Plasma Turbulence Research on MPP Platforms

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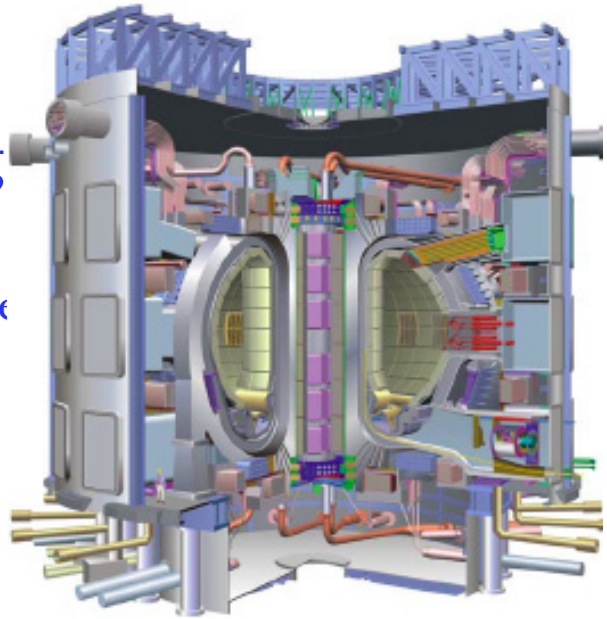
Collaborative Particle Simulation Efforts for Magnetic Fusion Energy Science



- SciDAC Center for Gyrokinetic Particle Simulation of Turbulent Transport in Burning Plasmas (GPSC)

  -- PPPL (W. W. Lee - PI), Columbia, Colorado, ORNL, UC-Irvine UCLA, UC-Davis, UT-Knoxville

- SciDAC FSP Center for Plasma Edge Simulation (CPES)

  -- NYU (C. S. Chang - PI), Caltech, GA, LBNL, Lehigh, UC-Irvine, Colorado, ORNL, MIT, Rutgers, PPPL, Utah, UT-Knoxvillle

- ASCR/MICS Project for Multi-Scale Gyrokinetic Particle Simulation of Magnetized Plasmas (MSG)

  -- PPPL (W. W. Lee - PI), Columbia

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Scientific Discovery through Advanced Computing: Gyrokinetic Particle Simulation (PIC) of Turbulence Transport for Magnetic Fusion Plasmas

- C90 ('93) -- identified ion temperature gradient (ITG) drift instability as the primary candidate for turbulent transport in TFTR tokamak
- C90 ('96) -- provided the theoretical explanation for the isotope effects observed in tokamaks
- T3E ('98) -- established global zonal flow physics as the new paradigm for ITG turbulence
- Seaborg ('02) -- observed the transition of size scaling from Bohm to GyroBohm
- Seaborg ('04) -- identified turbulence spreading as the mechanism for the transition of size scaling; discovered the importance of energy conservation for steady state transport
- X1E ('05) -- observed the convergence of steady state transport through high resolution ITG simulations

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Basic Principles of Particle Simulation

- Vlasov Equation in 5 (or 6) - dimensional phase space is solved in gridless Lagrangian coordinates

  -- Nonlinear PDE $\longrightarrow$ Linear ODE

- Maxwell's Equations are solved in 3 - dimensional Eulerian coordinates

  -- Linear PDE

- Collisions are treated as sub-grid phenomena

  -- Monte-Carlo Processes

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Special Considerations for Particle Pushing

Mixed representations:

x_j, f_j and w_j -- data for j-th particle

u_g and v_g - data for the g-th grid

- Charge: scatter and add operation -- particle to grid

  u(x_j) = u(x_j) + w_j, j --- particle

- Solve: grid only

  ∇^2 v_g = u_g,

- Force: gather operation -- grid to particle

  f_j = v(x_j)

- Push: particle only

  x_j = x_j + f_j

- Sensitive to memory bandwidth and memory latency

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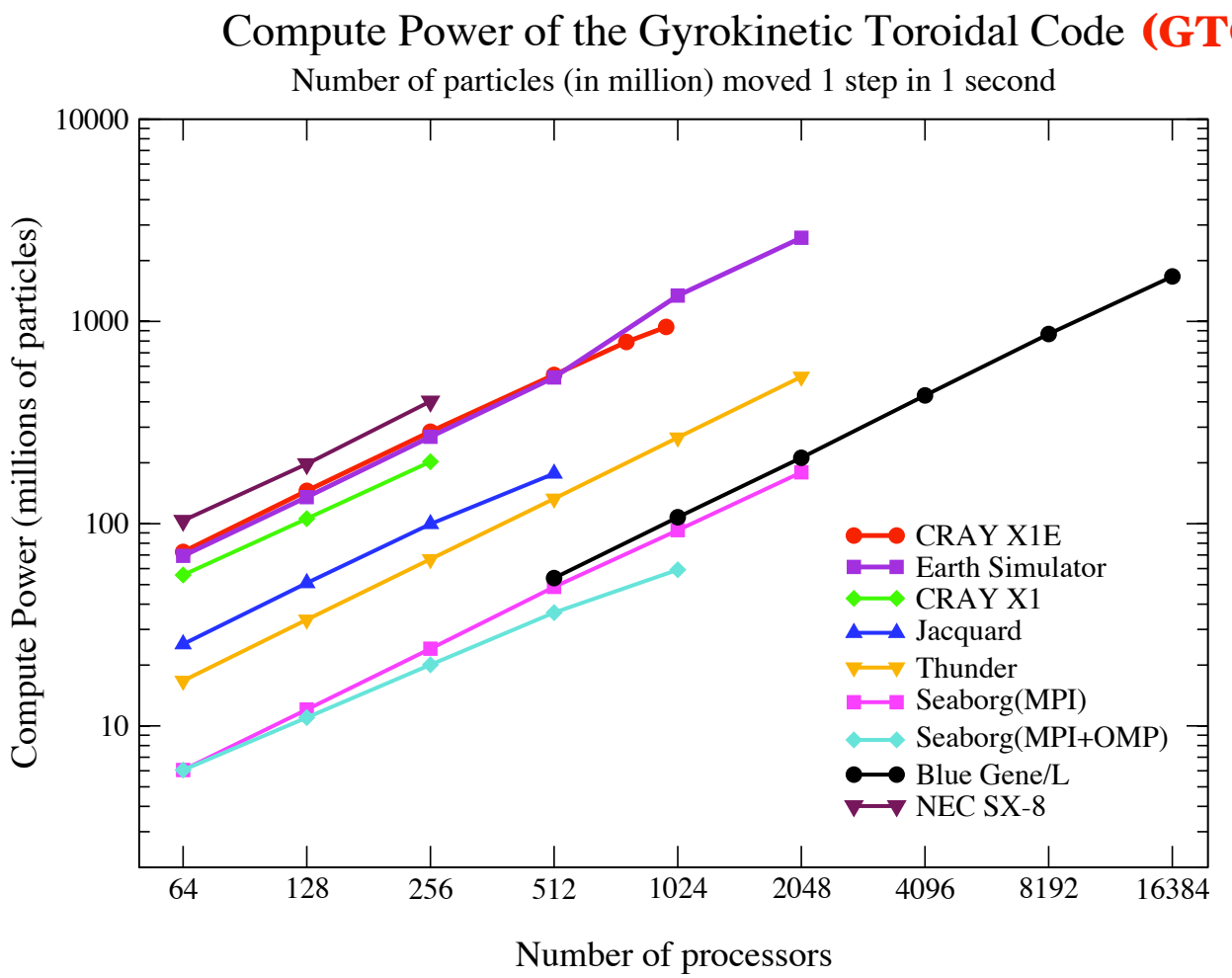
GTC performance on MPP platforms aiming for ITER-size Plasmas

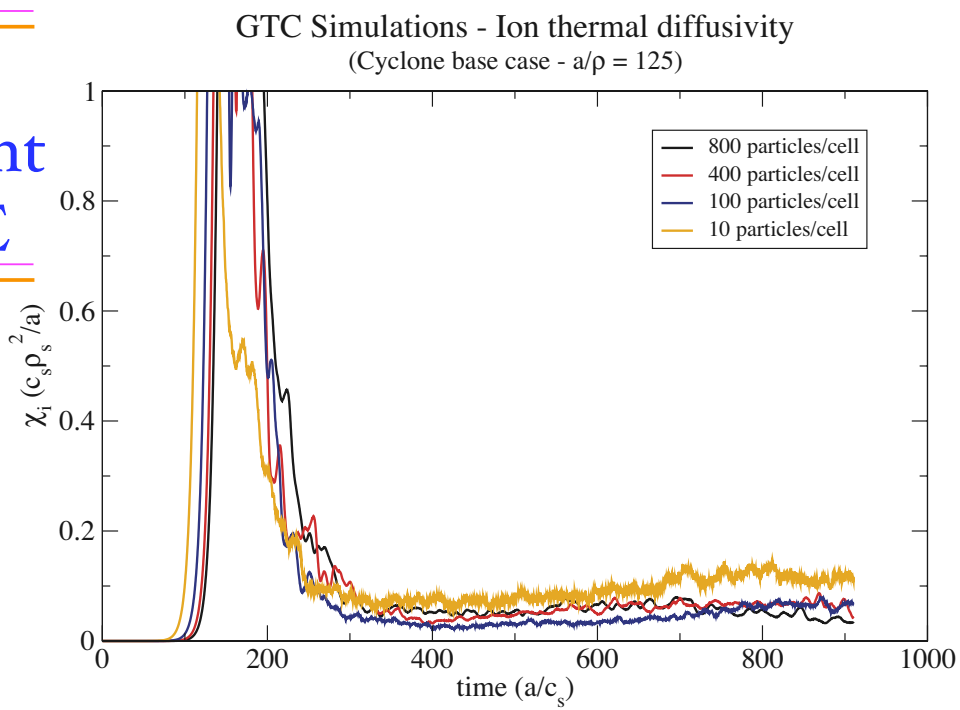
- Gyrokinetic particle codes are very portable, scalable and efficient on both cache-based and vector-parallel MPP platforms
- 3.7 teraflops achieved on the Earth Simulator with 2048 processors using 6.6 billion particles

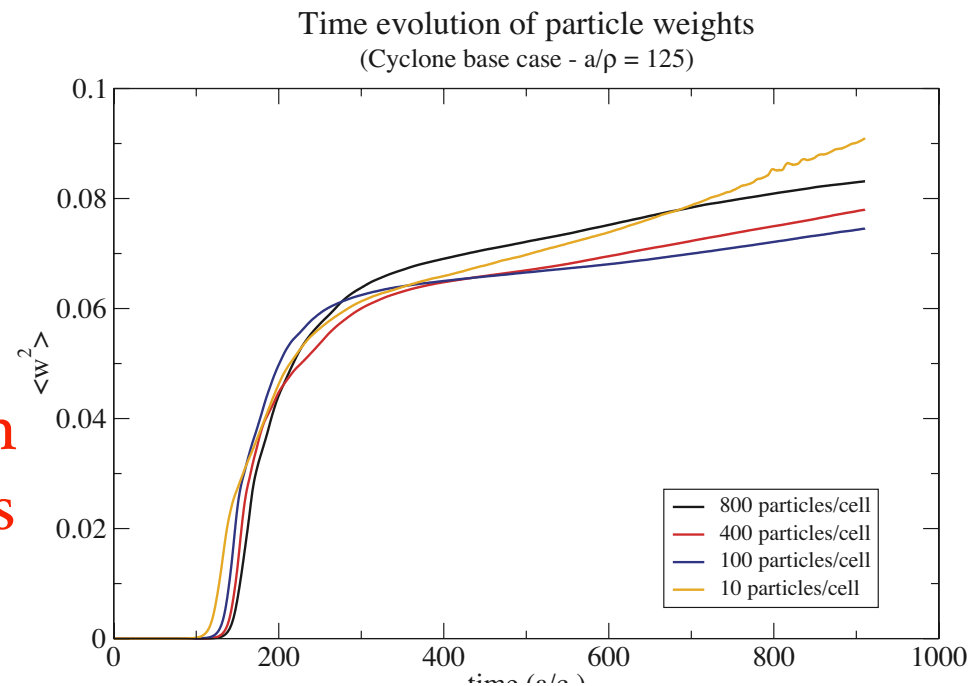


Convergence tests of ion temperature gradient drift turbulence on X1E

Number of Particles per cell

10
100
400
800





- Nonlinear terms related to energy conservation is included in the simulation
- Discrete particle noise is apparently not a problem

Summary

- Particle codes are very adaptable to both cache-based and vector-parallel MPP processors

- In collaborations with the TOPS ISIC, we have used the PETSc toolkit for solving the elliptic field equations on MPP platforms

- Collaborations with the SDM ISIC and visualization efforts are ongoing

- To make gyrokinetic PIC as a predictive tool for turbulent transport for ITER, we need at least one order of magnitude increase of the present X1E computing power

- For integrated simulations of ITER, we may need another order increase or more

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