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Computational Plasma Physics at the Bleeding Edge: Simulating Kinetic Turbulence Dynamics in Fusion Energy Sciences

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Advanced computing is generally recognized to be an increasingly vital tool for accelerating progress in scientific research in the 21st Century. The imperative is to translate the combination of the rapid advances in super-computing power together with the emergence of effective new algorithms and computational methodologies to help enable corresponding increases in the physics fidelity and the performance of the scientific codes used to model complex physical systems. If properly validated against experimental measurements and verified with mathematical tests and computational benchmarks, these codes can provide more reliable predictive capability for the behavior of complex systems, including fusion energy relevant high temperature plasmas. The magnetic fusion energy research community has made excellent progress in developing advanced codes for which computer run-time and problem size scale very well with the number of processors on massively parallel supercomputers. A good example is the effective usage of the full power of modern leadership class computational platforms from the terascale to the petascale and beyond to produce nonlinear particle-in-cell simulations which have accelerated progress in understanding the nature of plasma turbulence in magnetically-confined high temperature plasmas. Illustrative results provide great encouragement for being able to include increasingly realistic dynamics in extreme-scale computing campaigns to enable predictive simulations with unprecedented physics fidelity. Some illustrative examples will be presented of the algorithmic progress from the magnetic fusion energy sciences area in dealing with low memory per core extreme scale computing challenges for the current top 3 supercomputers worldwide. These include advanced CPU systems (such as the IBM-Blue-Gene-Q system and the Fujitsu K Machine) as well as the GPU-CPU hybrid system (Titan).