

The SciDAC ProtoFSP Center for Plasma Edge Simulation (CPES) [<http://www.cims.nyu.edu/cpes/>] was awarded to New York University, Courant Institute of Mathematical Sciences in FY 2006. C.S. Chang was the institutional and national project PI. It's mission was 1) to build kinetic simulation code applicable to tokamak edge region including magnetic divertor geometry, 2) to build a computer science framework which can integrate the kinetic code with MHD/fluid codes in multiscale, 3) to conduct scientific research using the developed tools. CPES has built two such edge kinetic codes XGC0 and XGC1, which are still the only working kinetic edge plasma codes capable of including the diverted magnetic field geometry. CPES has also built the code coupling framework EFFIS (End-to-end Framework for Fusion Integrated Simulation), which incubated and used the Adios ([www.olcf.ornl.gov/center-projects/adios/](http://www.olcf.ornl.gov/center-projects/adios/)) and eSiMon (<http://www.olcf.ornl.gov/center-projects/esimon/>) technologies, together with the Kepler technology.

The CPES project went through two international reviews with excellent results: one in 2008 and the other in 2010. There was one revision among the scientific milestone goals by the reviewers: the L-H transition milestone was replaced by the 3D RMP physics milestone.

The project has been highly successful in both fulfilling the above three scientific goals and in being a role-model in the collaborative research activities among computer scientists, applied mathematicians, and fusion physicists. Numerous referred journal papers have emerged by the NYU PI, which include:

- (1) Hoyul Baek, Seunghoe Ku and C.S. Chang, "Neoclassical polarization drift of collisionless single ions in a sheared radial electric field in a tokamak magnetic geometry," *Phys. Plasmas*, 13, 012503 (2006)
- (2) C. S. Chang and S. Ku, "*Particle simulation of neoclassical transport in the plasma edge*," *Contrib. Plasma Phys.* 46, 496–503 (2006)
- (3) S. Ku, C.S. Chang, M. Adams, et al., "Gyrokinetic particle simulation of neoclassical transport in the pedestal/scrape-off region of a tokamak plasma," *Journal of Physics: Conference Series* 46 (2006) 87
- (4) Gunyoung Park and C.S. Chang, "A 5-1/2-dimensional theory for fast and accurate evaluation of the cyclotron resonance heating using real-space wave representation," *Phys. Plasmas* 14, 052503 (2007)
- (5) D.A. Batchelor, M. Beck, A. Becoulet, R.V. Budny, C.S. Chang, et al, "Simulation of Fusion Plasmas: Current Status and Future Direction," *Plasma Science and Technology* 9, 312 (2007)
- (6) G. Park, J. Cummings, C.S. Chang, Podhorszki, S. Klasky, etc, "Coupled simulation of kinetic pedestal growth and MHD ELM crash," *Journal of Physics: Conference Series* 78, 012087 (2007)

- (7) J. E. Menard, M.G. Bell, R.E. Bell, ..., C.S. Chang, et al., Overview of recent physics results from the National Spherical Torus Experiment (NSTX), *Nuclear Fusion* 47, S645 (2007)
- (8) J R Cary, J Candy, ... C S Chang, et al, "Introducing FACETS, the Framework Application for Core-Edge Transport Simulations," *J. Phys: Conf. Series* 78, 012086 (2007)
- (9) Y. Chen, S. E. Parker, G. Rewoldt, S. Ku, G. Y. Park, C-S Chang, "Coarse-graining the electron distribution in gyrokinetic simulations," *Phys. Plasmas* 15, 055905 (2008)
- (10) C.S. Chang, S. Ku, "Spontaneous rotation sources in a quiescent tokamak edge plasma," *Phys. Plasmas* 15, 062510 (2008)
- (11) J. Cummings, A. Pankin, N. Podhorszki, G. Park, S. Ku, R. Barreto, S. Klasky, C. S. Chang, H. Strauss, L. Sugiyama, P. Snyder, D. Pearlstein, B. Ludascher, G. Bateman, A. Kritiz and the CPES Team, "Plasma Edge Kinetic-MHD Modeling in Tokamaks Using Kepler Workflow for Code Coupling, Data Management and Visualization," *Commun. Comput. Phys.* 4, 675 (2008)
- (12) C S Chang, S Klasky, J Cummings, et al, "Toward a first-principles integrated simulation of tokamak edge Plasmas," *J. Phys: Conf. Series* 125, 012042 (2008)
- (13) C.S. Chang, S. Ku, et al, "Whole Volume Integrated Simulation of Plasma Turbulence in Realistic Diverted-Tokamak Geometry," *Journal of Physics: Conference Series* 180 (2009) 012057.
- (14) M. Adams, S. Ku, P. Worley, D'Azevedo, J. Cummings, C.S. Chang, "Scaling to 150K cores: recent algorithm and performance engineering developments enabling XGC1 to run at scale," *Journal of Physics: Conference Series* 180 (2009) 012036
- (15) C. S. Chang, S. Ku, P. H. Diamond, Z. Lin, S. Parker, T. S. Hahm and N. Samatova, "Compressed ion temperature gradient turbulence in diverted tokamak edge," *Phys. Plasmas* 16, 056108 (2009)
- (16) H.R. Strauss, L. Sugiyama, G.Y. Park, C.S.Chang, S. Ku, and I. Joseph, "Extended MHD simulation of resonant magnetic perturbations," *Nuclear Fusion* 49, 055025 (2009)
- (17) S. Ku, C.S. Chang, and P.H. Diamond, "Full-f gyrokinetic particle simulation of centrally heated global ITG turbulence from magnetic axis to edge pedestal top in a realistic tokamak geometry," *Nuclear Fusion* 49, 115021 (2009)
- (18) X. Q. Xu, E. Belli, K. Bodi, J. Candy, C. S. Chang, B. I. Cohen, R. H. Cohen, P. Colella, A. M. Dimits, M. R. Dorr, Z. Gao, J. A. Hittinger, S. Ko, S. Krasheninnikov, G. R. McKee, W. M. Nevins, T. D. Rognlien, P. B. Snyder, J. Suh, M. V. Umansky, "Dynamics of kinetic Geodesic-Acoustic modes and the radial electric field in tokamak neoclassical plasmas," *Nuclear Fusion*, 49 065023 (2009).

- (19) S.H. Park, Suk Jae Yoo, Choong-Seock Chang, “Molecular dynamics simulation of hyperthermal neutrals generated by energetic ion impact on a metal plate,” Appl. Phys. Lett. 107, 13304 (2009)
- (20) D.A. Gates, et al, C. Chang among many authors, “Overview of results from the National Spherical Torus Experiment (NSTX),” Nucl. Fusion 49, 104016 (2009)
- (21) R. Maingi, S.M. Kaye, R.E. Bell, T.M. Biewer, C.S. Chang, D.A. et al, “Overview of L–H power threshold studies, in NSTX,” Nucl. Fusion 50, 064010 (2010)
- (22) G.Y. Park, C.S. Chang, I. Joseph, and R. Moyer, “Plasma transport in stochastic magnetic field caused by vacuum resonant magnetic perturbations at diverted tokamak edge,” Physics of Plasmas 17, 102503 (2010)
- (23) G. Dif-Pradalier, P. H. Diamond, V. Grandgirard, Y. Sarazin, J. Abiteboul, X. Garbet, Ph. Ghendrih, and A. Strugarek, S. Ku and C. S. Chang, “On the validity of the local diffusive paradigm in turbulent plasma transport,” Phys. Rev. E 82, 025401(R) (2010)
- (24) S. Kaye, R. Maingi, D. Battaglia, R.E. Bell, C.S. Chang, B.P. LeBlanc, J. Hosea, H. Kugel, H. Meyer, G.-Y. Park, J.R. Wilson, “L-H Threshold Studies in NSTX,” submitted to Nucl. Fusion
- (25) R. F. Schmitt, L. Guazzotto, H. Strauss, G. Y. Park, and C.-S. Chang, “Free-boundary magnetohydrodynamic equilibria with flow,” Phys. Plasmas 18, 022502 (2011)
- (26) G. Dif-Pradalier, P. H. Diamond, V. Grandgirard, Y. Sarazin, J. Abiteboul, X. Garbet, Ph. Ghendrih, G. Latu, A. Strugarek, S. Ku, and C. S. Chang, “Neoclassical physics in full distribution function gyrokinetics,” Physics of Plasmas 18, 062309 (2011)
- (27) Weigang Wan, Scott E. Parker, Y. Chen, G.Y. Park, C.S. Chang, D. Stotler, “The pinch of cold ions from recycling in the tokamak edge pedestal,” Phys. Plasmas, 18, 056116 (2011)
- (28) Y. Sarazin, V. Grandgirard, J. Abiteboul, S. Allfrey, X. Garbet, Ph. Ghendrih, G. Latu, A. Strugarek, G. Dif-Pradalier, P.H. Diamond, S. Ku, C.S. Chang, B F McMillan, T M Tran, L Villard, S Jolliet, A Bottino, P Angelino, “Predictions on heat transport and plasma rotation from global gyrokinetic simulations,” Nuclear Fusion 51, 103023 (2011)
- (29) Ye Jin, Sriram Lakshminarasimhan, Neil Shah, Zhenhuan Gong, C.S. Chang, Jackie Chen, Stephane Ethier, Hemanth Kolla, Seung-Hoe Ku, Scott Klasky, Robert Latham, Robert Ross, Karen Schuchardt, Nagiza F. Samatova, “S-preconditioner for Multi-fold Data Reduction with Guaranteed User-controlled Accuracy,” ICDM 2011

- (30) Sriram Lakshminarasimhan, John Jenkins, Isha Arkatkar, Zhenhuan Gong, Hemanth Kolla, Seung-Hoe Ku, Stephane Ethier, Jackie Chen, C.S. Chang, Scott Klasky, Robert Latham, Robert Ross, and Nagiza F. Samatova, “ISABELA-QA: Query-driven Analytics with ISABELA-compressed Extreme-Scale Scientific Data,” Super Computing 2011
- (31) G. Dif-Pradalier, J. Gunn, G. Ciraolo, C.S. Chang, G. Chiavassa, P. Diamond, N. Fedorczak, Ph. Ghendrih, L. Isoardi, M. Kocan, S. Kud, E. Serre, P. Tamain, Tore Supra Team, “The Mistral base case to validate kinetic and fluid turbulence transport codes of the edge and SOL plasmas,” Journal of Nuclear Materials 415 (2011) S597–S600
- (32) S. M. Kaye, R. Maingi, D. Battaglia, R.E. Bell, C.S. Chang, J. Hosea, H. Kugel, B.P. LeBlanc, H. Meyer, G.Y. Park, and J.R. Wilson, “L-H threshold studies in NSTX,” Nucl. Fusion 51, 113109 (2011)

Numerous invited presentations by the PI at major scientific conferences have also resulted:

C.S. Chang, Invited Talk, “Integrated Simulation of Fusion Plasmas on Extreme scale HPC,” 21<sup>st</sup> International Toki Conference, Nov. 21 – Dec. 1, 2011, Toki-City, Japan

C.S. Chang, Invited Talk, “Kinetic Neoclassical Physics of RMP Penetration and Plasma Response in Diverted Tokamak Geometry,” Invited Talk, KIAA Workshop, Peking University, China, June 6–9, 2011

C.S. Chang, Keynote Speaker, “Tokamak Fusion Research Through Advanced Computing,” The 20th KSEA Northeast Regional Conference, Edison, NJ June 24-25, 2011

C.S. Chang, Invited (Extended Oral) Talk, “Kinetic Simulation of RMP Penetration, Plasma Transport, and Pedestal Response in Diverted Tokamak Geometry,” 5<sup>th</sup> International Workshop on Stochasticity in Fusion Plasmas, April 11–14, 2011, Jülich, Germany

C.S. Chang, Invited Talk, “Magnetically Confined Fusion for Limitless Green Energy Source of the Future,” US-Korea Conference on Science, Technology, and Entrepreneurship (UKC), Aug. 11-15, 20, 2010, Seattle, WA

C.S. Chang, Featured Invited Talk, “Whole Volume, Integrated Gyrokinetic Particle Simulation in Realistic Diverted Tokamak Geometry,” SciDAC2009, June 14-19, 2009, San Diego, CA,

C.S. Chang, Invited Tutorial, Festival de Théorie 2009, July 6-24 2009, *Aix-en-Provence, France*, “Nonlocal and multiscale simulation of the neoclassical and ITG turbulence dynamics, and the rotation generation in the core-edge integrated full-f simulation”

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C.S. Chang, Invited Lecture, Festival de Théorie 2009, July 6-24 2009, *Aix-en-Provence, France*, “Simulation of rotation, turbulence, neoclassical, and atomic physics in realistic diverted tokamak geometry”

C.S. Chang, Invited Talk, 4<sup>th</sup> IAEA Technical Meeting on the Theory of Plasma Instabilities, May 18-20, 2009, Kyoto University, Japan “Compressed ITG turbulence in diverted tokamak edge”

C.S. Chang, Invited Talk, International Plasma Edge Theory (PET) conference, Rostov, Russia, Sept. 2-4, 2009, “Edge and pedestal kinetic Simulation”

C.S. Chang, Invited Talk, The 14th International Congress on Plasma Physics (ICPP2008), September 8-12, 2008, Fukuoka, Japan, “Physics of Edge Plasma”

C.S. Chang, Invited Talk, 50th Annual Meeting, American Physical Soc., Division of Plasma Physics, November 17 - 21, 2008, Dallas, Texas, “Radially compressed full-f ITG turbulence dynamics across the pre-transition L-mode edge pedestal in magnetic separatrix geometry”

C.S. Chang, Invited Lecture, 2008 ITER Summer School, July 22-25, Fukuoka, Japan, “Computational Knowledge”

C.S. Chang, Invited Talk, 3rd IAEA Technical Meeting on Plasma Instabilities, 26-28 March. 2007, York, U.K , “Edge pedestal and plasma rotation physics from XGC particle simulation”