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Scientific Discovery through Advanced Computing in Plasma Science

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Advanced computing is generally recognized to be an increasingly vital tool for accelerating progress in scientific research during the 21st Century. For example, the Department of Energy's "Scientific Discovery through Advanced Computing" (SciDAC) Program was motivated in large measure by the fact that formidable scientific challenges in its research portfolio could best be addressed by utilizing the combination of the rapid advances in super-computing technology together with the emergence of effective new algorithms and computational methodologies. The imperative is to translate such progress into corresponding increases in the performance of the scientific codes used to model complex physical systems such as those encountered in high temperature plasma research. If properly validated against experimental measurements and analytic benchmarks, these codes can provide reliable predictive capability for the behavior of a broad range of complex natural and engineered systems. This talk reviews recent progress and future directions for advanced simulations with some illustrative examples taken from the plasma science applications area. Significant recent progress has been made in both particle and fluid simulations of fine-scale turbulence and large-scale dynamics, giving increasingly good agreement between experimental observations and computational modeling. This was made possible by the combination of access to powerful new computational resources together with innovative advances in analytic and computational methods for developing reduced descriptions of physics phenomena spanning a huge range in time and space scales. In particular, the plasma science community has made excellent progress in developing advanced codes for which computer run-time and problem size scale well with the number of processors on massively parallel machines (MPP's). A good example is the effective usage of the full power of multi-teraflop (multi-trillion floating point computations per second) MPP's to produce three-dimensional, general geometry, nonlinear particle simulations which have accelerated progress in understanding the nature of plasma turbulence in magnetically-confined high temperature plasmas. These calculations, which typically utilized billions of particles for thousands of time-steps, would not have been possible without access to powerful present generation MPP computers and the associated diagnostic and visualization capabilities. In general, results from advanced simulations provide great encouragement for being able to include increasingly realistic dynamics to enable deeper physics insights into plasmas in both natural and laboratory environments. The associated scientific excitement should serve to stimulate improved cross-cutting collaborations with other fields and also to help attract bright young talent to the computational science area.