Pushing the Envelope of Fusion Edge Physics on Extreme Scale HPCs
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"Toroidal" Tokamak Geometry

ITER Poloidal cross-section

Torus, not a straight cylinder: physics becomes more complicated through the magnetic inhomogeneity and the toroidal mode coupling.

What science are we studying?

Edge plasma self-organizes into a steep pedestal shape (H-mode)
- Smaller and cheaper tokamak, by allowing a hot plasma at plasma edge
- Challenging physics: Scale inoperable plasma, turbulence and neutral particle dynamics across steep gradient, and in contact with material wall
- Non-equilibrium thermodynamics, hence non-Maxwellian
- "Fluid closure" is difficult
- Large amplitude nonlinear coherent turbulence structures, "blobs."

XGC1, with its excellent portability, could take advantage of all the LCFs tested so far

- A result from close collaboration between ASCR and OFES Scientists.

XGC1 Performance: Weak Particle Scaling on O2 grid

Computing Resources for XGC in 2015

- INCITE: 270M hours
  - Titan: 170M hours (Extreme scale jobs with full physics, 10-20PFs, usually 90% capability computing)
  - Mira: 100M hours (Large scale jobs with partial physics at 3.3 PFs, \approx 1.3 capability computing)
- NERSC: 70M hours (capacity computing on Edison, \approx 1.5PFs)

Pre-Exascale Program

- CAAR at OLCF: postdoc support
- NERSC at NERSC. Tier 1, postdoc support

Predictions for DIII-D & NSTX are in the right ballpark

- DIII-D: 90M hours
- NSTX: 70M hours

Cross-validation of E&M modes between XGC1 and GEM

ITG-KBM Transition Verification

6D particle dynamics for validating 5D gyrokinetic equations (U. Colorado)

Kinetic-Kinetic Multiscale Integration

Kinetic-electrons

Kinetically-electrons

Kinetically-ion-electrons

Kinetically-ion-ion

Holding the correct multi-scale dynamics is very important in the multi-scale code coupling

Further development of XGC1, with SciDAC Institutes and HPC Centers

Physics capability

- Electromagnetic turbulence
- Edge electrons can be more than fluid: Gyratonic ions + fluid electrons.
- This choice removes the "cancellation issue" in the kinetic ion & E&M
- kinetic electrons physics can be added later in the form of closures.
- Utilize the good work by GEM (delta-E, core plasma) for technology transfer to XGC1, including the 4D-verification work.

Kinetico-electric multi-scale integration

- Pre-exascale programs (in CAAR and NERSC)
- Vectorization
  - Guida Formanik: OpenACC for easier portability
  - Heterogeneous management
- Multiple GPUs in a node
- Fault tolerance
- Implict and variational time stepping

Correct transport in coarse-grained XGC1

Correct transport in coarse-grained XGC1

Computational capability

- Flexible data formats: RDB, XML, HDF5
- Data analysis: on the fly analysis
- Data sharing: post processing
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