Gyrokinetic Particle Simulations of Plasma Turbulence and Kinetic-MHD Physics

SciDAC Principal Investigators: W. W. Lee[1], S. E. Parker[2], Z. Lin[3], V. K. Decyk[4]
Partnership Principal Investigators: D. E. Keyes[5], K.-L. Ma[6], and M. Beck[7]

This letter is in response to the recent DoE Program Notice DE-FG01-04ER04-09 on receiving grant applications for the development of scientific simulation codes for fusion energy sciences. In this regard, we propose to use gyrokinetic particle codes on massively parallel computers for studying plasma turbulence and kinetic-MHD physics relevant to the present magnetic fusion experiments in the U. S. and abroad. In particular, we plan to use this undertaking to lay the groundwork for an integrated fusion simulation project in the future and to develop the capabilities for studying confinement and transport physics related to burning plasmas in ITER.

The project is a laboratory/university collaboration involving experts from related disciplines. Three of the SciDAC PI's for the proposal are pioneers of the field of gyrokinetic particle simulation and have been active participants in the MFE-sponsored computational initiatives for the past ten years. Among their contributions, for example, are the development of gyrokinetic particle simulation and perturbative δf methods, the confirmation of the existence of global toroidal ITG modes, and the interplay between global zonal flow, ITG turbulence, and the resulting scaling trends. The other SciDAC PI is a PIC algorithms expert. The three partnership PI's are leaders in applied mathematics, visualization and data management, respectively.

There are two major codes in the project. The global gyrokinetic toroidal code (GTC) at PPPL/UCI has been a workhorse for the last five years producing many exciting results. The work has helped to explain many experimental trends and inspired many national and international collaborations. The code has also been shown to be efficient on many MPP platforms. For example, on Seaborg at NERSC, its single processor efficiency is about 12% and the code scales nearly linearly up to 2000 processors. On the Earth Simulator supercomputer in Japan, the code is ten times faster than on Seaborg, reaching 18% for single processor efficiency. The SUMMIT code at the University of Colorado is a general geometry electromagnetic flux-tube code. It has the electron dynamics and finite-β effects for more realistic simulations, and has also been used successfully for developing new physics and numerical algorithms.

The proposed project will continue to develop these two codes by improving their capabilities to handle neoclassical and turbulent transport physics as well as kinetic-MHD effects in general geometry for shaped plasmas. To achieve higher single processor efficiency, we intend to use techniques developed for the gaming industry. To include electromagnetic effects in GTC, we need state-of-the-art Poisson solvers for efficiency and scalability on MPP platforms, such as PETSc (Argonne National Laboratory) and HYPRE (Lawrence Livermore National Laboratory). Close interaction with the Columbia group in this undertaking and on algebraic multigrid methods is essential. The SUMMIT code will be expanded to a full-cross section wedge code. Comparisons between the two codes will enhance our understanding of local and global physics. To strengthen the diagnostic effort for codes running with billions of particles with millions of grid points, the UC-Davis group will help us with visualization and the UT-K group with data management. We believe the proposed project uses the most appropriate tools available to us presently in physics,

mathematics and computer science for studying ITER-relevant physics.

Principal Investigators

Scientific Discovery through Advanced Computing

W. W. Lee[1], Project Director
Laboratory Fellow
Plasma Physics Laboratory
Princeton University
Princeton, NJ 08543
wwlee@pppl.gov
(O) 609-243-2647
(F) 609-243-2662

S. E. Parker[2]
Associate Professor
Department of Physics
University of Colorado
Boulder, CO 80309
sparker@colorado.edu
(O) 303-492-3292
(F) 303-492-0642

Z. Lin[3]
Assistant Professor
Department of Physics & Astro
University of California at Irvin
Irvine, CA 92697
zhihongl@uci.edu
(O) 949-824-2717
(F) 949-824-2174

V. K. Decyk[4]
Research Physicist
Department of Physics &Astronomy
University of California at Los Angeles
Los Angeles, CA 90095
decyk@physics.ucla.edu
(O) 310-206-0371
(F) 310-825-4057

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Scientific Application Program Partners

D. E. Keyes[4]
Professor
Department of Applied Physics & Applied Mathematics
Columbia University
New York, NY 10027
david.keyes@columbia.edu
(O) 212-854-1120

K.-L. Ma[5]
Professor
Department of Computer Science
UC-Davis
Davis, CA 95616
ma@cs.ucdavis.edu
(O) 530-752-6958

M. Beck[6]
Associate Professor
Department of Computer Science
University of Tennessee
Knoxville, TN 37996
mbeck@utk.edu
(O) 865-974-3548

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