Discussion:
ELM and Edge Plasma Studies for Proposal

- Edge plasma – Theoretical/simulation issues for all phenomena that perturb the plasma boundary are related
- ELMs and ELM-free edge plasma oscillations, non-axisymmetric fields (RMP, error fields, toroidal ripple)
- Scrape-off layer and wall interactions -> VDEs, disruptions, ELM loads on wall

Accomplishments

- Over past period, developed plasma/vacuum/rigid boundary wall model for fully nonlinear simulation
  - 5 yrs ago (SciDAC CPES) proposed ELM simulation using 32 cpus for 10-20 hrs in an annulus around plasma edge. Now 768 cpus for 200+ cpu-hours, whole plasma to wall
  - Resistivity decreased from $S=10^5$ to 3.3×10^7 with vacuum $S \leq 10^3$, vacuum density $n_{vac}/n_o \leq 0.1$ (large gradient from plasma to vacuum)
- Great improvements in codes over past contract period: Physics, numerical algorithms, methods
  - Code speed up by large factor (M3D estimated 20x, time spent in solver decreased from 90% to 25% or less)
- Results look similar to experimental ELMs
- Results challenge plasma theory
  - Chaotic magnetic tangle is expected from Hamiltonian perturbation theory for freely moving plasma boundary. Flux tubes not well defined.
  - Linearized perturbation theory breaks down => Nonlinear stability criteria

Accomplishments

- Starting to couple MHD and particle codes with 3D MHD ELM fields
  - SciDAC CPES: M3D and XGC (thru next year?)
- Links to experimental teams and data established
  - DIII-D, NSTX, C-Mod, JET for ELMs, RMPs, ELM-free modes disruptions
- Visualization, including movies, 3D viz was vital for ELM analysis!!
  - Needs extension and improvement. Vector streamlines. Turbulent data.
  - Size, speed issues for larger simulations.
  - Complexity means time-consuming learning curve → Need connection to viz expert(s), but code-users/physicists need to know the basics.

Computing Trends

- Much larger (although not much faster) computers are becoming aggressively multi-core
  - GPU sub-processing (Cray next year – testing now)
  - Exascale: “10^{18} in 2018” (unknown architecture)
- Fluid-based plasma equations don't parallelize well – weak scaling only goes so far. How should CEMM approach this?
  - (ITER is the extreme example of weak scaling: ρ_i/a=40 -> 200)
  - Transition to MHD turbulence: Theoretical and numerical issues
    - More explicit time-stepping helps, but Courant condition is limiting
    - Related to turbulence in fluid dynamics. More complicated!
  - Two-fluid should be more turbulent than MHD. Anisotropic pressure.
  - Hybrid particle/fluid? Multiple runs (eg, parameter scans) per job?
- Visualization and data analysis are vital
  - Code parallelization and large data sets. Which programs/tools?
  - Large data: Methods of extraction, compression, (storage, reconstruction?)

Trends – plasma boundaries

- Vacuum and wall models:
  - Disruption studies (Strauss) use thin resistive wall / ideal vacuum(GRIN)/ ideal conducting wall
  - Many questions:
    - Electrical sheath to the wall? (MHD is quasi-neutral, no sheath.)
    - Currents in walls? Need holes and nonaxisymmetric breaks in wall $\rightarrow E_\phi$ in plasma. Currents flow into wall?
    - Density sources – impurities, ionization, ...
    - Machine field coils, field correction coils? Stabilization plates?
- Nonaxisymmetric magnetic fields (RMPs, including inboard side, error fields and error field "correction," toroidal field ripple
- Toroidal rotation (poloidal rotation?)
  - Magnetic shielding of non-axisymmetric exterior fields exists
  - Particle losses from plasma edge drive rotation?

V & V

- Validation and Verification of *nonlinear* simulations
  - ELM simulations show how difficult it is to compare to experiments in enough detail to verify relatively simple phenomena, like the magnetic tangle
  - Detailed data from specialized diagnostics exists for a limited number of discharges, usually not the ones that prove to be the best examples of a phenomenon
  - Experimental reconstructions are not very accurate (spurious internal modes found in simulation, no toroidal rotation, edge profiles don't match core)
  - Comparison will be indirect
    - Very difficult to measure inside plasma
    - Need dedicated experiments and/or diagnostics
  - Needs close collaboration with experimentalists
- Simulation by more than one nonlinear code