

## **DOE Final Technical Report**

**Project Title: Center for the Study of Plasma Microturbulence**

**Institution: University of Colorado, Boulder**

**Principal Investigator: Scott E. Parker**

**Award Number: DE-FC02-08ER54960**

This document is the Final Technical Report for DOE cooperative agreement DE-FC02-08ER54960, titled "Center for the Study of Plasma Microturbulence ." Scott E. Parker was the University of Colorado Principal Investigator (PI) on this cooperative agreement. The PI of the Center for the Study of Plasma Microturbulence, Scientific Discovery through Advanced Computing (SciDAC) project was W.M. Nevins, Lawrence Livermore National Laboratory. This Final Technical Report covers the period between February 15, 2008 and February 2/14 2011. The cooperated agreement supports the summer salary of the PI and part of Dr. Yang Chen, who is Senior Research Associate in the Department of Physics at the Univ. of Colorado at Boulder. There was also funding provided for Ph.D. graduate student Jianying Lang who received her Ph.D, This cooperative agreement and grant DE-FC02-08ER54954, titled "Gyrokinetic Turbulence Simulations of Turbulent Transport," Scott E. Parker PI, support the personnel in our research group studying core gyrokinetic turbulence simulations. That being understood, there is some overlap in the reported progress.

We have discovered a possible "natural fueling" mechanism in tokamak fusion reactors using large scale gyrokinetic turbulence simulation. In the presence of a heat flux dominated tokamak plasma, cold ions naturally pinch radially inward. If cold DT fuel is introduced near the edge using shallow pellet injection, the cold fuel will pinch inward, at the expense of hot Helium ash going radially outward. By adjusting the cold DT fuel concentration, the core DT density profiles can be maintained. We have also shown that cold source ions from edge recycling of cold neutrals are pinched radially inward. This mechanism may be important for fully understanding the edge pedestal buildup after an ELM crash. These results were highlighted in an Invited Talk, by W. Wan at the 2010 American Physical Society Division of Plasma Physics meeting and are discussed in two publications (listed below).

Work specific to DE-FC02-08ER54960 includes benchmarking the gyrokinetic turbulence codes in the electromagnetic regime. This includes cyclone base case parameters with a increasing plasma beta. The code comparisons include GEM, GYRO and GENE. There is good linear agreement between the codes using the Cyclone base case, but including electromagnetics and scanning the plasma beta. All the codes have difficulty achieving nonlinear saturation as the kinetic ballooning limit is approached. GEM does not saturate well when beta gets above about 1/2 of the ideal ballooning limit. We find that the lack of saturation is due to the long wavelength  $k_y$  modes being nonlinearly pumped to high levels. If the fundamental  $k_y$  mode is zeroed out, higher values of beta nonlinearly saturate well.

Additionally, there have been studies to better understand CTEM nonlinear saturation and the importance of zonal flows. This is in collaboration with D. Ernst, MIT. This collaborative work with Ernst is specific to cooperative agreement DE-FC02-08ER54960. We have continued our investigation of trapped electron mode (TEM) turbulence following [Lang 07]. More recently, we have focused on the nonlinear saturation of TEM turbulence. An important feature of TEM is that in many parameter regimes, the zonal flow is unimportant [Dannert 05, Lang 07]. We find that when zonal flows are unimportant, zonal density is the dominant saturation mechanism [Lang 08]. We developed a simple theory that agrees with the simulation and predicts zonal density generation and feedback stabilization of the most unstable mode even in the absence of zonal flow. This work was published in Ref. [Lang 08], and is the subject of Jianying Lang's Ph. D. Thesis. Comparisons between GEM and GS2 and the role of zonal flow where the topic of D. Ernst, et al. 2008 IAEA paper [Ernst 08] and of Darin Ernst's APS-DPP invited talk and a related collaborative paper was published in Physics of Plasmas [Ernst09].

In collaboration with G. Rewoldt, PPPL we are using GEM to simulate NSTX discharges. This work was presented at the past two American Physical Society - Division of Plasma Physics meetings. Previous results by Rewoldt directly comparing GEM simulation of equilibrium data from DIII-D shot 128527 at  $t=3.45$  seconds have been published in Ref. [Chen 08]. We have also done verification and validation on DIII-D in collaboration with C. Holland and T. Rhodes and this work has been published in the journal Nuclear Fusion (see publications below). Good agreement with GYRO and DIII-D flux levels were reported in the core region.

### Related References

[Chen 07] Y. Chen and S. Parker, J. Comput. Phys. **220** 839 (2007)

[Chen 08] Y. Chen, S. Parker, G. Rewoldt, S. Ku, G. Park, C. Chang, Phys. Plasmas, **15** 055905 (2008).

[Ernst 08] D. Ernst, J. Lang, W. Nevins, M. Hoffman, Y. Chen, W. Dorland, S. Parker, "Role of Zonal Flows in TEM Turbulence through Nonlinear Gyrokinetic Particle and Continuum Simulation," IAEA-CN-165/TH/P8-39

[Lang 07] J. Lang, Y. Chen, S. Parker, Phys. Plasmas **14** 082315 (2007)

[Lang 08] J. Lang, S. Parker, Y. Chen, Phys. Plasmas **15** 055907 (2008)

[Chang09] "Compressed ion temperature gradient turbulence in the diverted tokamak edge," C. Chang, S. Ku, P. Diamond, Z. Lin, S. Parker, T. Hahm, N. Samatova, Phys Plasmas **16** 056108 (2009)

[Ernst09] "Role of zonal flows in trapped electron mode turbulence through gyrokinetic particle and continuum simulation," D. Ernst, J. Lang, W. Nevins, Y. Chen, W. Dorland, S. Parker, *Phys. Plasmas* **16** 055906 (2009)

[Wan09] "Natural Fueling of Tokamak fusion reactor," W. Wan, S. Parker, Y. Chen and F. Perkins, submitted to *Phys. Rev. Lett.* (2009)

[Lang 09] "Gyrokinetic delta-f particle simulation of the TAE," J. Lang, Y. Chen, S. Parker, G. Fu, *Phys. Plasmas* **16** 102101 (2009)

[Chen 09] "Particle-in-cell simulation with Vlasov ions and drift kinetic electrons," Y. Chen and S. Parker, *Phys. Plasmas* **16** 052305 (2009)

### **Recent Publications and APS Invited Talks**

*Natural Fueling of the Core and Edge in a Tokamak Fusion Reactor*, W. Wan, Invited Talk, American Physical Society Division of Plasma Physics, Chicago, IL, November 8-12, 2010, *Bull. Amer. Phys. Soc.* Vol. 55, 193 (2010).

*Kinetic stability of alpha driven TAEs in ITER Plasmas*, Y. Chen, Invited Talk, in collaboration with S. Parker, American Physical Society – Division of Plasma Physics Meeting, Nov. 8-12, Chicago, IL, *Bull. Amer. Phys. Soc.* Vol. 55, p. 289 (2010).

*Natural fueling of a tokamak fusion reactor*, W. Wan, S. Parker, Y. Chen, F. Perkins, *Phys. Plasmas* **17** 040701 (2010).

*Nonlinear simulation of the toroidal Alfvén eigenmode with source and sink*, J. Lang, G. Fu, Y. Chen, *Phys. Plasmas* **17** 042309 (2010).

*Linear gyrokinetic simulation of high-n toroidal Alfvén eigenmodes in a burning plasma*, Yang Chen, Scott E. Parker, J. Lang, and G.-Y. Fu, *Phys. Plasmas* **17**, 102504 (2010)

*The pinch of cold ions from recycling in the tokamak edge pedestal*," Weigang Wan, Scott E. Parker, Yang Chen, Gunyoung Park, Choong-Seock Chang and Daren Stotler, *Phys. Plasmas* **18**, 056116 (2011).

*Fluid electrons with kinetic closure for long wavelength energetic particles driven, modes*," Y. Chen and S.E. Parker, *Phys. Plasmas* **18**, 055703 (2011)

*L-mode validation studies of gyrokinetic turbulence simulations via multiscale and multifield turbulence measurements on the DIII-D tokamak*. T.L. Rhodes, C. Holland, S.P. Smith, A.E. White, K.H. Burrell, J. Candy, J.C. DeBoo, E.J. Doyle, J.C. Hillesheim, J.E. Kinsey, G.R. McKee, D. Mikkelsen, W.A. Peebles, C.C. Petty, R. Prater, S. Parker,

Y. Chen, L. Schmitz, G.M. Staebler, R.E. Waltz, G. Wang, Z. Yan and L. Zeng, Nucl. Fusion **51** 063022 (2011).