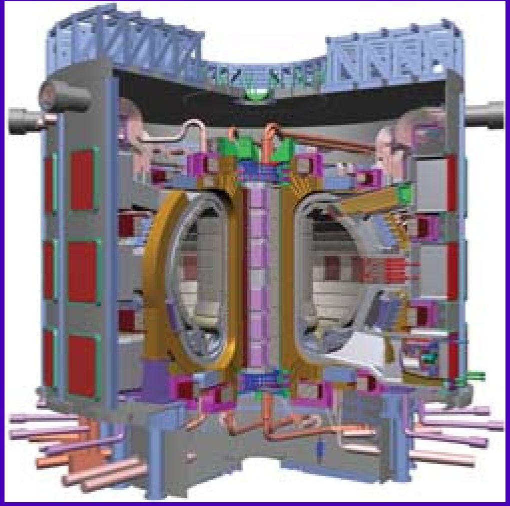
Transport barrier is vital for fusion reactors

- All trials to see spontaneous confinement transition in first principles fusion plasma simulation have failed so far.



What is missing in simulations?

- Full kinetics
- Consistent background
- Plasma core-edge coupling



DEISA project (fullfgk) goal

- Simulate spontaneous tokamak confinement transition and related self-organization of emergent large structures at experimental conditions
- Use first physics principles full phase-space gyrokinetic particle code ELMFIRE.

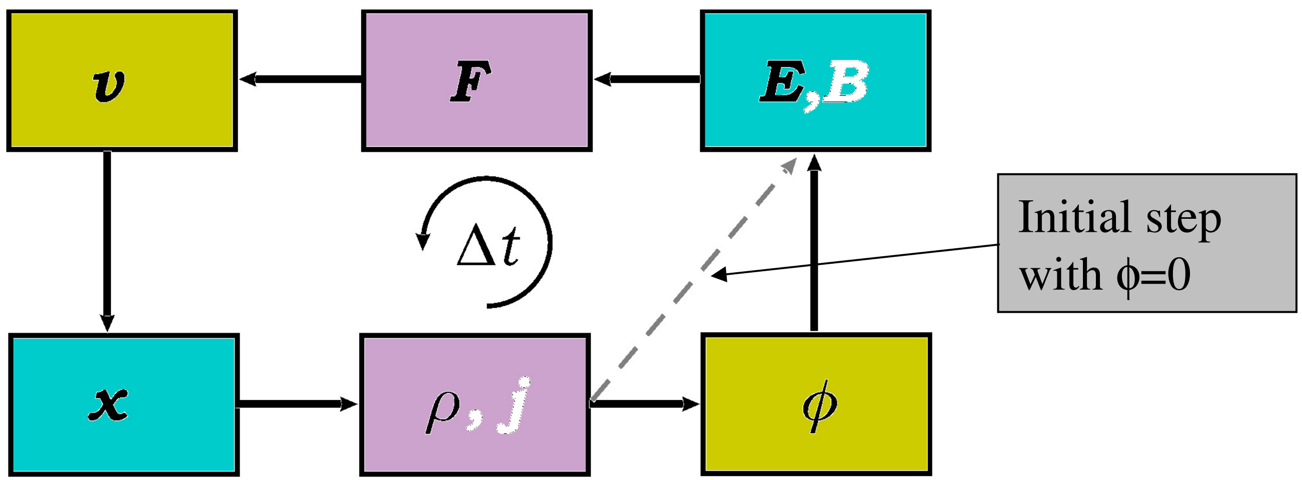
Section II
The ELMFIRE code; a gyrokinetic full f plasma PIC code

Calculation flux in particle codes

Acceleration and increment of velocity

Calculation of forces from fields and velocity

Computation of electric field. Magnetic is given.



Displacements and new positions. Boundary conditions.

Calculation of density. Current profile fixed.

Resolution of Poisson equation for the electrostatic potential.

ELMFIRE code (J. Comput. Phys. 227 (2008) 5582)

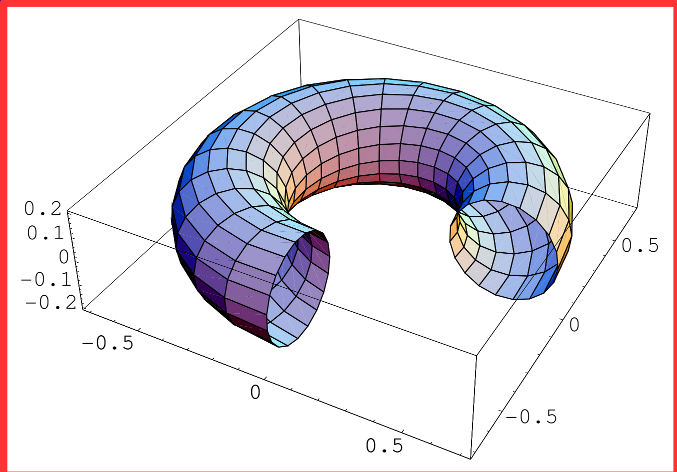
- Full *f* nonlinear gyrokinetic particle-in-cell approach for global plasma simulation (present version electrostatic). Implicit solvers for ion polarization and electron parallel nonlinearity.

$$\nabla^2\Phi + \frac{q^2}{mB\epsilon_0}\int\left[(\Phi - \langle\Phi\rangle)\frac{\partial\langle f\rangle}{\partial\mu} - \frac{m}{q\Omega}\langle f\rangle\nabla_\perp^2\langle\Phi\rangle\right]\mathrm{d}v = -\frac{1}{\epsilon_0}(q\tilde{n}_i(\vec{r}) - en_e(\vec{r}))$$

- Magnetic coordinates (ψ,θ,ς) Boozer '81, Guiding-center Hamiltonian White & Chance, '84.

- Gyrokinetics is based on Krylov-Boholiubov averaging method in description of FLR effects (P. Sosenko, '01).

- Based on free software: PETSc and GSL for math calc.



Memory and CPU time characteristics

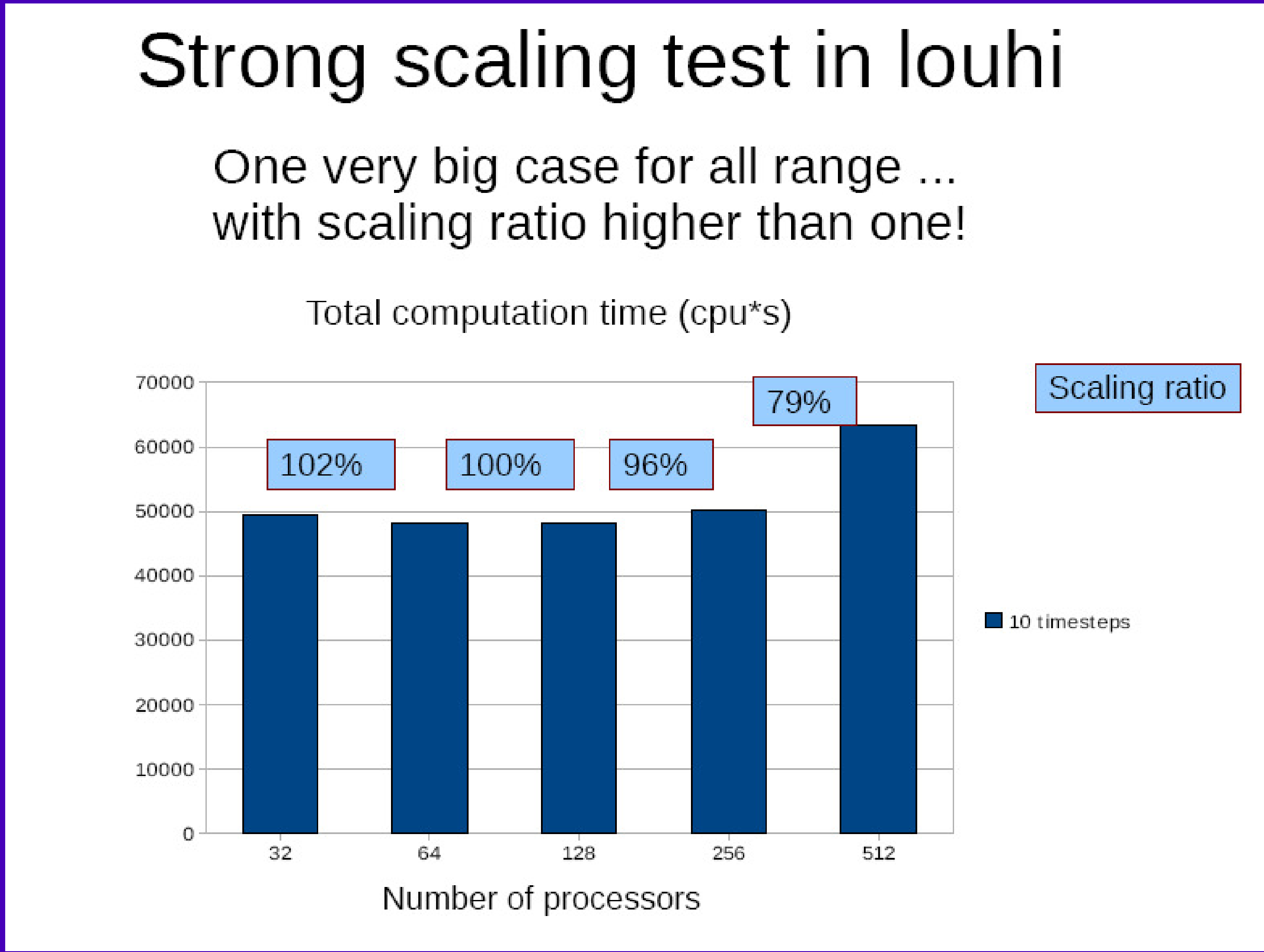
- ELMFIRE is a powerful code with excellent parallelization in most tasks.
- CPUtime (T) is directly related to the number of markers being treated in a single processor (N_p/P).
- Memory usage (M) is proportional to the size of grid (G), since it is not properly splitted among processors.
- The number of particles per cell lies in certain limits.
- $T \sim N_p/P$; $M \sim G$; $N_p \sim G$ -> $M \sim P*T$

Section III
Resources and DEISA experience

Available resources

- CSC (The Finnish IT Center for Science) and RZG (Rechenzentrum Garching) provide shared use of high-end parallel computers.
  - IBM eServer cluster 1600. 512 processors with 2.2TFlops, 384GB RAM and High Performance Switch communication.
  - Cluster of 768 AMD OpteronTM processors up to 3.2TFlops, 1600GB RAM, Infiniband network.
  - Cray XT4 (Hood): 70TFlop, 70TB RAM; HP ProLiant Supercluster, 10.6 Tflop, 100 TB

3D Inteconnect topology very suitable to tightly linked parallel processes like ELMFIRE



DEISA experiences (1)

- ELMFIRE project “fullfgk” was granted computation time in the Distributed European Infrastructure for Supercomputing Applications.
- ELMFIRE has had access to supercomputers in CSC and RZG, with up to 512 processors available.
- 165750 normalized CPUh were granted (comparable to total use of ~250000 normalized CPUh for ELMFIRE simulations at CSC during 2006)
- RZG machine architecture was the same as Ibmsc at CSC, so no big effort to apply (compile libraries inside binary etc) → flexible use of both Deisa resources and resources applied from CSC (20% of resources were allocated to louhi).

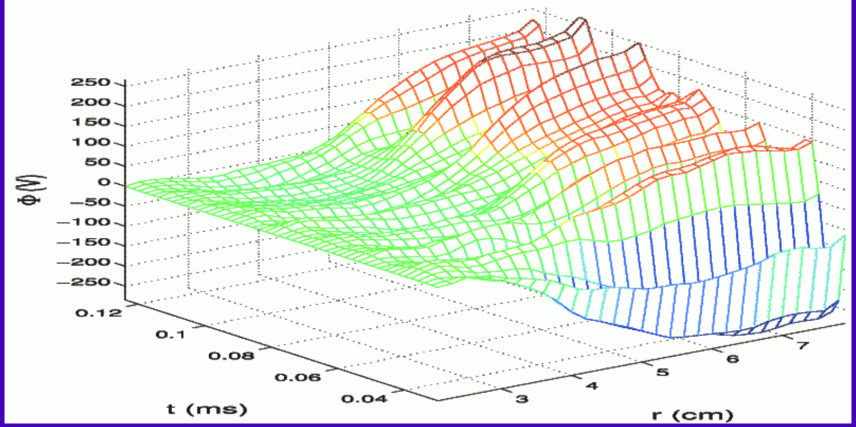
DEISA experiences (2)

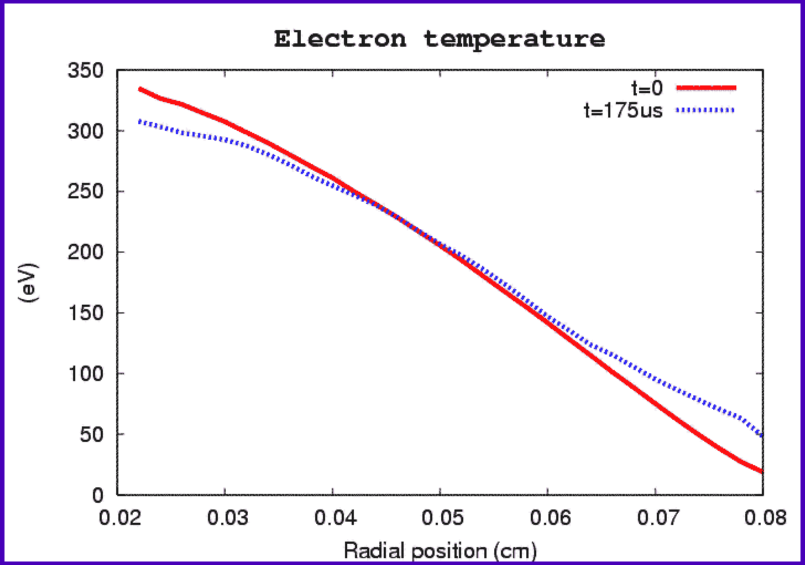
- Characteristic for our simulation: lot of data as an output to be analysed
- Initial troubles with data transfer (which is slow): need to allocate time for this, otherwise data is lost. This can be significant fraction of total CPU time allocated.
- Qeueing time sometimes quite long
- Not possible to check how the runs proceed → resources wasted sometimes

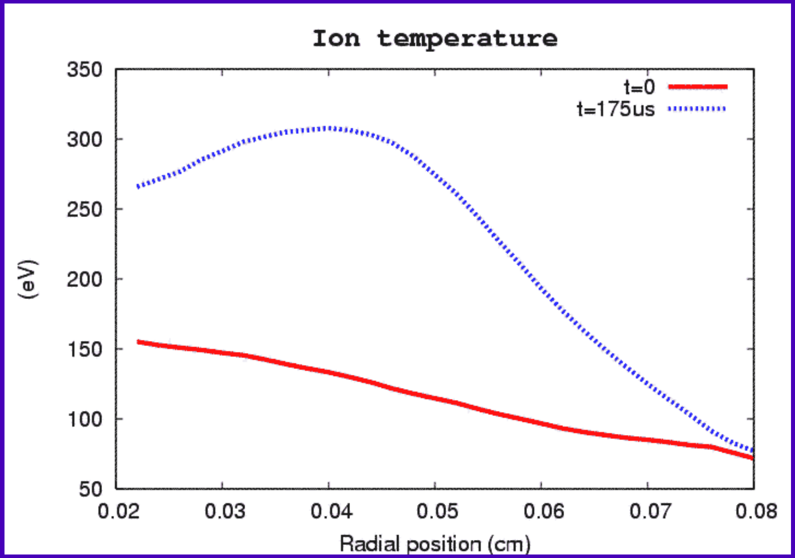
Section IV
Transport simulations

Case 1 under study: LH heated FT-2

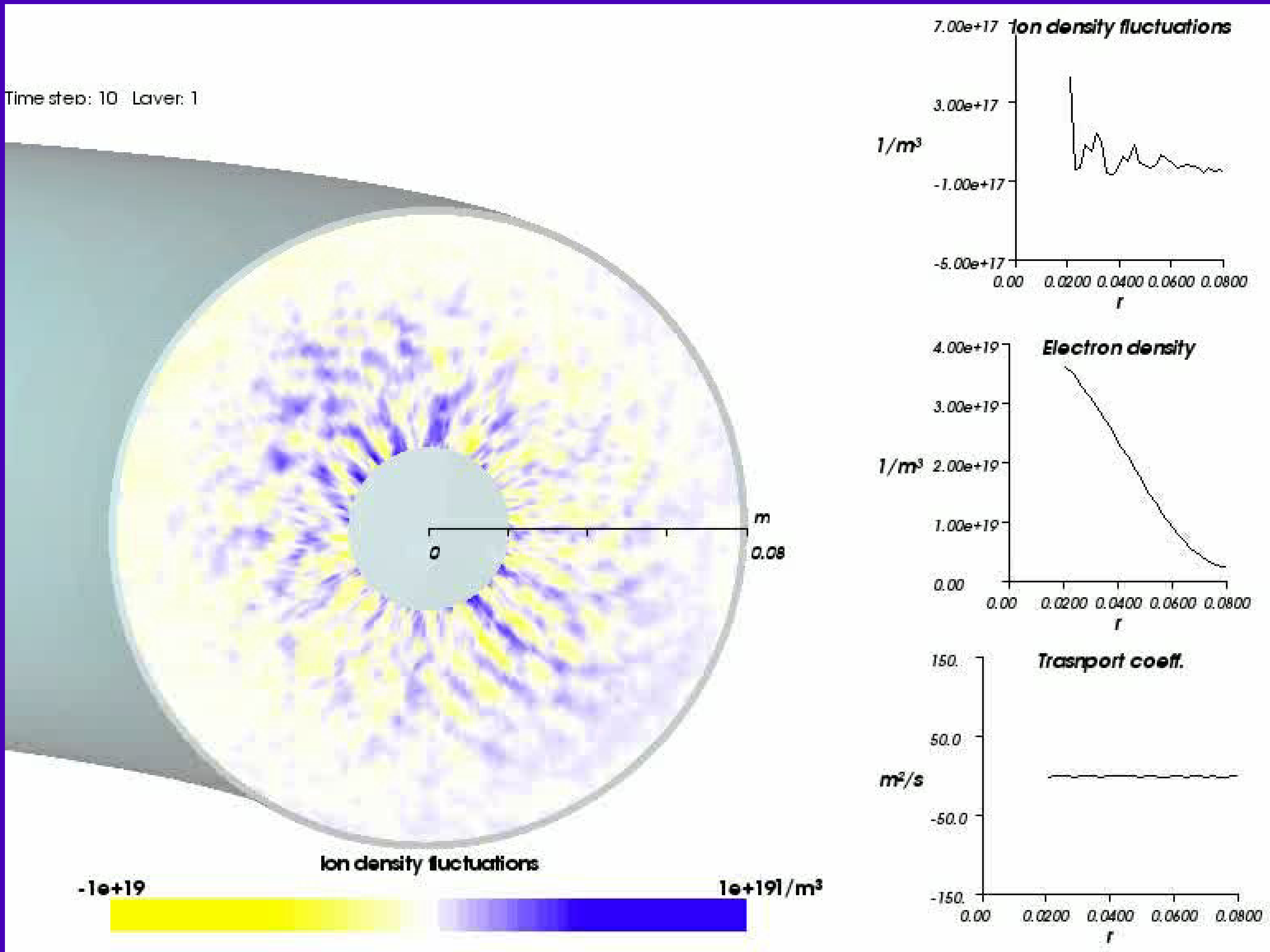
- Heating phase for 100 kW LH heated 22 kA FT-2 tokamak (O^{8+} impurities included).





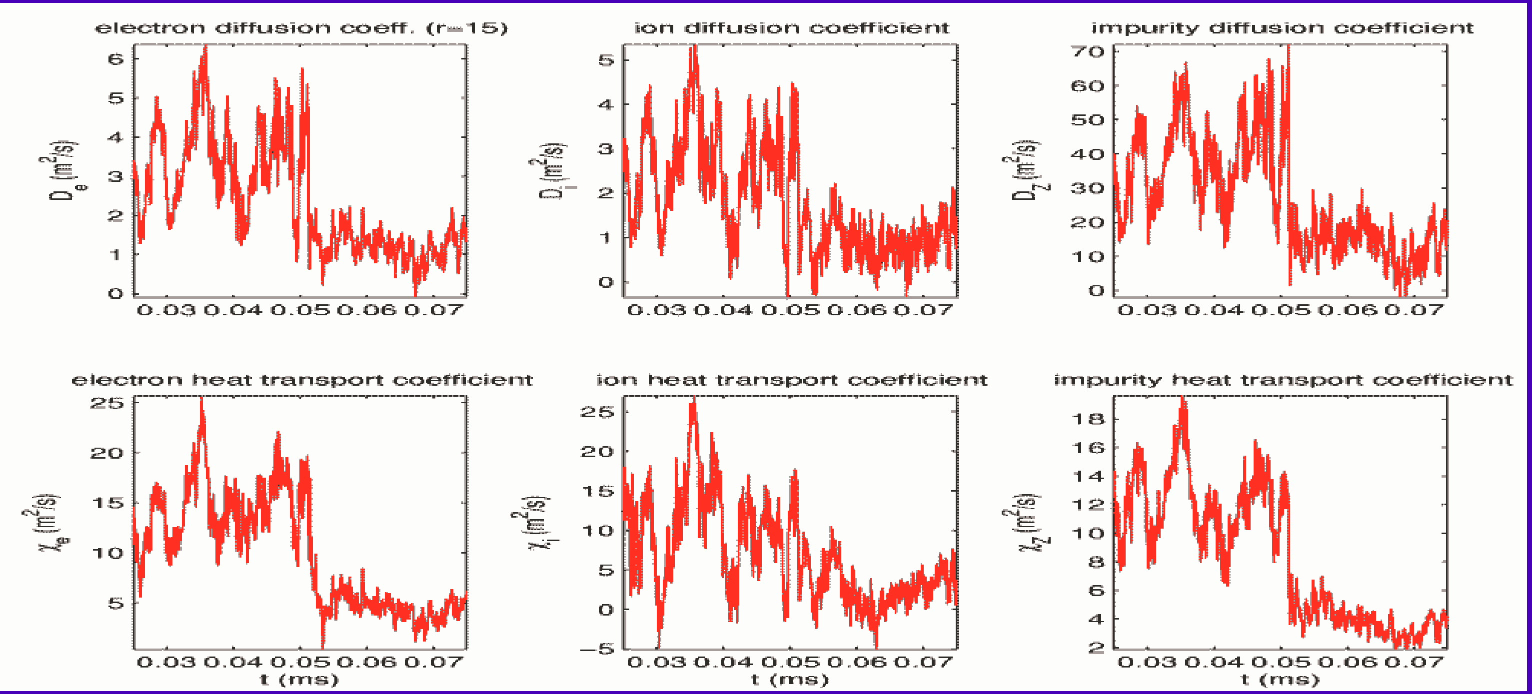


Transport transient with sheared flows appears in FT-2 simulation



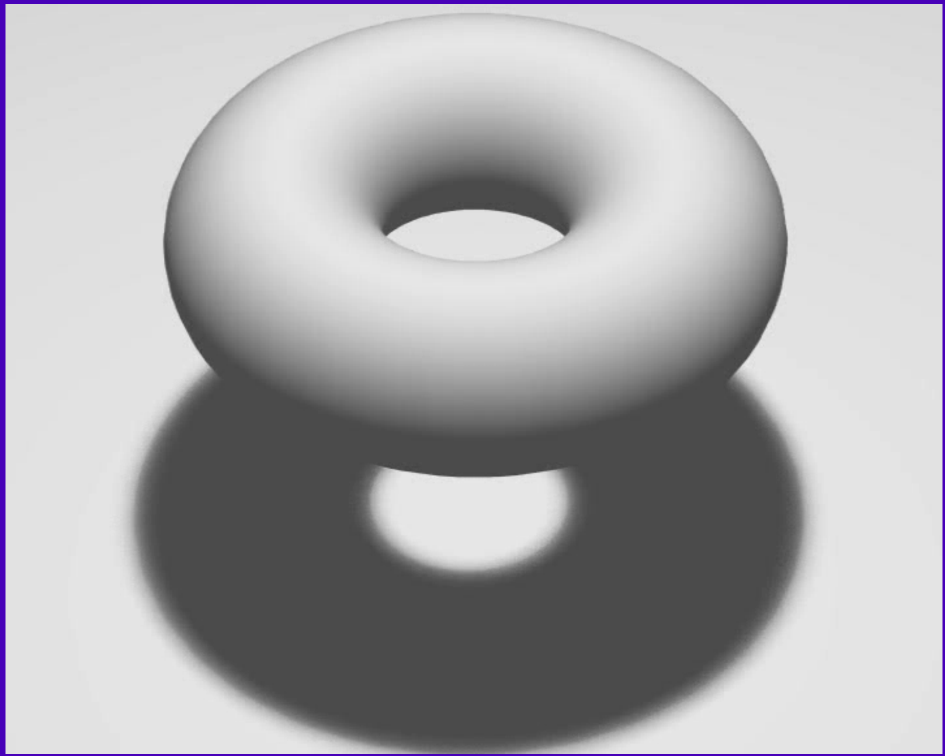
Evolution of diffusivity

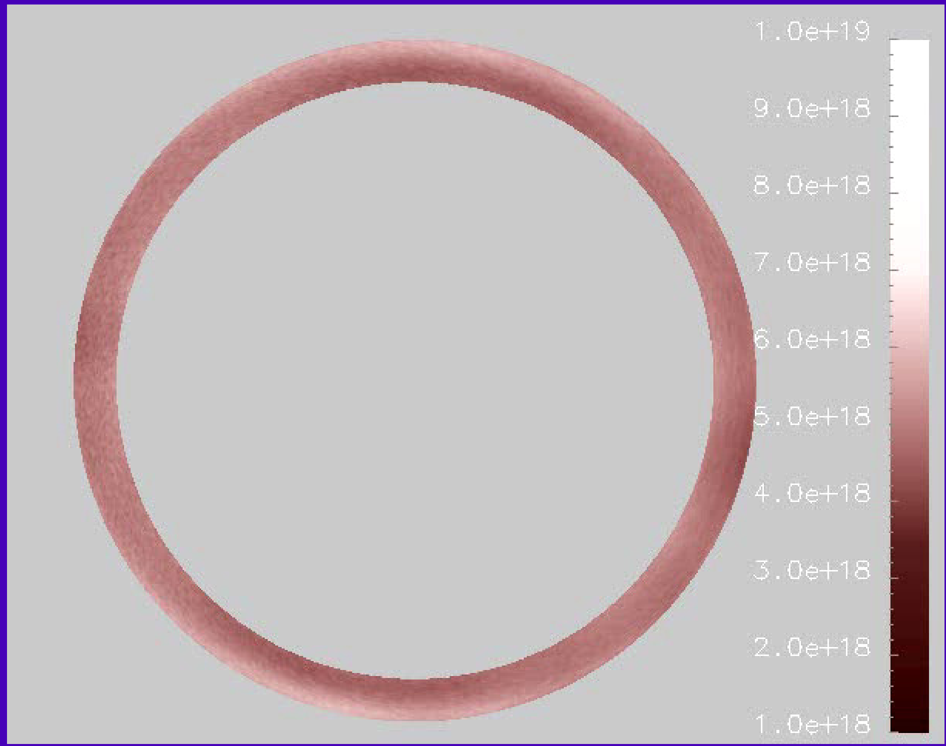
- Both particle diffusivity and heat conductivity drop drastically when poloidal flow shear destroys the turbulent structures
- The figures show values from the middle radius



Case 2 under study: Heated ASDEX Upgrade (AUG) pedestal plasma

Plasma minor radius 0.5 m, major radius 1.5 m, B=2 T, I=1 MA

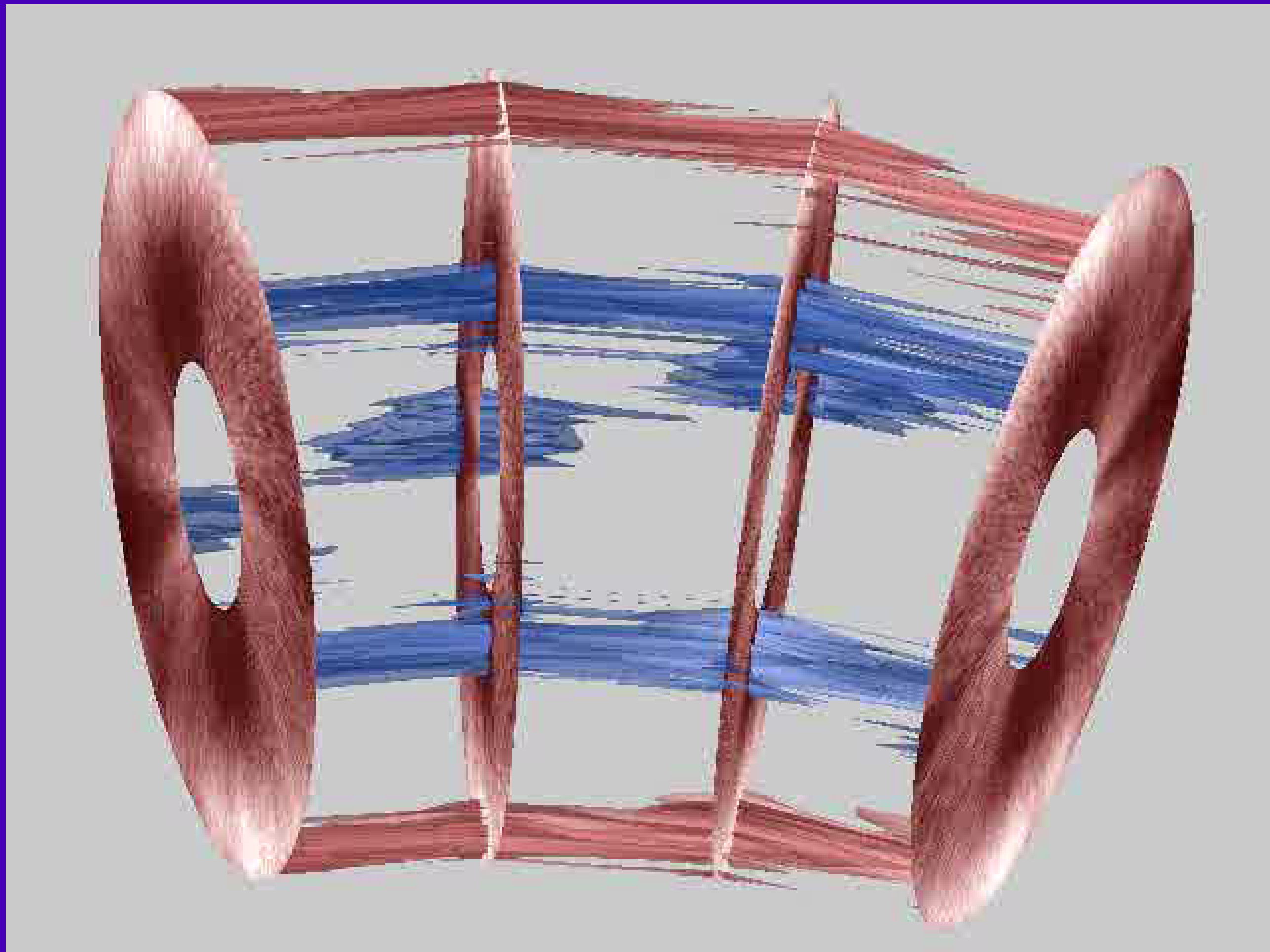




AUG pedestal challenge for computing

- Average production run: 66 million ions and electrons (920 per cell) in 30x600x4 grid with 1 μs time steps run up to 200 μs in 12 hours with 256 processors. Takes 360 MB memory in each processor
- Grand challenge run: 264 million ions and electrons (3680 per cell) in 30x600x4 grid with 1 μs time steps run up to 1 ms in 120 hours with 512 processors. Takes 720 MB memory in each processor

Both neoclassical and turbulence effects simulated in the pedestal density



Conclusions

- Successful 5D gyrokinetic full *f* PIC simulations of tokamak electrostatic turbulence and transport for core plasma.
- Careful benchmarking of the codes is performed in appropriate limits for the turbulence saturation and neoclassical characteristics.
  - Linear and nonlinear benchmarking.
- Spontaneous internal transport barrier formation is seen in a small heated tokamak. Edge confinement transition not yet seen.
- To find edge transition, the extension of calculations to the open field line region in the edge is probably needed > larger grid & more particles

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