Sherwood 2014 Program

International Sherwood Fusion Theory Conference
March 21-26, Bahia Resort Hotel, San Diego, California

Monday, March 24

8:15am – 8:30am (*Room: Mission Bay Ballroom ABC*)
Welcome, Announcements—Sergei Krasheninnikov, UCSD

8:30am – 9:30am, Chair: Sergei Krasheninnikov, UCSD
Rob Goldston, PPPL, “Understanding and innovation in magnetic fusion”

9:30am – 10:00am
Jeff Freidberg, MIT, “Designing a tokamak fusion reactor no plasma physics required”

10:00am – 10:30am – Morning Break (*Room: Mission Bay Ballroom ABC*)

10:30am – 11:00am, Chair: Chris Hegna, University of Wisconsin
Wrick Sengupta, University of Maryland, “Trapped particle precession and effective mass in Rosenbluth-Hinton type zonal flows”

11:00am – 11:30am
John O’Bryan, University of Wisconsin, “Simulation flux rope evolution and relaxation during non-inductive startup in the Pegasus ST”

11:30am – 12:00 noon
Yi-Min Huang, PPPL, “Rapid change of field-line connectivity and reconnection in stochastic magnetic fields”

1:30pm – 3:30pm – Poster Session I (*Room: Bayside Pavilion*)

3:30pm – 4:00pm – Afternoon Break (*Room: Bayside Pavilion*)

4:00pm – 6:00pm – Poster Session II (*Room: Bayside Pavilion*)

Tuesday, March 25

8:20am – 8:30am (*Room: Mission Bay Ballroom ABC*)
Announcements – Sergei Krasheninnikov, UCSD

8:30am – 9:30am, Chair: Emily Belli, General Atomics
Russel Caflisch, UCLA, “Accelerated simulation of coulomb collisions in plasmas”

9:30am – 10:00am
Scott Parker, University of Colorado, “Nonlinear gyrokinetic simulations of the tokamak edge Pedestal”

10:00am – 10:30am – Morning Break (*Room: Mission Bay Ballroom ABC*)

10:30am – 11:00am, Chair: Joshua Breslau, PPPL
Michael Barnes, University of Texas, “On a local solution to a global problem: treating radial profile variation and intrinsic momentum transport in a flux tube gyrokinetic code”

11:00am – 11:30am
Matthew Lilley, Imperial College London, “On the formation of phase space holes and clumps”

11:30am – 12:00noon
Samuel Lazerson, PPPL, “An enstrophy minimizing method for 3D MHD equilibrium with flow”

4:00pm – 6:00pm – Poster Session III (*Room: Bayside Pavilion*)

4:00pm – 4:30pm – Afternoon Break (*Room: Bayside Pavilion*)

6:00pm – 7:00pm – Reception (*William D. Evans Sternwheeler*)

7:00pm – 10:00pm – Banquet/Poster Awards (*William D. Evans Sternwheeler*)

Wednesday, March 26

8:20am – 8:30am (*Room: Mission Bay Ballroom ABC*)
Announcements – Sergei Krasheninnikov, UCSD

8:30am – 9:30am, Chair: John Finn, LANL
Dan Barnes, Tri Alpha, “Plasma theory as private enterprise”

9:30am – 10:00am
Hank Strauss, HRS Fusion, “Toroidal rotation produced by disruptions and ELMs”

10:00am – 10:30am – Morning Break (*Room: Mission Bay Ballroom ABC*)

10:30am – 11:00am, Chair: Andrew Cole, Columbia University
Denise Hinkel, LLNL, “Alpha heating in ICF implosions at the National Ignition Facility”

11:00am – 11:30am
Alexander Pigarov, UCSD, “Dynamic boundary plasma-wall modeling of ELMy H-mode”

11:30am – 12:00noon
Roman Smirnov, UCSD, “Modeling of tungsten and beryllium dust impact on ITER-like plasma edge”

Poster # **Monday March 24th, Poster Session I 1:30pm – 3:30pm (Room: Bayside Pavilion)**

1	Rob Goldston, *PPPL*, “Understanding and innovation in magnetic fusion”
2	Jeff Freidberg, *MIT*, “Designing a tokamak fusion reactor no plasma physics required”
3	Wrick Sengupta, *University of Maryland*, “Trapped particle precession and effective mass in Rosenbluth-Hinton type zonal flows”
4	John OôBryan, *University of Wisconsin*, “Simulation flux rope evolution and relaxation during non-inductive startup in the Pegasus ST”
5	Yi-Min Huang, *PPPL*, “Rapid change of field-line connectivity and reconnection in stochastic magnetic fields”
6	A.Y. Pankin, *Tech-X Corporation*, ñCan the anomalous effects improve the prediction of neoclassical poloidal rotation?ò
7	O. Izacard, *UCSD*, ñSelf-Consistent Global Dynamics of Microturbulence in Presence of a Magnetic Islandò
8	C. J. McDevitt, *LANL*, ñTurbulence-driven bootstrap current in low-collisionality tokamaksò
9	J.J. Ramos, *MIT*, ñIntrinsically Quasineutral Formalism for Electromagnetic Plasma Dynamicsò
10	A.H. Kritz, *Lehigh University*, ñValidation of MMM7.1 and TGLF Models for Anomalous Thermal Transportò
11	W. Lee, *UCSD*, ñElectromagnetic effects on high-beta blob transportò
12	J.A. Breslau, *PPPL*, ñHalo currents and the M3D boundary conditionsò
13	E. Hameiri, *NYU*, ñMHD plasma relaxation with mass flow and finite pressureò
14	I. Pusztai, *MIT*, ñLocal gyrokinetic simulation of high mode number kink instabilitiesò
15	J. Lee, *NYU*, ñProgress on a high-order direct q-solver for static axisymmetric equilibriaò
16	E. C. Howell, *University of Wisconsin-Madison*, "Nonlinear Simulations of Interchange Modes in Spheromaks"
17	J.W. Burby, *PPPL*, ñVariational integrators for perturbed non-canonical Hamiltonian systemsò
18	A.H. Boozer, *Columbia University*, ñNon-axisymmetric magnetic fields and toroidal plasma confinementò
19	P. Montag, *MIT*, ñNew Features of the Quasi Coherent Mode and Novel Theoretical Modelò
20	W.X. Wang, *UCSD*, ñNon-neoclassical poloidal flow induced by micro-turbulenceò
21	J.R. King, *Tech-X Corporation*, ñLinear and nonlinear studies of edge harmonic oscillations with the NIMROD codeò
22	L.E. Sugiyama, *MIT*, ñToroidal and nonlinear mode coupling effects on instabilities in fusion plasmasò

23 F.I. Parra, *University of Oxford* , ñNon-local effects on neoclassical flows and fluxes in transport barriersò

24 C. L. Ellison, *PPPL* , ñEvaluation of symplectic algorithms for the integration of guiding center trajectoriesò

25 G.M. Staebler, *General Atomics* , ñProperties of the Gyro-kinetic Turbulence Electric Field Spectrum with Mean Field Parallel and ExB Velocity Shearò

26 C. Sung, *MIT* , ñStudying changes in electron temperature fluctuations across the ohmic confinement transition using nonlinear gyrokinetic simulationò

27 J. D. Hanson, *Auburn University* , ñProbability Distributions and 3D Equilibrium Reconstructionò

28 J.-Y. Ji, *Utah State University* , ñA framework for moment equations for magnetized plasmasò

29 J. P. Sauppe, *University of Wisconsin-Madison* , ñHelicity Conservation and Two-Fluid Relaxation Modeling for Reversed-Field Pinchesò

30 D. N. Smithe, *Tech-X Corporation* , ñRF Models for Plasma-Surface Interactionsò

31 R.E. Waltz, *General Atomics* , ñPrediction of fusion alpha loss in ITER from local marginal stability to Alfven eigenmodesò

32 D.D. Ryutov, *LLNL* , ñA churning mode and plasma convection in the vicinity of the poloidal field nullò

33 N.M. Ferraro, *General Atomics* , ñResistive Wall Model in M3D-C1ò

34 C. J. Hansen, *University of Washington* , ñThe PSI-TET framework for 3D MHD: application to injector coupling and current drive in HIT-SIò

35 Z. Wang, *UCI* , ñNonlinear Generation of Zonal Structures by Toroidal Alfven Eigenmodes in Gyrokinetic Simulationsò

36 E.A. Startsev, *PPPL* ,ñGyrokinetic simulation of the tearing mode instabilityò

37 E. D. Held, *Utah State University* , ñNeoclassical Transport Benchmark with NIMRODò

38 T. Zhou, *MIT* , ñMagnetic Reconnection in Well Confined Plasmas: Paradox and Nature of Excited Modesò

39 C.R. Cook, *University of Wisconsin* , ñBAE gap modification due to a magnetic islandò

40 C.G. L. Martins, *University of Texas at Austin* , ñA 4D map for escape from resonance: negative energy modes and nonlinear instabilityò

41 C. H. Ma, *Peking University* , ñGlobal gyro-Landau-fluid simulations in BOUT++ frameworkò

42 B.C. Lyons, *Princeton University* , ñCoupled neoclassical-magnetohydrodynamic simulations of axisymmetric plasmasò

43 S. Kobayashi, *LPP* , ñGyrokinetic simulations of collisionless reconnection in turbulent non-uniform plasmasò

44 Y. Wang, *LANL* , The Effect of Magnetic Fields to the Divertor Sheathò

45 M.R. Halfmoon, *University of Tulsa* , ñEnergetic Particle Effects on Tearing Mode Stability with Varying ßò

Poster #	**Monday March 24th, Poster Session II 4:00pm – 6:00pm (Room: Bayside Pavilion)**
1	M. Landreman, *University of Maryland* , ñ4D Fokker-Planck calculations of neoclassical effects in tokamak pedestals and stellaratorsò
2	A.L. Becerra, *University of Wisconsin,* ñGeneralized resistive wall boundary conditions for toroidal geometry in NIMROD and initial studies for NSTX equilibriaò
3	C. R. Sovinec, *University of Wisconsin-Madison* , ñDevelopment and Verification Tests for Vertical Displacement Studies with NIMRODò
4	C. Flint, *William & Mary* , ñLarge Eddy Simulation Lattice Boltzmann Representation of 2D MHD Turbulenceò
5	L. E. Zakharov, *PPPL* , ñContinuously Flowing Liquid Lithium (${}_{24}{}^{7}$FLiLi) - the key to tokamak fusionò
6	S.D. James, *University of Tulsa* , óSelf-consistent calculations of the interaction between drift wave turbulence and the tearing modeò
7	R. Fitzpatrick, *U. Texas at Austin,* ñDetermination of Non-Ideal Response of a High Temperature Plasma to a Static External Magnetic Perturbation via Asymptotic Matchingò
8	P.J. Morrison, *University of Texas at Austin* , Pot Pourri
9	D. Fulton, *UCI* , ñGyrokinetic particle simulation of linear instabilities in edge plasmas.ò
10	F. Zonca, *ENEA* , ñSpontaneous excitation of convective cells by kinetic Alfven wavesò
11	A.D. Turnbull, *General Atomics* , ñStabilization of the Vertical Instability by Non-axisymmetric Coilsò
12	M.V. Umansky, *LLNL* , ñNon-spectral Landau-fluid model for non-collisional and weakly collisional parallel electron transportò
13	X. Tang, *LANL* , ñRecycling at tungsten surface and its impact on boundary plasmasò
14	V.V. Mirnov, *University of Wisconsin-Madison,* ñEffect of parallel electron thermal conduction on resistive drift and tearing modes in non-uniform RFP plasmasò
15	P. Zhu, *University of Science and Technology of China* , ñNIMROD Simulations of Plasma Response to Resonant Magnetic Perturbations in DIII-D Experimentsò
16	T. G. Jenkins, *Tech-X Corporation* , ñActive control of ECCD-induced tearing mode stabilization in coupled NIMROD/GENRAY HPC simulationsò
17	B. Sturdevant, *University of Colorado at Boulder* , ñImplicit ŭf Lorentz Ion Orbit Averaging and Sub-Cyclingò
18	G.L. Delzanno, *LANL* , òWhen the conventional model of dust transport in tokamaks begins to breakò
19	H. Weitzner, *NYU* , ñRepresentation of an Ideal Magnetohydrodynamic Equilibrium in a Toroidal Domain Near a Magnetic Axisò
20	G. I. Hagstrom, *Courant Institute of Mathematical Sciences* , ñStability of Inhomogeneous Equilibria of Hamiltonian Continuous Media Field Theoriesò
21	A. Wurm, *University of Texas at Austin* , ñAction principles for reduced fluid modelsò
22	W. W. Lee, *PPPL* , ñEffects of Background-Inhomogeneity-Generated Zonal Flows on Microinstabilities and Plasma Pressure Balanceò

23 M. Kotschenreuther, ñAdvanced divertor configurations (x-divertor and x-point divertor) on present tokamak experimentsò

24 E.V. Belova, *PPPL* , ñCoupling of Neutral-beam-driven Compressional Alfvén Eigenmodes to Kinetic Alfvén Waves in NSTXò

25 C. C. Hegna, *University of Wisconsin-Madison* , ñThe effects of weakly 3-D equilibria on the MHD stability of tokamak pedestalsò

26 J. Chowdhury, *University of Colorado at Boulder* , ñStudy of microtearing mode in the core of NSTX with GEMò

27 Z. Guo, *LANL* , ñNonlinear evolution of transport induced anisotropic electron distributionò

28 B. Coppi, *MIT* , ñHigh Energy Plasma Associates with Black Holes at Near and Far Distancesò

29 W. Zhang, *Institute of Physics* , ñGyrokinetic Simulations of Energetic Particle Turbulence and Transportò

30 W. Zhang, *Institute of Physics* , ñGyrokinetic Simulations of Energetic Electron Driven Alfven Instabilityò

31 A. Airoldi, *CREATE Consortium* , ñAnomalous Transport Processes Including Self-organization for Fusion Burning Regimes in Ignitorò

32 J.F. Ma, *University of Texas* , ñGlobal Two-Fluid and Gyro-Landau-Fluid simulations of the pedestal turbulence in DIII-D divertor geometryò

33 I. Krebs, Max-Planck/*PPPL* , ñProgress on Nonlinear Sawtooth Simulations using M3D-C1ò

34 R.H. Cohen, *LLNL* ,òSimulation of neoclassical transport in a divertor geometry with COGENTò

35 H. Zhu, *Peking University* , ñGlobal Geodesic Acoustic Eigenmode in Toroidal Plasmasò

36 F. Winterberg, *University of Nevada* , ñMutual Colliding Impact Fast Ignitionò

37 A. K. Ram, *MIT* , ñScattering of radio frequency waves by edge density fluctuations and by blobsò

38 D. Zhao, *Peking University* , ñTesting the high turbulence level breakdown of low-frequency gyrokinetics against high-frequency cyclokinetic simulationsò

39 A. Oganesov, *William & Mary* , ñUnitary Highly Parallelized Algorithms for Nonlinear Systemsò

40 V.A. Izzo, *General Atomics* , ñSimulation and validation of massive-gas-injection in the presence of 3D fieldsò

41 J. McClenaghan, *UCI* , ñGyrokinetic particle simulation of internal kink modes in tokamaksò

42 A.H. Glasser, *University of Washington* , ñComputation of Outer Region Matching Data for Resistive Instabilities with DCONò

43 P.B. Snyder, *General Atomics* , ñSuper H-Mode: Pedestal Bifurcation to Enable High Performanceò

44 C. S. Ng, *PPPL* , ñSurface Currents during a Major Disruptionò

45 F. Ebrahimi, *Princeton University* , ñPhysics of forced magnetic reconnection in coaxial helicity injection experiments in NSTXò

Poster # **Tuesday March 25th, Poster Session III 4:00pm – 6:00pm (Room: Bayside Pavilion)**

1 Dan Barnes, *Tri Alpha*, “Plasma theory as private enterprise”

2 Russel Caflisch, *UCLA*, “Accelerated simulation of coulomb collisions in plasmas”

3 Hank Strauss, *HRS Fusion*, “Toroidal rotation produced by disruptions and ELMs”

4 Denise Hinkel, *LLNL*, “Alpha heating in ICF implosions at the National Ignition Facility”

5 Alexander Pigarov, *UCSD*, “Dynamic boundary plasma-wall modeling of ELMy H-mode”

6 Roman Smirnov, *UCSD*, “Modeling of tungsten and beryllium dust impact on ITER-like plasma edge”

7 Scott Parker, *University of Colorado,* “Nonlinear gyrokinetic simulations of the tokamak edge Pedestal”

8 Michael Barnes, *University of Texas*, “On a local solution to a global problem: treating radial profile variation and intrinsic momentum transport in a flux tube gyrokinetic code”

9 Matthew Lilley, *Imperial College London*, “On the formation of phase space holes and clumps”

10 Samuel Lazerson, *PPPL*, “An enstrophy minimizing method for 3D MHD equilibrium with flow”

11 S.R. Hudson, *PPPL*, ñA new class of magnetic confinement device in the shape of a knotò

12 V. A. Svidzinski, *FAR-TECH*, ñPlasma dielectric response in inhomogeneous magnetic field near electron cyclotron resonanceò

13 E.A. Belli, *General Atomics*, ñNon-Axisymmetric and Poloidal Asymmetry Effects on the Neoclassical Transport in the Tokamak Plasmasñ

14 J. Ball, *University of Oxford*, ñIntrinsic momentum transport in up-down asymmetric tokamaksò

15 J.A. Spencer, ñECRH Models for Guiding-Center Orbits in Parabolic Magnetic Mirrorsò

16 J. Bao, *Peking University*, ñParticle simulation of lower hybrid wave propagation in fusion plasmasò

17 L. Guazzotto, *University of Rochester*, ñMHD Pedestal Formation in Time-Dependent Simulations with Poloidal Viscosityò

18 N.T. Howard, ORISE, ñUnderstanding the Role of Electron-Scale Turbulence in the Tokamak Core Using Multi-Scale, Gyrokinetic Simulation of Alcator C-Mod Dischargesò

19 J. Guterl, *UCSD*, ñAtomistic modeling of molecular hydrogen desorption from tungsten surfaceò

20 B. Covele, ñImplementation of an advanced x-divertor on ITER without design changesò

21 S. I. Krasheninnikov, UCSD, ñModel of ablation of large high-Z material dust grain in fusion plasmaò

22 S.A. Galkin, *FAR-TECH*, ñRole of plasma surface current in tokamak disruption eventsò

23 E.M. Bass, *Oak Ridge Institute for Science Education*, ñLinear stability of edge turbulence using two-fluid models in BOUT++ñ

24 Y. Chen, *Univ. of Colorado at Boulder*, ñOn Gyrokinetic Simulations of Low-n MHD Modesò

25 G. Lu, *Southwestern Institute of Physics*, ñA critical gradient analysis to better understand measured and predicted plasma responses in the DIII-D tokamakò

26 X. Wei, *Zhejiang University*, ñFull particle orbit calculation in toroidal plasmas based on boris schemeò

27 Z. R. Wang, PPPL, ñDrift Kinetic Effect on 3D Plasma Response in High-beta DIII-D Plasmasò

28 D.P. Brennan, *Princeton University*, ñControl of resistive wall modes in a cylindrical tokamak with plasma rotation and complex gainò

29 W. Horton, *University of Texas at Austin*, ñPenetration of Lower Hybrid Waves with Density Fluctuations for ITER-like Plasmasò

30 X.Q.Xu, *LLNL*, ñCharacteristics of Peeling-Ballooning modes and its energy loss scaling with increasing collisionalityò

31 D. A. Spong, *ORNL*, ñModels for energetic particle instability and transport in general toroidal configurationsò

32 X. Li, *Institute of Computational Mathematics and Scientific/Engineering Computing*, ñThe Tokamak MHD (TMHD) plasma modelò

33 L. Merriman, MIT, ñTheory and Feasible Experiments on D-3He and D-D Burning Plasmasò

34 W. A. Farmer, *UCLA*, ñBallooning modes localized near the null point of a divertorò

35 B. Basu, *MIT*, ñSpontaneous Rotation of Axisymmetric Plasmas and Its Connection to Collective Modesò

36 D. Liu, *UCI*, ñGTC simulation of tearing modes in fusion plasmasò

37 L.-M. Imbert-Gerard, *NYU*, ñNumerical approximation of resonant lower hybrid waves in the cold plasma modelò

38 A. E. White, *MIT*, ñMulti-channel transport studies in Alcator C-Mod Plasmas: probing the role of ITG/TEM stability crossing in rotation reversalsò

39 D. Meyerson, *University of Texas at Austin*, ñSimulation of Field Aligned Blobs in the Scrape off Layerò

40 E. G. Evstatiev, *FAR-TECH*, ñVariational approach to kinetic, fluid, and hybrid plasma simulationsò

41 J.E. Kinsey, *CompX*, ñThe Energy Transport Shortfall in the H-mode Deep Core and L-mode Near Edge Regionsò

42 A. Cardinali, *ENEA,* ñStudy of Lower Hybrid Wave Propagation and Absorption in Tokamak Plasma by Hamiltonian Theoryò

43 A. J. Cole, *Columbia University*, ñVariational Principles with Padé Approximants for Tearing Mode Analysisò

44 P. Valanju, ñApplication of x-divertors with comprehensive design constraints in demo/reactorsò

45 O. Meneghini, Oak Ridge Associated Universities , "Modeling of transport phenomena in tokamak plasmas with neural networks"

Abstracts of Oral Presentations

A local solution to a global problem: treating radial profile variation and intrinsic momentum transport in a flux tube gyrokinetic code

M. Barnes[1] and F. I. Parra[2]
1) Physics Department and Institute for Fusion Studies, The University of Texas at Austin, Austin, TX 78712, USA
2) Rudolf Peierls Centre for Theoretical Physics, University of Oxford, 1 Keble Road, Oxford OX1 3NP, UK

Tokamak plasmas are routinely observed to rotate even in the absence of an externally applied torque. This `intrinsic' rotation exhibits several robust features, including rotation reversals with varying plasma density and current and rotation peaking at the transition from low confinement to high confinement regimes. Conservation of toroidal angular momentum dictates that the intrinsic rotation is determined by momentum redistribution within the plasma, which is dominated by turbulent transport. For up-down symmetric magnetic equilibria, the turbulent momentum transport, and thus the intrinsic rotation profile, is driven by formally small effects that are usually neglected in simulations and analysis.

We present a gyrokinetic theory that makes use of the smallness of the poloidal to total magnetic field ratio to self-consistently treat the dominant effects driving intrinsic turbulent momentum transport in tokamaks. These effects (including slow radial profile variation, slow poloidal turbulence variation, and diamagnetic corrections to the equilibrium Maxwellian) have now been implemented in the local, delta-f gyrokinetic code GS2. We describe important features of the numerical implementation; in particular, the novel WKB-like method used to capture 'global' effects in a flux tube simulation domain. Finally, we present numerical results illustrating the impact of these formally small effects on intrinsic turbulent momentum transport and compare with experimental observations of intrinsic rotation reversals.

Oral

Designing a Tokamak Fusion Reactor
No Plasma Physics Required

J. P. Freidberg and J. Minervini
MIT Plasma Science and Fusion Center

This work describes some basic tokamak reactor results that are well known by a small portion of the fusion community, but not by most others, particularly the new generation of plasma physicists. Specifically, the work demonstrates that the overall design of a tokamak fusion reactor is actually determined almost entirely by the constraints imposed by nuclear physics and fusion engineering. Virtually no plasma physics is required to determine the main design parameters of a reactor: n, T_i, T_e, a, R_0, B_0. Instead, the "nuclear physics – fusion engineering" designed reactor makes **<u>demands</u>** on the plasma physics that must be satisfied in order to generate power. It is the job of the plasma physics community to discover ways to meet these demands. If the demands cannot be met, the design must be altered to accommodate the plasma physics, and this is always in a direction to make the final reactor less desirable economically. Since the design without worrying about plasma physics is already not very attractive economically, there is not a lot room to cure poor plasma performance.

As implied, many of the results presented here have already been obtained by sophisticated and detailed numerical design studies, for instance as in the ARIES series of fusion reactors. What is new in the present work is that the basic design can be carried out entirely analytically with the final parameters being semi-quantitatively accurate. That is, they are much more accurate than what might be expected from simple scaling relations and back-of-the-envelope estimates. The calculation thus provides a crisp, compact, logical design procedure for a tokamak fusion reactor in a simple-to-understand analytical framework.

Once the design is determined the resulting plasma physics demands are substituted into the well-known constraints arising in tokamak physics, for example the Troyon limit, Greenwald limit, kink stability limit, H-mode confinement time limit, etc. Some of these constraints are satisfied, while some are not. This is crucial information, since knowledge of the unsatisfied constraints defines a set of "show-stopping" plasma physics issues. These issues must be solved in order for the tokamak to lead to a power reactor. They, therefore, define several critical areas of fusion research which should probably be carried out on existing facilities in order to learn, sooner rather than later, whether solutions are possible. If solutions do exist, they may involve clever plasma physics. However, the reactor design presented here also suggests that certain high leverage fusion engineering innovations can, perhaps surprisingly, lead to plasma physics solutions while simultaneously improving reactor reliability. The specific plasma physics show stoppers and high leverage engineering innovations have been identified and will be presented at the conference.

Poster but could be an oral tutorial type talk if so desired by the selection committee

Alpha Heating in ICF Implosions at the National Ignition Facility*

D. E. Hinkel[1], O. A. Hurricane[1], D. A. Callahan[1], M. A. Barrios Garcia[1], L. F. Berzak Hopkins[1], D. T. Casey[1], P. Celliers[1], C. Cerjan[1], E. L. Dewald[1], T. R. Dittrich[1], T. Doeppner[1], J. L. Kline[2], S. LePape[1], T. Ma[1], A. G. MacPhee[1], J. L Milovich[1], A. E. Pak[1], H.-S. Park[1], P. K. Patel[1], B. A. Remington[1], J. D. Salmonson[1], P. T. Springer[1], and R. Tommasini[1]

[1]*Lawrence Livermore National Laboratory, P. O. Box 808, Livermore, California, 94551, USA*

[2]*Los Alamos National Laboratory, Los Alamos, New Mexico, 87545, USA*

The National Ignition Facility (NIF) has been conducting experiments using the indirect drive approach, with the goal of achieving thermonuclear burn in the laboratory. In these experiments, up to 1.8 MJ of ultraviolet light (0.35 micron) is injected into a 1 cm scale, gas-filled hohlraum, to implode a 1 mm radius capsule that contains a solid DT fuel layer.

Research at NIF has made good progress over the course of the last year. An increase in laser power early in the pulse (i.e., "High Foot") makes the capsule more robust by preventing hydrodynamic instabilities, which mix cold ablator material into the central hotspot, thereby quenching the ignition process. These "high foot" NIF shots have achieved record yield. In these implosions, the amount of fusion yield that derives from alpha-heating is almost equal to the yield from compression alone, nearly doubling the total number of neutrons.

Over the course of the next year, plans to further improve this yield include improving the shape of the implosion (keeping it more spherical as it converges by a factor of ~ 30), and improving hohlraum performance (by changing the shape of the hohlraum from cylindrical to rugby). This campaign also plans to push the capsule to higher velocity (and thus higher yield), and further plans to explore "medium foot" options.

* This work was performed under the auspices of the US Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344.

Prefer Oral Presentation

Rapid Change of Field Line Connectivity and Reconnection in Stochastic Magnetic Fields

Yi-Min Huang, A. Bhattacharjee

Department of Astrophysical Sciences and Princeton Plasma Physics Laboratory, Princeton University

Allen H. Boozer

Department of Applied Physics and Applied Mathematics, Columbia University

Abstract

Magnetic fields depending on three spatial coordinates generally have the feature that neighboring field lines exponentiate away from each other and become stochastic. Such a generic condition can occur in a number of contexts in fusion plasmas such as tokamaks or reversed-field pinches in the presence of multiple tearing modes, or in the solar corona. Under the condition of large exponentiation, the ideal constraint of preserving magnetic field line connectivity becomes exponentially sensitive to small deviations from ideal Ohm's law, which may potentially lead to rapid magnetic reconnection. This idea of breaking field line connectivity by stochasticity is tested with numerical simulations based on reduced magnetohydrodynamics equations with a strong guide field line-tied to two perfectly conducting end plates. Starting from an ideally stable force-free equilibrium, the system is allowed to undergo resistive relaxation. During the early phase when the system evolves quasi-statically, it is found that regions of high field line exponentiation (akin to quasi-separatrix-layers) are associated with rapid change of field line connectivity and strong induced flow. However, although the field line connectivity of individual field lines can change rapidly, the overall pattern of footpoint mapping appears to deform gradually. From this perspective, field line exponentiation appears to cause enhanced diffusion rather than reconnection during this phase. At a later time, it is found that resistive quasi-static evolution can cause the ideally stable initial equilibrium to cross an ideal stability threshold. Onset of the instability causes formation of intense current filaments, followed by rapid change of field line mapping into a qualitatively different pattern. It is in this phase that the change of field line connectivity may be more appropriately designated as magnetic reconnection. Our results reveal and address the difficulty in distinguishing magnetic reconnection from enhanced diffusion in the presence of field line stochasticity. Rapid change of field line connectivity appears to be a necessary, but may not be sufficient, condition for fast reconnection.

[Oral]

An enstrophy minimizing method for 3D MHD Equilibrium with Flow

Samuel A. Lazerson,* Stuart Hudson, and David Gates
PPPL
(Dated: January 2, 2014)

A variational technique for finding steady state solutions to the set of ideal MHD equations, with finite velocity terms, is described. In this formulation it is assumed that flows self-organize into minimum enstrophy states and no axisymmetric assumptions are made. As a result the derived equations are applicable to both axisymmetric and 3D systems (stellarators and perturbed tokamaks). The resulting minimized quantity is no longer the energy of the system but rather a linear combination of the flow enstrophy and magnetic energy. The constraints of magneic helicity, flow helicity, cross helicity, and mass are invoked to ensure the extremized states are non-trivial. This avoids the ill-posed problem of minimizing the ideal MHD kinetic energy term subject to such constraints. The resulting set of coupled Beltrami-like equations then define the system with three helicity multipliers. The constraint of flow helicity may then be relaxed, resulting in a similar system of equations (with two helicity multipliers). The analysis presented focuses on the incompressible limit ($\nabla\cdot\vec{v} = 0$) which is relevant to many perturbed tokamaks, stellarators, and reverse field pinches (RFP). The force free limit ($\nabla p = 0$) is directly applicable to the RFP and may be expanded to tokamaks and stellarators (by invoking a stepped pressure). The cylindrical limit is explored to develop connections between the angular momentum and flow vorticity. The physical implications of minimizing this functional are discussed.

On the formation of phase space holes and clumps

M. K. Lilley [1], R. M. Nyqvist [2], H. L. Berk [3],

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We show that the formation of phase space holes and clumps in kinetically driven, dissipative systems is not restricted to the near threshold regime, as previously reported and widely believed. Specifically, we observe hole/clump generation from the edges of an unmodulated phase space plateau, created by the excitation, phase mixing and subsequent dissipative decay of a kinetically driven, linearly unstable bulk plasma mode in the electrostatic bump on tail model (the standard paradigm transferable to the general wave-particle interaction processes). This has now allowed us to elucidate the underlying physics of the hole/clump formation process for the first time. Holes and clumps are side-band negative energy waves, which arise due to the sharp gradients at the interface between the plateau and the nearly unperturbed, ambient distribution, which destabilise in the presence of dissipation in the bulk plasma. We confirm this picture by demonstrating that the formation of such nonlinear structures does not in general rely on a “seed” wave. In fact regimes of linear stability for the bulk plasma can still generate holes and clumps, so long as a plateau exists. In addition, we observe repetitive cycles in which 1) a large plateau is first formed; 2) it is gradually eroded as hole/clump pairs detach, making the plateau smaller; 3) nonlinear interactions within the smallest plateau initiates a rebuild process to a large plateau state. This cycle appears insensitive to initial conditions and persists for a long time

ORAL

Simulated flux rope evolution and relaxation during non-inductive startup in the Pegasus ST[1]

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The dynamics and relaxation of magnetic flux ropes produced during non-inductive startup of the Pegasus Toroidal Experiment [Eidietis, *J. Fusion Energy.* **26**, 43 (2007)] are simulated with nonlinear MHD and two-fluid plasma models. A single injector is represented by a localized source-density for magnetic helicity and thermal energy. Results show development of a hollow tokamak-like profile of average $J_{\|}$ from a sequence of co-helicity merging events, wherein adjacent passes of the helical flux rope merge and reconnect, releasing flux-rope rings from the driven flux rope.[O'Bryan, *Phys. Plas.* **19**, 080701 (2012)]. Accumulation of poloidal flux over multiple relaxation events redirects the driven flux rope so that its path traces a toroidal surface. The presence of a quasi-separatrix layer during ring formation events is supported by analysis of the squashing-degree parameter (Q), where magnetic field-lines launched from the bottom surface of the domain produce a rolled surface of large Q. The layer bifurcates twice, once between non-reconnecting passes and again between reconnecting passes of the driven flux rope. Chaotic scattering during ring formation is also apparent from the distribution of magnetic field-line lengths. The longest magnetic field-lines correlate well with the largest values of Q. Scaling studies demonstrate that the topological evolution of the flux ropes is robust to variation in the viscosity and number diffusivity parameters.

The merging of adjacent passes of the driven flux rope constitutes coherent dynamo action that affects the global distribution. The effective MHD dynamo loop voltage–primarily from the vertical displacement of the flux rope–concentrates symmetric poloidal flux during ring formation and transfers significant energy to the flux-rope ring. Computations with the two-fluid plasma model produce qualitatively similar plasma evolution. The Hall dynamo effect acts over a much smaller region than the MHD dynamo and primarily contributes to the shaping of the current ring. Similar to experimental results, the magnetic fluctuations during helicity injection are approximately 5% of the toroidal field with significant activity in the 10-20 kHz range. After cessation of the simulated current drive, temperature and current profiles broaden and closed flux surfaces form rapidly, leaving a tokamak-like plasma suitable for transition to other forms of current drive.

[1]Work Supported by the U.S. Dept. of Energy

Oral Session Requested

Nonlinear Gyrokinetic Simulations of the Tokamak Edge Pedestal

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Gyrokinetic turbulence simulations are finely tuned to accurately capture the low fluctuation levels and weak density and temperature gradients typical in core tokamak plasmas. In contrast, the tokamak edge pedestal has relatively short gradient scale lengths and large electromagnetic fluctuations. This makes direct gyrokinetic simulation of the edge extremely challenging. In this talk we discuss these challenges and the significant progress made in this research area. Global gyrokinetic simulations find an unstable intermediate-n mode that resembles the MHD "peeling-ballooning mode" (PBM), thought to be responsible for the ELM. Linear simulations show that the kinetic PBM is an electromagnetic instability, propagates in the electron diamagnetic direction, has a real frequency in the drift-Alfven range, and is sensitive to the q-profile.[1,2] With the experimental q-profile, the intermediate-n kinetic PBM dominates over the high-n "kinetic ballooning mode" in most cases. Simulations with the unstable kinetic PBM nonlinearly saturate at high levels, with amplitudes peaking in the intermediate-n range. This qualitative behavior is found for simulations of several different DIII-D and C-Mod plasma discharges near the end of an ELM cycle. The general numerical magnetic equilibrium is used including up-down asymmetry. The stabilizing effect of the equilibrium radial electric field (Er) is found to be relatively weak both linearly and nonlinearly. While the linear growth rate of the KPBM is sensitive to the magnetic equilibrium, we found that except for the q-profile, the effects of the magnetic parameters are only quantitative. The results indicate that the density gradient, the q-profile, and hence the bootstrap current, are crucial for determining the stability of the KPBM.

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Oral

Dynamic boundary plasma-wall modeling of ELMy H-mode

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Physical processes in the boundary plasma and wall material strongly influence many of the most crucial issues of magnetic fusion science, such as: parameters of the edge plasma pedestal in H-mode (and, therefore, the core plasma confinement and fusion power); impurity contamination; divertor-plasma detachment; hydrogen isotope content in plasma and wall; transient and peak power load handling; and lifetime of plasma-facing components (PFCs). In current tokamaks the L-to-H mode transition as well as the recovery of H-mode pedestal after the ELMs involve simultaneous changes in both plasma transport and absorption/desorption processes of the working gas from PFCs.

The goal of our research is to study the roles of wall-related physical processes (adsorption, desorption, trapping, implantation, sputtering, etc) in the dynamics of ELMy H-mode discharges. Here we demostrate the dominant role of wall deuterium absorption and outgassing phenomena in the H-mode pedestal evolution during the ELM cycle.

In our studies, we use a new version of UEDGE code, called UEDGE-MB [A.Yu. Pigarov et al., PoP 18 (2011)], which implements the Macro-Blob approach allowing to simulate the spatiotemporal effects of highly intermittent, filamentary, non-diffusive transport observed during the ELMs. UEDGE-MB also incorporates time-dependent models for particle recycling, wall temperature, and deuterium inventory for each material boundary of the 2-D modeling domain.

We present the results of UEDGE-MB simulations of experimental data for H-mode DIII-D shots with type-I ELMs and with different pedestal plasma densities and ELM frequencies. Temporal evolutions of pedestal plasma profiles, divertor recycling, particle and power loads on divertor plates and chamber wall, surface temperature, and wall inventory in a sequence of ELMs are modeled and compared to the experimental time-dependent data. Short (during ELMs) and long (between ELMs) time scale variations of the pedestal and divertor plasmas are discussed. We show that the ELM recovery includes the phase of relatively dense and cold post-ELM divertor plasma evolving on a several ms scale, which is set by the transport properties of H-mode barrier. The global gas balance in these shots is analyzed. The calculated rates of deuterium deposition during the ELM and wall outgassing between the ELMs are compared to the ELM particle losses and NBI fueling rate, correspondingly. The sensitivity study of the pedestal and divertor plasmas to the model assumptions on the gas deposition and release on material surfaces is presented. The performed simulations show that the dynamics of pedestal particle inventory is dominated by the transit intense deuterium deposition into the wall during ELMs followed by the continuous gas release between ELMs roughly at constant rate. The dynamic deposition/release equilibrium attained in the saturated wall in a sequence of many ELMs and the roles of different plasma-material interaction processes in generating gas release are analyzed.

ORAL

Trapped particle precession and effective mass in Rosenbluth-Hinton type zonal flows

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Abstract

If an initial radial $\boldsymbol{E}$ field is set up in an axisymmetric collisionless tokamak, this results in GAMs. The latter Landau damp, leaving a residual steady $\boldsymbol{E}$ field[1,2] which is smaller than the initial field by a factor of $\approx 1.6q^2/\sqrt{\epsilon} \gg 1$ The final $\boldsymbol{E}$ field is consistent with conservation of toroidal angular momentum given the initial $\boldsymbol{E}$ field. It is well known that for a steady state $\boldsymbol{E}$, trapped particles (TPs) will undergo a rapid toroidal precession at the speed $\sim q u_E/\epsilon$, where u_E is the $\boldsymbol{E} \times \boldsymbol{B}$ drift. We observe, however, that the toroidal momentum in the precessing TPs is much larger than the residual Rosenbluth-Hinton (RH) toroidal momentum. Upon calculating the bounce-averaged TP toroidal flow from the RH distribution function, using conventional energy coordinates, we find the TP toroidal flow speed to be much smaller than the expected precession speed. Further, the calculation yields a nonzero poloidal flow for TPs. In addition, the RH effective mass is smaller than is expected from simple drift models: in particular, the origin of the effective mass can be described in analogy to the Lagrangian of two mass beads on a rigid massless rod pushed perpendicularly, with the beads free to slide along the rod, but one bead constrained to a linear 1-D channel to mimic the TPs. We show that the above-mentioned apparent discrepancies can be resolved by transforming to energy coordinates shifted with respect to the $v_{||}$ coordinate,with the shift[3] proportional to u_E. We show, in fact, that even in the limit of small $\boldsymbol{E}$, the corresponding first order shift in the phase space Jacobian must be retained as it acts on the zeroth order distribution function. Allowing for this Jacobian shift yields the correct precession and a zero poloidal flow of the TPs. The effective mass, if calculated separately for TPs and CPs, is in accordance with the precession based on the toy model Lagrangian. However, the composite effective mass is smaller and in agreement with the RH calculation. Underlying reasons for this are discussed. The calculations are essentially done in the sub-bounce-frequency limit, an assumption that fails near the separatrix. To explore the dynamics near the separatrix, a more general calculation based on action-angle coordinates has been commenced which may allow for low bounce frequency effects. This will be briefly described.

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Oral session

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Modeling of tungsten and beryllium dust impact on ITER-like plasma edge

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With the progress of magnetic fusion toward increasing power and duration of plasma discharges, the plasma-wall coupling and its impact on performance of plasma edge and divertor, in particular, gain growing importance due to operational limits of wall materials. The large stationary or intermittent particle and heat fluxes can damage plasma-facing components, i.e. tungsten divertor and beryllium walls in ITER [1], leading to production and mobilization of metallic dust and droplets. Transport and ablation of such dust in the boundary plasmas is an important mechanism of impurity contamination, which can significantly affect fusion plasma operation.

In this work we investigate impact of tungsten and beryllium dust/droplets on edge plasmas in ITER-like discharge using computer simulations with the coupled dust-plasma transport code DUSTT/UEDGE [2]. The mixed Monte-Carlo/multi-fluid code allows to model self-consistently the dynamics of dust in tokamak peripheral plasma and the plasma response to the dust-impurity contamination. Various scenarios of the dust injection in divertor and upstream plasmas are modeled, taking into account the first 21 charge states of tungsten and all that of beryllium impurities. The dust of sizes ranged from 1μm to 100μm and mass rates of dust injection varied from 1mg/s up to ~1g/s are simulated. We demonstrate that injection of beryllium and tungsten dust with rates ~300mg/s and ~30mg/s, correspondingly, can significantly impact ITER operation leading to the divertor plasma detachment and degradation of the pedestal temperature. Larger amounts of dust can further cause divertor plasma thermal instability and discharge termination. The impurity radiation patterns, divertor heat load profiles, dust material in-core penetration and wall redeposition profiles are also analyzed for the considered dust injection scenarios. Significant differences in these effects caused by beryllium and tungsten dust, as well as by dust of different sizes are demonstrated. The implications of the obtained results on dust production limits in ITER are discussed.

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Prefer oral presentation.

Toroidal rotation produced by disruptions and ELMs

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In several experiments, including NSTX [1], Alcator C-Mod [2], and JET [3], it was observed that disruptions were accompanied by toroidal rotation. There is a concern that there may be a resonance between rotating toroidal perturbations and the resonant frequencies of the ITER vacuum vessel, causing enhanced damage. We present MHD simulations with M3D [4], as well theory, demonstrating that disruptions can produce toroidal rotation. Edge localized modes (ELMs) can also produce poloidal and toroidal rotation.

Net toroidal rotation requires [5] three conditions. (1) The poloidal magnetic field penetrates the wall, which is a condition that the plasma can transmit torque to the wall. (2) Rotation requires vertical asymmetry, which can be produced by a VDE. Simulations and theory indicate that the magnitude of the rotation is a stong function of VDE displacement. (3) Rotation requires MHD turbulence. In disruption simulations, the thermal quench and rotation generation occur at the same time, and are caused by toroidally varying MHD perturbations. The rotation persists into the current quench. Theory indicates that at least two modes, with poloidal and toroidal mode numbers $(m, n), (m + 1, n)$ must be present to cause toroidal rotation.

The toroidal velocity has a zonal structure, changing sign from the plasma core to the edge region. The maximum velocity can be an order of magnitude larger than the net velocity. Work is in progress to identify the scaling of the rotation with plasma parameters and assess its importance for ITER.

Rotation is also seen in MHD simulations of ELMs. It is possible that this mechanism is a cause of intrinsic toroidal rotation observed in H mode tokamaks. Theory gives toroidal rotation Alfvén Mach number, $M_\phi \approx 10^{-2}\beta_N$. This is consistent with a scaling [6] for intrinsic toroidal rotation.

Supported by USDOE and ITER

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ORAL

Abstracts of Poster Presentations

Anomalous Transport Processes Including Self-organization for Fusion Burning Regimes in Ignitor*

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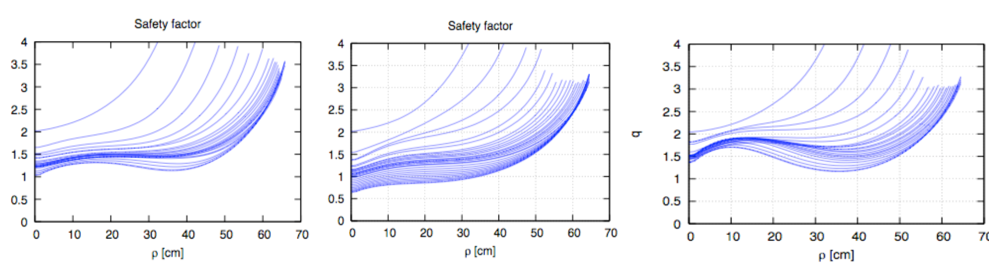
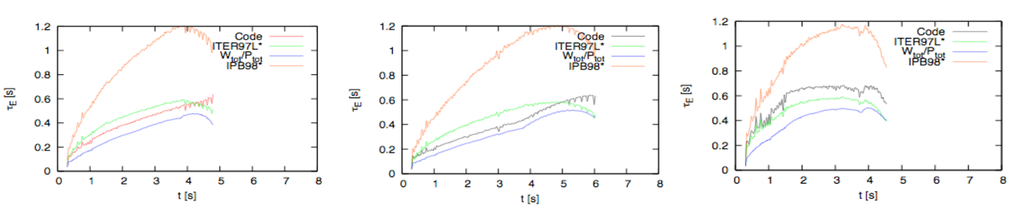
The most advanced simulation scenario for the Ignitor experiment assumes $B_T \simeq$ 13 T and $I_p \simeq 11$ MA [B.Coppi *et al., Nucl. Fus.* **53**, 104013 (2013)]. For this, a special version of the JETTO equilibrium-transport code [A. Airoldi and G. Cenacchi, *NF* **37**,1117 (1997)] was developed and employed by adopting thermal transport coefficients combined with “profile-consistency” considerations. Results obtained by applying different models of the electron thermal diffusion are compared. For the ion thermal energy diffusion the neoclassic ion thermal diffusion coefficient, increased by a fraction of the electron diffusion coefficient is adopted. The first considered model assumed the Coppi-Mazzucato coefficient with an addition due to the collisionless trapped electron mode and to its extension in different collisionality regimes[B. Coppi *et al.*, *Phys. Scr.* **45**,112(1992)]. Relevant results are given in Report MIT-PTP 99/06 by B.Coppi *et al.* By operating at optimized plasma parameters ($\langle n_e\rangle \simeq 4.7\text{x}10^{20}\text{m}^{-3}$, $\langle Z_{eff}\rangle \approx 1.2$) ignition is achieved shortly after the end of the current ramp (at t=4.75s, with the end of current ramp at $t \simeq$ 4s). Similar optimized plasma parameters, by using a mixed Bohm-gyro-Bohm model, lead to attain ignition with a delay of about $\simeq 1.2$s. The poloidal beta is $\beta_p \simeq 0.2$ in both cases [Paper GP8.00028, APS-DPP Bulletin 2013]. More recently the so-called “Coppi-Tang” model, used to predict plasma profiles and parameters for the ITER experiment [T.A. Kasper, W.H. Meyer *et al., Nucl. Fus.* **51**, 013001(2011)], was applied. In this case ignition is achieved at t=4.5s while $q(\psi)$ remains well over unity. Here the central the evolution of $q(\psi)$ corresponding to different cases is given



while the corresponding energy confinement times are compared to those obtained adopting the ITER97L scaling.



*Sponsored in part by the US DOE. Poster preferred.

Potpourri

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Constrained MHD stability. T. ANDREUSSI, F. PEGORARO, *Pisa, Italy* – Following up on previous work [Phys. Plasmas **19**, 052102 (2012); **20**, 092104 (2013)] we present examples of MHD equilibria for which we compare/contrast Lagrangian, Eulerian, and Dynamically Accessible stability. These kinds of stability differ by the constraints employed. Such constraints will be discussed, along with examples ranging from simple convective instability to MRI configurations with flow.

Mock fields and helicity. Z. YOSHIDA, *Tokyo, Japan* – Ideal MHD has magnetic helicity and cross helicity as Casimir invariants of its noncanonical Hamiltonian structure. However, loop integrals such as the Kelvin circulation theorem or local magnetic flux $\oint \mathbf{A} \cdot \mathbf{dr}$ are not manifest in the noncanonical formalism. We show how to recover such loop invariants by using an early idea [PJM, Z. Naturforschung **42a**, 1115 (1987)] and appropriately introducing *mock* fields that do not affect the dynamics but carry Lagrangian information. The construction is general and a series of examples will be given.

Dirac brackets for model construction. C. CHANDRE, E. TASSI, *Marseille, France* – We show how Dirac's theory of constained dynamics can be used to obtain Hamiltonian reduced models, where chosen constraints become constants of motion. To demonstrate the method we show that the Vlasov-Poisson (VP) equations along a constant magnetic field are obtained from the Vlasov-Maxwell system. In this case Dirac's primary constraint is freezing $\mathbf{B}$, while a secondary constraint is $\nabla \times \mathbf{E}$. This corresponds to a critical case where Dirac's matrix of constraints is not invertible. Nonetheless, a novel method exists to explicitly compute the Dirac bracket without additional constraints, leading to the usual Hamiltonian formulation for VP. As another example we derive the Hamiltonian structure of the modified Hasegawa-Mima equation from the ion fluid equations. Casimir invariants, an infinite class of constants of motion, are naturally obtained for this model.

POSTER

Intrinsic momentum transport in up-down asymmetric tokamaks

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Abstract.

Recent work demonstrated that breaking the up-down symmetry of tokamak flux surfaces removes a constraint limiting intrinsic momentum transport, and hence toroidal rotation, to be small [1]. We show, through MHD analysis, that ellipticity is most effective at introducing up-down asymmetry throughout the plasma. Then, we detail an extension to GS2 [2], a local δf gyrokinetic code that self-consistently calculates momentum transport, to permit up-down asymmetric configurations. Accordingly, tokamaks with tilted elliptical poloidal cross-sections were simulated to determine nonlinear momentum transport. The results, which agree with experiment, suggest that a toroidal velocity gradient, $\frac{1}{v_{thi}}\frac{du_{\zeta i}}{d\rho}$, of 5% of the temperature gradient, $\frac{1}{T_i}\frac{dT_i}{d\rho}$, is sustainable. Here v_{thi} is the ion thermal speed and $\rho \equiv r/a$ is the minor radial coordinate normalized to the tokamak minor radius. It seems that up-down asymmetry is the most feasible method to generate the current experimentally-measured rotation levels in reactor-sized devices.

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Particle electromagnetic simulation of lower hybrid waves

Jian Bao, Zhihong Lin and Animesh Kuley

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A global particle simulation is carried out to study lower hybrid waves in both the cylindrical and toroidal geometries for the first time. In our simulation model, ion dynamics is described by the fully kinetic Vlasov equation and electrons are treated as guiding centers using drift kinetic equation. This model has been implemented in the global gyrokinetic toroidal code GTC with a realistic electron-to-ion mass ratio. GTC simulations of electrostatic dispersion relation and linear electron Landau damping of lower hybrid wave are consistent with theory. Lower hybrid wave propagation in toroidal geometry shows that the poloidal harmonic number is no longer conserved due to the poloidal asymmetry of the equilibrium magnetic field. However, for cylindrical geometry with constant magnetic field, the poloidal mode number does not change. Electromagnetic simulation model of RF waves is also implemented into GTC code, the dispersion relation of slow wave in lower hybrid frequency range is well benchmarked.

Poster

Jan. 10, 2014

Linear stability of edge turbulence using two-fluid models in BOUT++ *

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We explore linear stability in the edge and near-edge region of a DIII-D tokamak L-mode discharge using a range of two-fluid models implemented in the BOUT++ code [1]. The goal is to identify instabilities that may help explain a well-known systematic under-prediction of near-edge transport and turbulence by gyrokinetic and gyrofluid codes [2]. Localized linear stability predictions from three-field and six-field (Braginskii-like) models are compared across the separatrix, with comparison to local stability predictions of the gyrokinetic code GYRO [3] where gyrokinetic ordering permits (out to $\rho \approx 0.9$). We also compare two-fluid linear stability results including and excluding the open-field-line region beyond the separatrix in the simulation domain. Finally, we discuss the impact of including the equilibrium current gradient drive (known to be important for tearing and peeling modes, but not retained in standard gyrokinetic orderings) and newly implemented gyrofluid closures on our results.

*This work supported in part by the U.S. Department of Energy under DE-AC05-06OR23100 and DE-FG02-07ER54917.

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Poster presentation requested

Generalized resistive wall boundary conditions for toroidal geometry in NIMROD and initial studies for NSTX equilibria [1]

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A generalized thin resistive wall boundary condition is implemented in NIMROD, making it possible to study both cylindrical and toroidal geometries with arbitrary poloidal axisymmetric shaping. The magnetic fields inside the computational domain are matched at the wall with external fields found using the GRIN vacuum-field solver. With this new extended capability, NIMROD is used to study the stability of resistive wall modes. Initial studies are performed for a series of reconstructed NSTX equilibria from multiple times during a single shot with different normalized betas, the majority of which are above the n=1 no-wall stability limit. An effective beta scan is performed using linear NIMROD runs and the result is compared to the stability limit from DCON. Scans with varying wall resistivity are also performed. Plans for work on non-linear cases with rotation will be presented.
[1]Research supported by U. S. DoE under grant no. DE-FG02-86ER53218.

Poster

Non-Axisymmetric and Poloidal Asymmetry Effects on the Neoclassical Transport in the Tokamak Plasmas *

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The drift-kinetic code NEO is used to explore symmetry-breaking effects on the neoclassical transport in tokamak plasmas. The effects of toroidal non-axisymmetry due to magnetic field ripple and imposed resonant magnetic perturbations on the flows and transport are explored using a recent 3D extension NEO coupled with a new unique 3D local equilibrium solver, analogous to a 3D extension of the Miller formalism for shaped axisymmetry equilibria. The method allows for fast systematic studies of the effects of 3D flux surface shaping parameters and guarantees a strictly valid 3D magnetostatic equilibria. Analysis of the neoclassical toroidal viscosity with full kinetic corrections, non-ambipolar transport, and the flows in tokamak edge plasmas with non-axisymmetric perturbations are explored including kinetic electrons and impurity effects.

Poloidal asymmetry effects on heavy impurity neoclassical transport in rotating plasmas are also studied both analytically and numerically. The analytic theory of Romanelli and Ottaviani [1] for the particle flux of a trace heavy ion in a rotating plasma in the Pfirsch-Schluter regime is extended to allow for larger, more experimentally realistic impurity Mach numbers at finite aspect ratio, general geometry, and full main ion and impurity equilibrium gradients. The complete set of main and heavy ion transport and flow coefficients are derived. The theory is verified with NEO, which implements the Hinton-Wong [2] drift-kinetic formulation of strong rotation including centrifugal effects. Implications for studies of enhanced transport high-Z impurities, where central accumulation has been experimentally observed, are discussed. The analytic theory and NEO are also extended to include the poloidal electric field effects induced by RF minority species, which produces an in-out asymmetry.

*This work supported in part by the U.S. Department of Energy under DE-FG03-95ER54309 and DE-FC02-06ER54873.

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Poster presentation requested

Coupling of Neutral-beam-driven Compressional Alfvén Eigenmodes to Kinetic Alfvén Waves in NSTX

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Abstract.

Results of the first self-consistent simulations of neutral-beam-driven compressional Alfvén eigenmodes (CAEs) in the National Spherical Torus Experiment (NSTX) are presented. The hybrid code HYM has been used to investigate properties of CAE in NSTX. The HYM code is a 3D nonlinear, global stability code in toroidal geometry, which treats the beam ions using full-orbit, delta-f particle simulations, while the one-fluid resistive MHD model is used to represent the background plasma. Simulations for the H-mode NSTX discharge (shot 141398) show unstable CAE modes for a range of toroidal mode numbers, n=4-9, and frequencies below the ion cyclotron frequency. It is found that the essential feature of CAE modes in the NSTX is their coupling to kinetic Alfven wave (KAW) that occurs on the high-field side at the Alfven resonance location. Radial width of the KAW is found to be comparable to the fast ion Larmor radius. High-frequency Alfven eigenmodes are frequently observed in beam-heated NSTX plasmas, and have been linked to enhanced thermal electron transport and flattening of the electron temperature profiles. Coupling between CAE and KAW suggests a new mechanism to explain these observations, in which beam-driven CAEs dissipate their energy at the resonance location, therefore significantly modifying the energy deposition profile.

Poster

Non-axisymmetric magnetic fields and toroidal plasma confinement

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The physics of non-axisymmetry is a far more important topic in the theory of toroidal fusion plasmas than might be expected. (1) Even a small toroidal asymmetry in the magnetic field strength, $\delta \equiv \partial \ln B/\partial\varphi \sim 10^{-4}$, can cause an unacceptable degradation in performance. (2) Nevertheless, asymmetries—even large asymmetries $\delta \sim 0.2$—can give beneficial plasma control and circumvent issues, such as magnetic-configuration maintenance and plasma disruptions, that make axisymmetric fusion devices problematic.

Viewed from prospectives that are adequate for designing and studying axisymmetric plasmas, the physics of non-axisymmetric plasmas appears dauntingly difficult. Remarkably, Maxwell's equations provide such strong constraints on the physics of toroidal fusion plasmas that even a black-box model of a plasma answers many important questions. Kinetic theory and non-equilibrium thermodynamics provide further, but more nuanced, constraints.

A review has been written for the journal Nuclear Fusion, which makes the constraints of both Maxwell's equations and of kinetic theory and thermodynamics explicit, so these constraints can be used as a basis for the innovations and for the extrapolations that are required to go from existing experiments to fusion systems. The review outlines of a number of calculations that would of great importance to ITER and to the overall fusion program and that could be carried out now with limited resources. A few examples of topics are:

• The general magnetic field produced by currents outside of a plasma can be expressed as a sum of magnetic field distributions ordered by the efficiency with which they can be produced by distant currents. Stellarator designs of fusion systems have a factor of about ten more field distributions of acceptable efficiency than tokamak designs. Several hundred different magnetic field errors can penetrate from the coils to the plasma with only a factor of ten reduction in strength in a fusion system. The difficulty of error field control increases exponentially with the number of field distributions requiring control, so only a few error-field distributions can be controlled.

• Toroidal plasmas have a wide variation in sensitivity to different externally-produced magnetic-field distributions. A knowledge of the number and the form of the field distributions to which the plasma has a high sensitivity is important for tokamak control including error-field control and for stellarator design.

• The energy and the toroidal torque that are required for an external magnetic perturbation to perturb a plasma have a closely coupled dependence on the plasma rotation frequency, and there is an upper limit on the ratio of the torque to the energy. Both results follow from Maxwell's equations, so they are independent of the plasma model. There are important implications for the shielding of external perturbations from the plasma

• Non-equilibrium thermodynamics is consistent with kinetic theory only when the deviation $\hat{f}$ from a local Maxwellian f_M is small, where the distribution function is written as $f = f_M \exp(\hat{f})$. A small deviation $\hat{f}$ means $\int \hat{f}^2 f d^3V$ is small compared to the plasma density. Unless $\hat{f}$ is small, transport calculations require a full specification of sources and sinks. The magnitude of $\hat{f}$ is limited for consistency with fusion power. An application of this limit is to the applicability of current drive to fusion systems.

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Poster

Control of resistive wall modes in a cylindrical tokamak with plasma rotation and complex gain

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Abstract

Feedback stabilization of resistive and ideal magnetohydrodynamic (MHD) modes is studied based on a linear combination of the normal and tangential components of the magnetic field at the resistive wall. The analysis includes plasma rotation and complex gain, for both the normal and tangential components, $G_r + iG_i$ for the former and $K_r + iK_i$ for the latter. The imaginary part G_i is equivalent to wall rotation. The imaginary gain K_i has a qualitatively similar effect as G_i, although there is no simple equivalence to rotation. The analysis uses a cylindrical model for a tokamak with finite β in the visco-resistive tearing mode regime. The equilibrium is stable for $\beta = 0$ and the marginal stability values $\beta_{rp,rw}$, $\beta_{rp,iw}$, $\beta_{ip,rw}$ and $\beta_{ip,iw}$ (resistive plasma, resistive wall; resistive plasma, ideal wall; ideal plasma, resistive wall; ideal plasma, ideal wall) are found in order with increasing β. For any given β, stable regions of G, K space are studied as functions of the rotation and imaginary gain. The main results are: (a) imaginary gain or plasma rotation stabilizes below $\beta_{rp,iw}$ because rotation suppresses the diffusion of flux from the plasma through the wall and, more surprisingly, (b) imaginary gain or rotation destabilizes above $\beta_{rp,iw}$ because it prevents the feedback flux from entering the plasma through the resistive wall. Because of the equivalence of G_i with rotation, optimum stabilization in the $\beta > \beta_{rp,iw}$ regime is found when the equivalent wall rotation equals the plasma rotation at the mode rational surface. Sensitivity to the ratio τ_w/τ_t, the ratio of wall time to tearing time, is presented, as is the extension to the resistive-inertial regime. These results offer an intuitive basis on which to understand feedback stabilization in toroidal configurations accurately modeling experiment, where the physics is complicated by toroidal effects.

Poster

Halo currents and the M3D boundary conditions

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The nonlinear extended MHD code M3D [1] has been employed in the simulation of disruptions resulting from vertical displacement events in tokamaks including JET, NSTX, and ITER [2-4], with the goal of providing guidance as to the distribution and timing of the accompanying transient currents to be expected in the conducting structures surrounding the plasma, and to the resulting forces. The nature of the simulations is such that these currents and forces occur at the boundary of the computational domain, making the proper choice of boundary conditions especially critical to the reliability of the results. As has historically been typical with magnetofluid codes, the M3D boundary condition includes the prescription that the normal component of the fluid velocity vanish at the wall. It has been argued [5] that this prescription invalidates M3D's (and similar codes') prediction of vessel currents because it would seem to rule out the possibility of the advection of plasma surface currents into the wall as the plasma flows into it. We report here on the first of a series of systematic tests of this claim, involving the application of the M3D code to a range of idealized cases that aim to abstract the essential physics at issue from some of the complications involved in the attempt to model real-world devices using realistic parameters. Some conclusions will be drawn on two key issues: whether the M3D code, with some version of its present set of boundary conditions, is capable of reproducing the "Hiro" currents predicted by a simplified model [6]; and whether this model is more relevant to the ITER VDE scenario than the one M3D has been using thus far.

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POSTER

Variational integrators for perturbed non-canonical Hamiltonian systems

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Abstract

Finite-dimensional non-canonical Hamiltonian systems arise naturally from Hamilton's principle in phase space. We present a method for deriving variational integrators that can be applied to perturbed non-canonical Hamiltonian systems on manifolds based on discretizing this phase-space variational principle. Relative to the perturbation parameter ϵ, this type of integrator can take $O(1)$ time steps with arbitrary accuracy in ϵ by leveraging the unperturbed dynamics. Moreover, these integrators are coordinate independent in the sense that their time-advance rules transform correctly when passing from one phase space coordinate system to another. This work was supported by the U.S. Department of Energy under contract DE-AC02-09CH11466.

Keywords: variational integrators, geometric mechanics, perturbation theory

Poster

Study of Lower Hybrid Wave Propagation and Absorption in Tokamak Plasma by Hamiltonian Theory

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The ray tracing is a well-established technique that allows to study the propagation of the Lower Hybrid Wave in a tokamak plasma, and it is based on the WKB expansion of the wave equation. At the lowest order in the expansion parameter, the ray tracing makes possible to study the wave front dynamics in the 3D tokamak geometry. In this work the Hamiltonian character of the ray tracing equations is analytically and numerically investigated in order to deduce the physical properties of the wave trapped without absorption (for example the wave trapped at the edge owing to the inaccessibility condition) in the confined tokamak plasma (multipass). In this context the "Hamiltonian" is essentially the electromagnetic dispersion relation for the lower hybrid wave, and the canonically conjugate variables are the wave-vector and the position. The transition to the "Hamiltonian chaos" is analyzed because of two or more degrees of freedom characterizing the system that, for this reason, is non-integrable. The consequences on the traveling wave, in particular, on the evolution of the parallel wave-number have been accounted. The chaotic diffusion of the time-averaged parallel wave-number towards higher values has been evaluated in order to corroborate or disprove the filling of the spectral gap in the lower hybrid absorption mechanism [1]. Analytical calculations have demonstrated that the non-integrability is essentially due to the toroidal geometry or any other mechanism breaking the toroidal symmetry (magnetic ripple, density and magnetic fluctuation [2,3]). As long as toroidicity can be considered a perturbation of the cylindrical geometry (small inverse aspect ratio $\varepsilon << 1$) the non-integrable Hamiltonian system can be analytically studied by the perturbation theory where the zeroth order Hamiltonian H_0 is only one-degree freedom while the perturbed Hamiltonian H_1 is two. Moreover the non-integrability of the physical system can also affect the evolution of a bundle of trajectories when describing several modes radiated by the antenna (spectrum). For a non-integrable system, the spreading of the trajectories is exponential (Liapunov exponents), this leads to a destruction of the wave spectrum in relatively short time. Numerical analysis by means of a Runge-Kutta based algorithm implemented in a ray tracing code supply the analytical considerations. A numerical tool based on the symplectic integration of the ray trajectories has been developed and it is well suited to follow the boundle of rays in strong multipass regime.

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Poster

Potpourri

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Constrained MHD stability. T. ANDREUSSI, F. PEGORARO, *Pisa, Italy* – Following up on previous work [Phys. Plasmas **19**, 052102 (2012); **20**, 092104 (2013)] we present examples of MHD equilibria for which we compare/contrast Lagrangian, Eulerian, and Dynamically Accessible stability. These kinds of stability differ by the constraints employed. Such constraints will be discussed, along with examples ranging from simple convective instability to MRI configurations with flow.

Mock fields and helicity. Z. YOSHIDA, *Tokyo, Japan* – Ideal MHD has magnetic helicity and cross helicity as Casimir invariants of its noncanonical Hamiltonian structure. However, loop integrals such as the Kelvin circulation theorem or local magnetic flux $\oint \mathbf{A} \cdot \mathbf{dr}$ are not manifest in the noncanonical formalism. We show how to recover such loop invariants by using an early idea [PJM, Z. Naturforschung **42a**, 1115 (1987)] and appropriately introducing *mock* fields that do not affect the dynamics but carry Lagrangian information. The construction is general and a series of examples will be given.

Dirac brackets for model construction. C. CHANDRE, E. TASSI, *Marseille, France* – We show how Dirac's theory of constained dynamics can be used to obtain Hamiltonian reduced models, where chosen constraints become constants of motion. To demonstrate the method we show that the Vlasov-Poisson (VP) equations along a constant magnetic field are obtained from the Vlasov-Maxwell system. In this case Dirac's primary constraint is freezing $\mathbf{B}$, while a secondary constraint is $\nabla \times \mathbf{E}$. This corresponds to a critical case where Dirac's matrix of constraints is not invertible. Nonetheless, a novel method exists to explicitly compute the Dirac bracket without additional constraints, leading to the usual Hamiltonian formulation for VP. As another example we derive the Hamiltonian structure of the modified Hasegawa-Mima equation from the ion fluid equations. Casimir invariants, an infinite class of constants of motion, are naturally obtained for this model.

POSTER

On Gyrokinetic Simulations of Low-n MHD Modes

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A gyrokinetic ion/mass-less fluid electron hybrid model is implemented in the GEM code [Y. Chen and S. E. Parker, J. Comp. Phys. 220, 837 (2007)], using the same field solver as that used in the kinetic electron model. Only derivatives of the second order in the perpendicular plane (the $x-y$ plane in the field-aligned coordinates) are retained in the Laplacian operator. This approximation is valid for high-n drift waves, but may break down for low-n waves. For the Alfven eigenmodes a direct comparison between the approximate and the exact operator indicates that the approximation is valid for $n = 2$. We have recently used the model to simulate the $m = 1$ tearing mode in toroidal geometry, but have not been able to observe a mode of tearing parity and with the expected dependence of the mode growth rate on resistivity. We suspect that this is caused by the breakdown of the high-n approximation in the field equation. Another possible reason is the exclusion of the magnetic axis in the simulation, due to using the field-aligned coordinates. We present solutions to these two problems. The full 3-D Laplacian operator will be used, with derivatives along the field line treated iteratively. Finite difference will be applied in the radial direction so that the appropriate boundary condition at $r = 0$ can be incorporated, following McClenaghan on GTC simulation of the internal kink mode [PP8.00063, APS-DPP 2013].

poster

Study of microtearing mode in the core of NSTX with GEM

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Abstract

The observation of strong dependence of electron thermal transport on collisionality in case of spherical tokamaks like NSTX has led to the conclusion that the microtearing mode is a potential candidate responsible for anomalous transport of electrons [Guttenfelder *et al.*, Phys of Plasmas **19**, 022506 (2012)] from the system. Not only in spherical tokamaks, recent studies in conventional tokamaks have revealed that MTM modes can significantly affect the electron transport in tokamaks like ASDEX, JET etc. [Moradi *et al.*, Nucl. Fusion **53** (2013) 063025]. The mode is characterized by even parity in $A_{\|}$, and grows on the free energy provided by electron temperature gradient in the presence of collisionality. Motivated by recent experimental and subsequent computational studies in NSTX, we are carrying out a computational study based on particle in cell method of the microtearing mode for NSTX parameters in the core using the nonlinear gyrokinetic electromagnetic code GEM. The prime objective is to study microtearing mode using the global version of GEM to investigate how the profile effects play a role in the stability of the mode. The preliminary results with the flux tube version of GEM are qualitatively in agreement with previous results. A comparison of the results from local flux tube and global model of GEM will be presented.

Poster

Simulation of neoclassical transport in a divertor geometry with COGENT[1]

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We describe recent advances in COGENT, a continuum gyro-kinetic code (COGENT) being developed by the Edge Simulation Laboratory (ESL) collaboration. The current version of the code is 4-D and focused on transport properties of the plasma edge (including the scrape-off layer). COGENT has had a variety of simplified collision model options (e.g., Krook collisions, Lorentz collisions, a linearized model Fokker-Planck collisions, etc); our recent development work has focused on incorporation of the full (nonlinear) Fokker-Planck collision model. The implementation of the Fokker-Plank operator is discussed in detail, and results of initial verification studies are presented. In addition, we discuss initial results of cross-separatrix neoclassical transport simulations for parameters characteristic of the DIII-D tokamak. Simulations are performed for various collision-model choices and the results are used to assess sensitivity of edge/SOL transport properties to details of the collision model.

[1]Work performed for USDOE, at LLNL under contract DE-AC52-07NA27344 and at LBNL under contract DE-AC02-05CH11231

Poster preferred

Variational Principles with Padé Approximants for Tearing Mode Analysis

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Tearing modes occur in several distinct physical regimes, and it is often important to compute the inner layer response for these modes with various effects. There is a need for an approximate and efficient method of solving the inner layer equations in all these regimes. In this poster we introduce a method of solving the inner layer equations based on using a variational principle with Padé approximants. For all the regimes considered, the main layer equations to be solved are *inhomogeneous*, and Padé approximants give a convenient and efficient method of satisfying the correct asymptotic behavior at the edge of the layer. Results using this variational principle - Padé approximant method in three of these regimes are presented. These regimes are the constant-ψ resistive-inertial (RI) regime, the constant-ψ viscoresistive (VR) regime, and the non-constant-ψ RI regime. The last regime includes the exact non-constant-ψ regime and the inertial regime. The results show that reasonable accuracy can be obtained very efficiently with Padé approximants having a small number of parameters. The work of AJC was supported by the Department of Applied Physics and Applied Mathematics of Columbia University. The work of JMF was supported by the DOE Office of Science, Fusion Energy Sciences and performed under the auspices of the NNSA of the U.S. DOE by LANL, operated by LANS LLC under Contract No DEAC52- 06NA25396.

Prefer: poster

BAE gap modification due to a magnetic island

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The Beta-induced Alfven Eigenmode (BAE) gap is a break in the frequencies of the shear Alfven continuum. This gap is important because a discrete Alfven eigenmode can exist within the gap frequency range and will not be affected by continuum damping. In order for the BAE gap to appear, finite beta and toroidal effects must be present. Under these conditions, there is a coupling between the equation for shear Alfven waves involving inertia and bending energy terms and the sound wave equation. The presence of a magnetic island has been shown to cause an upshift in the BAE gap frequency[1]. In the absence of an island the minimum of the continuum frequencies is located at the resonant rational surface; the island moves the location of the minimum to the island separatrix as a result of the coupling between helical mode numbers. The physical mechanism for this shift will be described employing analytical modeling. An in-depth computational study of the scaling of this frequency shift with the magnetic island size will be detailed. This frequency shift has been computed by solving the generalized eigenvalue problem obtained from 3D MHD simulations with islands using the SIESTA code. The theory may help to explain some observed Alfvenic activity in MST discharges[2].
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Poster

IMPLEMENTATION OF AN ADVANCED X-DIVERTOR ON ITER WITHOUT DESIGN CHANGES

Recent results from CORSICA have indicated that an advanced X-Divertor may be attainable on ITER without any coil or divertor cassette design changes, and with all PF/CS coil currents within their specified limits. It was found that the coil current parameter space from a standard divertor (SD) to an X-Divertor (XD) is “continuous,” such that any amount of increase in the poloidal flux expansion at the target plates can be dialed – from a small perturbation to the SD, up to the point of maximal flux expansion where a design constraint is reached. At this preliminary stage of our investigations, as we reach the coil current limits, flux expansion at the outer target plate exceeds that of the SD by a factor of 3, and the Divertor Index (DI), a quantitative measure of field line flaring, peaks near 1.7 (DI for SD is 1). It is believed that a DI sufficiently greater than 1 may allow for controllable divertor detachment, drastically reducing heat flux at the target plates while maintaining the core plasma integrity. SOLPS 5.1 simulations of the ITER XD are run with full neutral-neutral interaction models to test this assertion.

Type: Poster

Authors: Brent Covele, Mike Kotschenreuther, Prashant Valanju, Swadesh Mahajan

When the conventional model of dust transport in tokamaks begins to break

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Long-pulse tokamaks like ITER or DEMO are characterized by much higher energy fluxes to the wall than present-day short-pulse tokamaks, implying stronger plasma-material interaction and higher quantities of dust produced in the chamber. Indeed, ITER is the first tokamak with dust safety and administrative limits, setting the maximum amount of dust that can be present at any given time in the machine [1]. For this reason, dust transport in tokamaks and dust destruction/survival have received a lot of attention in recent years [2-5].

Studies of dust transport typically involve solving simultaneously the following time-dependent equations: (1) the dust charging equation; (2) the dust equation of motion; (3) the dust heating equation; and (4) an equation for dust mass loss. The dust charging equation yields the dust charge due to collection of background plasma particles and electron emission processes, and is a necessary ingredient to calculate the forces acting on the dust grain and the energy fluxes. The expressions for the dust charging currents, forces and energy fluxes are normally expressed analytically in the framework of the Orbital-Motion-Limited (OML) theory [2-5].

In this work, we explore the regimes of validity of OML. We perform self-consistent Particle-In-Cell simulations of dust charging for conditions relevant to the edge of a tokamak, including thermionic emission from the dust grain. We study micron-sized tungsten dust, in a regime where the plasma Debye length is comparable (or smaller) than the dust radius. We find that OML can become inaccurate when the grain becomes positively charged: it can miss the transition between negatively and positively charged dust, and it can overestimate the dust charge, currents and the energy fluxes (the latter by 30-50% for the energy collected by the background electrons and for the parameters considered). This behavior is associated with the development of a non-monotonic potential (a potential well) near the dust grain due to the trapping of some of the thermionic electrons [6]. The controlling parameters are the dust size relative to the Debye length and the dust temperature relative to the background electron temperature. We also discuss a new charging theory that is much more accurate than OML for positively charged dust.

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Evaluation of symplectic algorithms for the integration of guiding center trajectories

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Abstract

Variational algorithms have recently shown promise for the long term integration of guiding center test particle dynamics [1, 2, 3, 4]. Good long-term numerical fidelity is obtained by inheriting discrete conservation laws from the phase-space action principle. The cornerstone of a variational algorithm is a choice of discrete Lagrangian, which approximates a small interval in time of the phase-space action. Freedom exists in the discretization procedure, and recent works have proposed a variety of discretization methods [5, 6]. In this contribution, a range of discretization procedures are applied to the guiding center system and the resulting algorithms evaluated for accuracy, stability, and run time. The degenerate nature of the guiding center Lagrangian makes the calculation of guiding center trajectories a non-trivial testing ground for novel discretizations and their corresponding algorithms. This work was supported by DOE Contract number DE-AC02-09CH11466.

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Preferred session: Poster

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Ballooning modes localized near the null point of a divertor

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The stability of ballooning modes localized to the null point in both the standard and snowflake divertors is considered. Ideal magnetohydrodynamics is used. A series expansion of the flux function is performed in the vicinity of the null point with the lowest, non-vanishing term retained for each divertor configuration. The energy principle is used with a trial function to determine a sufficient instability threshold. It is shown that this threshold depends on the orientation of the flux surfaces with respect to the major radius with a critical angle appearing due to the convergence of the field lines away from the null point. When the angle the major radius forms with respect to the flux surfaces exceeds this critical angle, the system is stabilized. Further, the scaling of the instability threshold with the aspect ratio and the ratio of the scrape-off-layer width to the major radius is shown.

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Poster

Resistive Wall Model in M3D-C1

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A resistive wall model has been implemented in the two-fluid code M3D-C1 by including the resistive wall and the external vacuum region within the computational domain. This method is expected to provide a more computationally scalable implicit solution than the approach in which the resistive wall is implemented as a boundary condition, because implementing such a boundary condition requires the nonlocal coupling of all boundary elements. In the model presented here, physical properties of the wall, such as temperature and resistivity, may vary in space and time. This allows the modeling of non-axisymmetric features of the wall, such as ports and TBMs, without requiring a non-axisymmetric mesh geometry. In addition, this implementation allows for walls of arbitrary thickness, which may be important for modeling RWMs in ITER. Initial results of linear and nonlinear calculations of resistive wall modes and vertical disruption events in NSTX and DIII-D are presented.

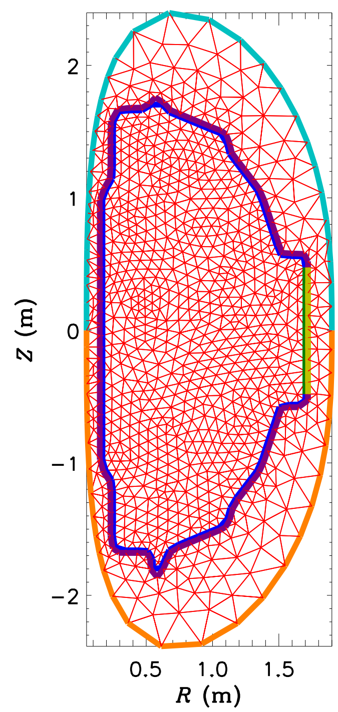

FIG. 1. A low-resolution mesh including a resistive wall approximating the NSTX vessel and passive plates.

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Poster presentation requested.

Determination of Non-Ideal Response of a High Temperature Plasma to a Static External Magnetic Perturbation via Asymptotic Matching

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Asymptotic matching techniques are used to calculate the response of a high temperature tokamak plasma with a realistic equilibrium to an $n = 1$ static external magnetic perturbation. The plasma is divided into two regions. In the outer region, which comprises most of the plasma, the response is governed by the linearized, marginally-stable, ideal-MHD equations. In the inner region, which is strongly localized around the various rational surfaces within the plasma (where the marginally-stable, ideal-MHD equations becomes singular), non-ideal effects such as resistivity and inertia are taken into account. The recently developed TOMUHAWC code is used to calculate the response in the outer region. The response in the inner region is obtained from Glasser-Greene-Johnson linear layer physics. For the sake of simplicity, we focus on the situation where the plasma at one of the internal rational surfaces is locked to the external perturbation, whereas that at the other surfaces is rotating.

Poster

Large Eddy Simulation Lattice Boltzmann Representation of 2D MHD Turbulence

Chris Flint, George Vahala (William & Mary), Linda Vahala (ODU), Min Soe (Rogers State)

Abstract

Direct numerical simulations (DNS) of strong MHD turbulence is limited by the achievable resolution, leading to unresolved scales. Large eddy simulations (LES) are one attempt to account for the effect of the dynamics of the subgrid scales on the physics by utilizing filter functions on the random fields. Reynolds averaged (RANS) methods are different, utilizing ensemble averages.

In direct LES of MHD turbulence, there is a closure problem due to the subgrid stress tensors. The simplest closure approximation is the Smagorinsky model in which the subgrid stress are related to the resolvable strain-rate tensor by some eddy transport coefficients.

Recently, Ansumali et. al. [2] have introduced an LES for the Lattice Boltzmann (LB) representation of Navier-Stokes turbulence. The beauty of this approach is that no closure approximations are now needed. The reason is that there are now 2 limit processes: (a) small Knudsen number $Kn << 1$ (by which kinetic equations are reduced to fluid equations), (b) filtering width $\Delta << 1$. In the LB representation, (with lattice vectors and corresponding distributions

$$\partial f_i / \partial t + \mathbf{e}_i \bullet \nabla f_i = -\left(f_i - f_i^{eq}\right) / \tau$$

one first filters the lattice kinetic equation. Because of the LB advection term (which replaces the nonlinear fluid convection) the closure problem arises only in the relaxation distribution function which depend on the conserved moments. In evaluating these nonlinear terms, one expands in powers of Δ. On proceeding to the *Kn* – expansion, one is forced into a scaling of the filter width Δ on *Kn* in order that the subgrid terms effect the fluid evolution at the transport time scales. It is this that yields closure in the LES-LB without further approximations.

We generalize this to MHD turbulence and discuss simulations on the Orszag-Tang vortex. The final filtered equation for the magnetic field takes the form

$$\frac{\partial \bar{B}_\alpha}{\partial t} + \frac{\partial\left[\bar{u}_\alpha \bar{B}_\beta - \bar{u}_\beta \bar{B}_\alpha\right]}{\partial x_\beta} = \eta \nabla^2 \bar{B}_\alpha + \frac{\Delta^2}{12L^2}\left\{\frac{\partial \bar{B}_\beta}{\partial x_\gamma}\frac{\partial^2 \bar{u}_\alpha}{\partial x_\beta \partial x_\gamma} - \frac{\partial \bar{u}_\beta}{\partial x_\gamma}\frac{\partial^2 \bar{B}_\alpha}{\partial x_\beta \partial x_\gamma}\right\}$$

illustrating that the filtering not only introduces an eddy resistivity tensor but also some direct effect on the filtered mean velocity.

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[Poster Presentation]

Gyrokinetic particle simulation of linear instabilities in edge plasmas.

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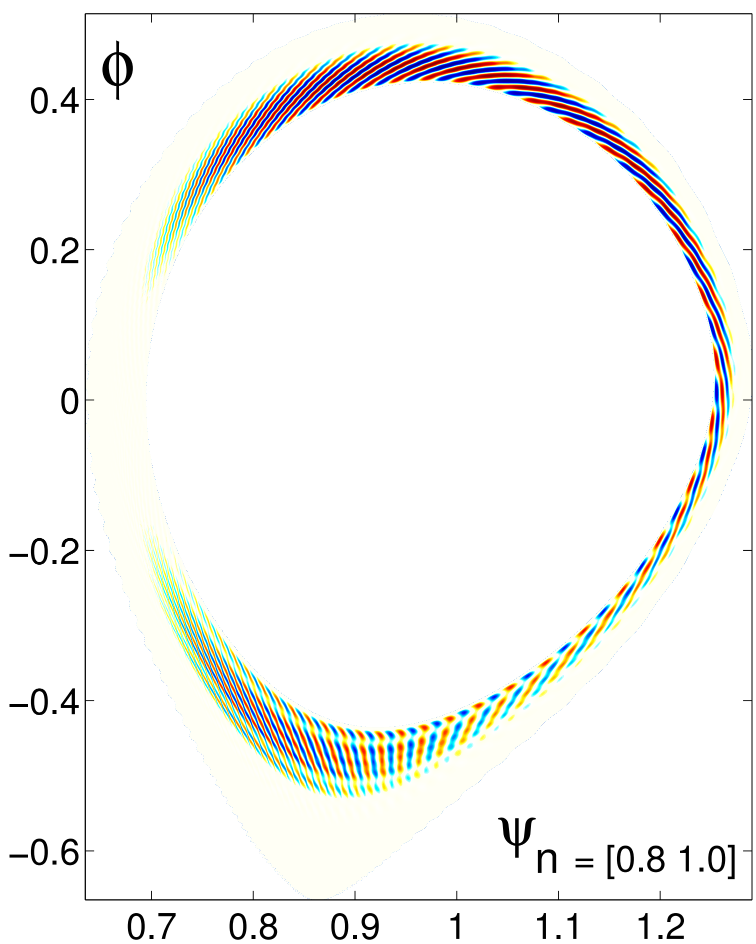
Understanding the physics in the edge pedestal region of toroidal plasmas is critical to obtaining confinement with high core temperatures. The pedestal region is characterized by large gradients in pressure, temperature, and density profiles, providing a source of free energy to drive instabilities, such as ion and electron temperature gradient modes (ITG/ETG), kinetic ballooning mode (KBM), and trapped electron modes (TEM). Studying these instabilities can provide information on the limits of allowable gradients in the pedestal.

In this study, we explore linear instabilities, in the pedestal region of the DIII-D discharge 131997 using the gyrokinetic toroidal code (GTC). Results using parameters from a region at the top of the pedestal show dominant mode to be an interchange instability. In the peak gradient region, a qualitatively different mode structure, peaking at $\theta = \pm \pi/2$ is observed. These qualitative mode structures may be controlled with the gradient strength. Additionally, we present initial progress in GTC simulations of edge turbulence in a field reverse configuration (FRC).



Request poster.

Role of plasma surface current in tokamak disruption events*

S.A. Galkin, V.A. Svidzinski, (FAR-TECH, Inc.), L.E. Zakharov (PPPL)

Role of the surface current which can arise on perturbed sharp plasma vacuum interface in tokamak during disruptions is still needed to be clarified and understood. Interest in such surface current was recently generated by a few papers (see [1-5] and references therein). In dangerous disruption events with plasma-touching-wall scenarios, the plasma surface current can be shared with the wall leading to the strong, damaging forces acting on the wall[1]. A relatively simple analytic definition of δ-function surface current proportional to a jump of tangential component of magnetic field nevertheless leads to a complex computational problem on the moving plasma-vacuum interface, requiring the incorporation of non-linear 3D plasma dynamics even in one-fluid ideal MHD. The Disruption Simulation Code (DSC), which had recently been developed in a fully 3D toroidal geometry with adaptation to the moving plasma boundary, is an appropriate tool for accurate self-consistent δ-function surface current calculation. Progress on the DSC-3D development will be presented. We will also discuss a plan to develop a Disruption Prediction and Simulation Suite (DPASS) of comprehensive computational tools to predict, model and analyze disruption events, and which will use DSC-3D as a starting and core tool. Getting matured, the DPASS will eventually address each aspect of the disruption problem: MHD, plasma edge dynamics, plasma-wall interaction, generation and losses of runaway electrons. Developed DPASS will be an important step toward the prediction of disruptions in ITER and understanding opportunities for mitigation schemes.

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Presentation: Poster

Computation of Outer Region Matching Data for Resistive Instabilities with DCON

A, H. Glasser, University of Washington
Z. R. Wang and J.-K. Park, Princeton Plasma Physics Laboratory

The DCON code[1] is widely used to determine the ideal MHD stability of axisymmetric toroidal plasmas. Since its initial development in 1996, we have intended to extend the code to compute the outer region matching data for resistive instabilities at high Lundquist number S, but the numerical methods used for that have proven unreliable. We have identified the cause of the problem as a well-known numerical instability of shooting methods. A new Galerkin method has been developed that uses most of the infrastructure of DCON while replacing the algorithm for computing matching data with one which is faster and more reliable, based on the theoretical work of Pletzer and Dewar.[2] We improve on the convergence properties of the method by using Hermite cubic basis functions rather than linear finite elements. These are effective at resolving nonresonant harmonics with continuous function values and first derivatives. They are supplemented by using analytically computed high-order resonant power series solutions near each singular surface as additional basis functions, which are effective at resolving resonant solutions. Ideal region matching data are then obtained from the coefficients of the small resonant basis functions rather than from an integral representation. We also use a flexible grid-packing algorithm, concentrating the grid in the neighborhood of the singular surfaces. Matching to the inner region model of Glasser, Greene, and Johnson,[3] solved numerically by the method of Glasser, Jardin, and Tesauro,[4] gives a complete picture of resistive stability. Excellent quantitative agreement with the MARS code,[5] for both growth rate and outer region eigenfunction, has been achieved for equilibria with many Fourier components, one singular surface, and a conducting wall at the edge of the plasma, but DCON is much faster and more robust. Results for equilibria with multiple singular surfaces and a vacuum region will also be presented.

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poster

MHD Pedestal Formation in Time-Dependent Simulations with Poloidal Viscosity.

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[2]Princeton Plasma Physics Laboratory

Finite toroidal and poloidal flows are routinely observed in the edge plasma region of tokamak experiments. MHD theory predicts that when the poloidal velocity is transonic with respect to the poloidal sound speed ($c_{sp} \equiv c_s B_p / B$, where B_p is the poloidal field) a transient will develop. After the end of the transient, a steady-state MHD pedestal in plasma density and pressure is left, with the height of the pedestal depending on the poloidal location. The formation of the MHD pedestal was demonstrated with time-dependent simulations with the resistive-MHD SIM2D code. In the present work, we explore the effect of poloidal viscosity on the formation of the MHD pedestal and investigate whether the presence of poloidal viscosity will inhibit the formation of a steady-state pedestal. Two approaches are used. First, the SIM2D code is modified to include the implementation of analytic expression for the poloidal viscosity obtained from the literature. Second, the M3DC1 code is used to perform simulations of transonic poloidal flows. In addition to giving us the chance to obtain an independent confirmation of the SIM2D results, the use of the M3DC1 code will also provide us with a tool in which poloidal viscosity expressions are already implemented. Therefore, M3DC1 will also give us an independent approach for evaluating the effect of poloidal viscosity on the formation of the MHD pedestal. Work supported by US Department of Energy Contract No. DE-FG02-93ER54215.

[Poster preferred]

Atomistic modeling of molecular hydrogen desorption from tungsten surface*

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Hydrogen retention and recycling on metallic plasma-facing components (PFCs) are among the key-issues for future fusion devices due to both safety and operational reasons. Understanding of these processes requires proper description of hydrogen desorption from metallic surface, which is usually modeled by the desorption flux $\Gamma_{out} = K_0 e^{-E/T} c_s^{\gamma}$. Desorption parameters (E,K_0,γ) may depend on various complex phenomena (e.g atomic islands, roughness, surface reconstruction, impurities, ect). For tungsten, which has been chosen as divertor material in ITER, values of E, K_0 and γ experimentally measured for fusion-related conditions show a large discrepancy [1]. Understanding mechanisms governing hydrogen desorption from tungsten and their dependencies on material conditions is thus required to model hydrogen desorption from tungsten PFCs.

We performed molecular dynamics and accelerated molecular dynamics(AMD) simulations [2] to analyze the diffusion and the coalescence of hydrogen on the surface and their effects on hydrogen recombination into molecules, provided that interaction potential between tungsten and hydrogen atoms is known. The only hydrogen tungsten potential available in literature is a Tersoff potential proposed in [3,4]. We show here that this potential cannot reproduce molecular desorption of hydrogen from tungsten surface due to an activation energy for hydrogen recombination of several eV. This activation energy is larger than the binding energy of single hydrogen atoms on tungsten surface, and hydrogen mostly desorb from tungsten as single atom, which contradicts experimental observations. We then give a detailed analysis of the Tersoff potential, showing that this potential cannot model molecular desorption due to three-body interactions. Amplitude of three-body interactions can be adjusted to lower the activation energy of hydrogen recombination process and reproduce some experimental features of hydrogen desorption as molecules from tungsten surface. We conclude that the Tersoff potential presently used to model hydrogen tungsten interactions overestimates three-body interactions at tungsten surface and cannot reproduce hydrogen molecular desorption from tungsten.

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Poster required

Stability of Inhomogeneous Equilibria of Hamiltonian Continuous Media Field Theories

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[2] University of Texas at Austin

There are a wide variety of $1 + 1$ Hamiltonian continuous media field theories that exhibit phase space pattern formation. In plasma physics, the most famous of these is the Vlasov-Poisson equation, but other examples include the incompressible Euler equation in two-dimensions and the Hamiltonian Mean Field (or XY) model. One of the characteristic phenomenon that occurs in systems described by these equations is the formation of cat's eye patterns in phase space as a result of the nonlinear saturation of instabilities. Corresponding to each of these cat's eyes is a spatially inhomogeneous equilibrium solution of the underlying model; in plasma physics these are called BGK modes, but analogous solutions exist in all of the above systems. We analyze the stability of inhomogeneous equilibria in the Single Wave model, which is an equation that was derived to provide a model of the formation of electron holes in plasmas. We use action angle variables and the properties of elliptic functions to analyze the resulting dispersion relation construct linearly stable inhomogeneous equilibria for in the limit of small numbers of particles and study the behavior of solutions near these equilibria.

Poster

Energetic Particle Effects on Tearing Mode Stability with Varying β

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Previous analysis of toroidal confinement experiments has shown that energetic ions in a slowing down distribution interact with and affect MHD mode stability, which has been extensively modeled for ideal MHD by kinetic corrections to the δW eigenvalue [1]. This study focuses on the mode-particle interactions between energetic particles and pressure-driven tearing modes in a toroidal configuration relevant to current experiments. Our equilibrium consists of a D-shaped poloidal cross section, a peaked pressure profile, and safety factor with finite shear to the magnetic axis. A series of equilibria with fixed safety factor and varying pressure are analyzed using a δf hybrid kinetic-mhd code in NIMROD. Also, an analytic reduced model is investigated to gain insight to the underlying physics of mode-particle interaction. The 2/1 tearing mode is found to be damped or stabilized by the addition of particles, with the most significant effects on the slow growing resistive mode [2]. The effect is mainly due to trapped particle resonance and causes the tearing mode to have a finite frequency. We combine our computational and analytic tools to explain this damping and stabilizing effect.

Poster abstract submission for 2014 Sherwood Fusion Theory Conference

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MHD PLASMA RELAXATION WITH MASS FLOW AND FINITE PRESSURE*

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Abstract

Taylor's relaxation theory is extended to plasmas with mass flow by having the cross helicity being a conserved quantity, similar to the magnetic helicity. Indeed, it is shown that the conservation of the cross helicity in MHD is the result of the conservation of *two* magnetic-like helicities in two-fluid plasmas.

The resulting relaxed state is similar to the one discussed by Finn and Antonsen [Phys. Fluids **26,** 3540 (1983)], and involves flow parallel to the magnetic field and constant temperature, but non-constant pressure. We provide a solution to the relaxed state as an asymptotic expansion in the typically small Alfven Mach Number of the flow.

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Probability Distributions and 3D Equilibrium Reconstruction

James D. Hanson and Mark Cianciosa

Auburn University

The V3FIT[1] 3D equilibrium reconstruction code is based on the VMEC[2] 3D equilibrium solver. V3FIT has been successfully used for 3D reconstruction on stellarators, reversed field pinches, and tokamaks[3].

The equilibrium reconstruction proceeds by a least-squares minimization of a chi-squared function

$$\chi^2 = \sum_i \frac{\left(S_i^{\mathrm{mod}}(p_j) - S_i^{observe}\right)^2}{\sigma_i^2}$$

where the observed signals $S_i^{observe}$ come from the experiment, and the model-computed signals S_i^{mod} depend on the reconstruction parameters p_j of the equilibrium model.

Recently added capabilities of the code include: specifying prior-knowledge of reconstruction parameter values, specifying equality and inequality constraints amongst reconstruction parameters, computing posterior variances and correlations of auxiliary quantities, and computing posterior correlations amongst reconstruction parameters. The reconstruction will be interpreted in terms of probability distributions in various spaces (signal space, reconstruction parameter space, and auxiliary parameter space) and examples of the new code capabilities will be shown.

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Poster

The effects of weakly 3-D equilibria on the MHD stability of tokamak pedestals*

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Abstract

The effects of a weakly three-dimensional distortion on an otherwise axisymmetric configuration are shown to be destabilizing to ideal MHD modes. The calculations assumes that the the 3-D fields are small and that shielding physics is present so that the equilibrium remains approximately topologically toroidal. A perturbation theory is employed that describes the coupling of different toroidal mode number harmonics in the construction of the eigenfunction. The effect of the 3-D equilibrium field on the spectrum are quantified through the construction of matrix elements. This calculation indicates that the "small" 3-D field is destabilizing to the most unstable (or least stable) ideal MHD mode.

The theory is specialized to the MHD stability of pedestal modes in the presence of shielded RMP fields. Previous work has demonstrated that local MHD stability properties (and hence microinstabilities) can be significantly altered by the presence of applied 3-D fields [1]. In this work, we expand these calculations in an effort to address whether RMP fields can affect 'global' peeling-ballooning modes. For this model, the dominant component of the 3-D field is modeled as the sum of eddy current response localized to their associated rational surfaces. This results in calculations of matrix elements that are products of eddy current amplitudes and a coupling coefficient computed from the properties of the eigenfunctions of the axisymmetric configuration. The physics of how the localized current structures affect the MHD stability of tokamak pedestals will be discussed.

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poster

Neoclassical Transport Benchmark with NIMROD *

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Utah State University

Abstract

Accurate and numerically efficient, continuum solutions to the electron, ion and hot particle drift kinetic equations have been implemented in the plasma fluid code NIMROD. The approach uses finite-elements in pitch angle and a set of collocation points in normalized speed for 2D velocity space. The spatial dependence of the distribution functions is treated using NIMROD's 2D finite-element representation in the poloidal plane and 1D Fourier expansion in the toroidal direction. As a first step toward hybrid fluid/kinetic simulations of neoclassical tearing modes in three spatial dimensions, we provide quantitative comparisons of neoclassical transport predictions made by the NIMROD, NEO‡ and NIES § codes for a variety of axisymmetric equilibria. The three codes involved in this study all use the full, linearized Coulomb collision operator. Excellent agreement for the bootstrap current and radial heat and particle fluxes is shown between NIMROD and NEO for a high-aspect-ratio, circular tokamak equilibrium and for a series of DIII-D-like equilibria with varying collisionality. Also, quantitative agreement between NIMROD, NEO and NIES is shown for the bootstrap current in an NSTX equilibrium. (Poster)

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†Tech-X Corporation

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Penetration of Lower Hybrid Waves with Density Fluctuations for ITER-like Plasmas

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Lower Hybrid [LH] ray propagation in toroidal plasma is shown to be controlled by combination of the launched RF spectrum, the poloidal variation of the magnetic field and the scattering of the waves by the drift wave density and magnetic fluctuations. The width of the poloidal and radial RF wave spectrum increases rapidly as the rays penetrate into higher density and temperature plasma inside the separatrix[1]. The electron temperature gradient [ETG] spectrum is particularly effective in scattering the LH waves due to its comparable wavelengths and phase velocities. ETG turbulence growth rates are modified by the extended high energy structures driven in the electron phase space density function. Radial gradients of the electron current profile drive an anomalous viscosity spreading the LH toroidal plasma current. The LH wave scattering is derived from a Fokker-Planck equation for the distribution of the ray trajectories with diffusivities derived from the drift wave fluctuations[2]. Condition for the chaotic diffusion for the rays is derived and compared with those from electron density fluctuation scattering. The poloidal and radial mode number spectra of the lower hybrid waves spread rapidly from the antenna launched spectrum for both single-pass and multi-pass absorption rays. Current antennas launch poloidal mode number spectra with broad n_{poloidal} spectra. Such spectra drive radially localized current profiles with confinement regimes in reversed magnetic shear [RS] in the steady state[3]. RS current density profiles produce reduced electron thermal transport. Core plasma current drive would require antennas with lower azimuthal mode spectra peaked at $m=0$ mode numbers. Two regimes of feedback control of the current profile are defined in terms of the slowing down time for the fast electrons and the rate of diffusion of the RF spectrum.

Acknowledgements: Work supported by the US DoE Grant to the University of Texas at Austin and IFRM, Cadarache, France.

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Nonlinear Simulations of Interchange Modes in Spheromaks
E. C. Howell and C. R. Sovinec
University of Wisconsin-Madison

Pressure driven interchange modes are studied for spheromak equilibria in a cylindrical flux conserver. A series of Grad-Shafranov equilibria are constructed with β ranging from 0.4% to 4.2%. These equilibria use a lambda profile representative of SSPX shot 14590, which had $\beta \approx 4.5\%$ [McLean et al, POP 13, 2006]. Linear calculations, using the NIMROD code [Sovinec et al, JCP 195, 2004] show that the $\beta = 0.4\%$ equilibrium is unstable to resistive interchange modes with linear growth rates up to $\gamma\tau_A \approx 6\%$ at a Lundquist number of $S \approx 10^4$. Ideal interchange modes are observed for equilibria with higher β. Linear growth rates as large as $\gamma\tau_A \approx 20\%$ are observed for the $\beta = 4.2\%$ case. Including the Hall term and ion gyroviscosity in the calculations increases the linear growth rates by $10 - 60\%$.

Nonlinear resistive MHD simulations of the $\beta = 4.2\%$ equilibrium show that the fluctuations saturate at a low level following an initial transient. The saturated fluctuating magnetic energy is 0.3% of the initial equilibrium magnetic energy. The resulting saturated state has a centrally peaked pressure profile that persists for many Alfven times. The transient reduces the peak temperature from 300eV to 240eV but increases the peak density from $5 \times 10^{-19} m^{-3}$ to $6 \times 10^{-19} m^{-3}$. The net change in peak pressure in only 5%. Nonlinear results from simulations that include the Hall term and ion gyroviscosity are also presented.

Work supported by the US DOE

Poster session

Numerical approximation of resonant lower hybrid waves in the cold plasma model

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[1] New York University, Courant Institute of Mathematical Sciences
[2] UPMC Univ Paris 06, Laboratoire Jacques-Louis Lions, France

The cold plasma model, which simplest form can be found in [1], displays cut-offs and resonances. Some aspects of the lower hybrid resonance were studied in [2], including the resonance where elliptic to hyperbolic transition that can be of interest for plasma heating.

The energy absorption in this model is related to unboundedness of the solutions, so that the classical mathematical framework is not adapted to this study. A previous study can be found in [3]. This presentation is dedicated to the description and numerical approximation of a theoretical solution of the lower hybrid resonance, obtained thanks to the limit absorption principle. The corresponding analysis is to be found in [4], and shows that the mathematical solution is singular. As a consequence, it is difficult to approximate it by any numerical method.

The numerical approximation of the singular solution can be performed following the steps of the theoretical study : first adding a regularization term to the dielectric tensor to get a bounded solution, and then pass to the limit as this term goes to zero to converge to the singular solution.

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For a poster presentation.

Self-Consistent Global Dynamics of Microturbulence in Presence of a Magnetic Island[*,†]

O. Izacard,[1,‡] S. D. James,[2] C. Holland,[1] and D. P. Brennan[3]

[1] *University of California - San Diego*
[2] *University of Tulsa*
[3] *Princeton University*

(Dated: January 15, 2014)

Understanding the physics of both large-scale magnetohydrodynamic instabilities and small-scale drift-wave microturbulence is essential for predicting and optimizing the performance of magnetic confinement based fusion energy experiments. While both types of instability have been investigated individually for many years now, less attention has been given to quantifying the interaction mechanisms between them. In this study, we use a newly formulated Hamiltonian four-field model to study interactions between slab ion temperature gradient (ITG) turbulence and a static magnetic island. "Global" simulations of the turbulence are performed using the BOUT++ code [1], and self-consistent equilibrium pressure and magnetic field profiles, in order to quantify the response of the turbulence as a function of distance from the island separatrix. The Harris current sheet equilibrium is used to incorporate a localized current layer at the center which smoothly transits to a constant magnetic field value at the edges. The results are then used to motivate future work aimed at understanding self-consistent island evolution in the presence of ITG turbulence. As a first step, flux-surface averaged turbulent stresses are calculated, and their expected impact on island evolution are discussed. The findings will also be compared against analytic predictions made using a previous wave-kinetic analysis.

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Simulation and validationof massive-gas-injection in the presence of 3D fields*

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To avoid localized melting of the first-wall, the ITER disruption mitigation system must achieve a certain degree of spatial uniformity in radiated power during a rapid shut-down. The assumption that increased uniformity of impurity injection (i.e., more spatially distributed gas jets) would lead necessarily to increased uniformity of emissivity was challenged by the finding in NIMROD MHD simulations that the m=1/n=1 mode during the thermal quench (TQ) produces a certain degree of asymmetry independent of impurity distribution [1]. The effect of the 1/1 mode on radiation asymmetry was subsequently tested in DIII-D by applying perturbing 3D fields prior to massive gas injection (MGI) in order to lock the mode to a particular phase. As expected, the results showed a dependence of the radiated power asymmetry on the applied n=1 phase only during the TQ—when the n=1 mode saturates—and not during the pre-thermal quench or current quench phases. Here we present 3D MHD simulations of MGI in DIII-D, with both the gas jet geometry and applied field spectrum matched as closely as possible to the experimental conditions. Each of four applied n=1 phases is simulated and compared to the DIII-D experimental results. A dependence on the applied field phase of both the timing and amplitude of the radiated power flash during the TQ is seen in the simulations, as in the experiments. While the radiation toroidal peaking factors (TPF) obtained experimentally are limited by the existence of only two toroidal measurements, the simulations allow validation against the 'synthetic' value of the TPF as well as comparison of the true value with that obtained by a two point measurement. Changes in the poloidal distribution of emmissivity are also found in both DIII-D and the NIMROD simulations. In light of new understanding of the 3D aspects of MGI, implications for the ITER disruption mitigation system are considered.

*This work was supported by the U.S. Department of Energy Grant No. DE-FG02-95ER54309.

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Poster presentation requested.

SELF-CONSISTENT CALCULATIONS OF THE INTERACTION BETWEEN DRIFT WAVE TURBULENCE AND THE TEARING MODE

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Magnetohydrodynamic (MHD) instabilities can influence the dynamics of turbulent fields, while the effects of microturbulence on the evolution of MHD instabilities is also known to be important. Accurately capturing the disparate scales involved in a self-consistent evolution of microturbulence and MHD instabilities is a challenging computational problem. Microturbulence involves very small spatial and temporal scales while the global evolution of MHD instabilities involves spatial and temporal scales several orders of magnitude larger. Using an Extended Hasegawa-Wakatani (EHW) model for the turbulence and coupling it to Ohm's law we can self-consistently capture the evolution of the turbulence and the nonlinear tearing mode. We have developed a new code, TURBO, to capture this evolution using an equilibrium with prescribed MHD stability properties and turbulent drives. Comparisons with analytic approximations for a turbulent resistivity and viscosity as integrals over the wave spectrum are also presented. Initial results indicate the turbulent resistivity exhibits a localized structure and oscillatory behavior given an imposed fixed island. These results provide a basis from which we can begin to understand the self-consistent evolution of the coupled island and turbulence system. We also discuss our approach for extending this work to a 5-field model, which includes the ion temperature gradient (ITG) mode.

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Active control of ECCD-induced tearing mode stabilization in coupled NIMROD/GENRAY HPC simulations

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Neoclassical tearing modes (NTMs) degrade plasma confinement and potentially trigger disruptions in toroidal plasmas. Application of actively controlled electron cyclotron current drive (ECCD) in or near the magnetic island formed by the NTM has been successfully shown to control or suppress these modes. However, because of uncertainties in the location of island O-points (where induced current has the greatest stabilizing effect) relative to the RF resonant region, the development and verification of integrated numerical models of this mode stabilization process is desirable. Such models, in conjunction with ongoing experimental efforts, will be of paramount importance in determining optimal NTM stabilization strategies for ITER.

In the advanced model for RF/extended-MHD interactions originally developed by the SWIM Project†, the equations and closures of extended MHD contain new terms arising from three-dimensional RF-induced quasilinear diffusion; these new terms are neither toroidally nor bounce-averaged. Because this quasilinear operator formulation models the equilibration of driven current within the island geometry using the same extended-MHD dynamics which govern the physics of island formation, a more accurate and self-consistent picture of island response to RF drive, including 3D effects, is obtained from the computational model. In tandem with these capabilities, a numerical active feedback control system has been developed which gathers data from synthetic diagnostics to dynamically trigger and spatially realign RF fields, such that optimal stabilization effects can be achieved throughout the simulations. High-performance computations which model the ECRF deposition using the GENRAY ray-tracing code, assemble the 3D quasilinear operator from ray and profile data, calculate the resultant forces within the NIMROD extended MHD code, and dynamically reposition the injected RF as the modes evolve will be presented. Insights into the efficacy of various control strategies will also be discussed.

This work is currently supported by the SciDAC Center for Extended MHD Modeling‡.

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†https://cswim.org; see also work by Hegna & Callen [Phys. Plasmas **16**, 112501 (2009)], J. J. Ramos [Phys. Plasmas **17**, 082502 (2010), **18**, 102506 (2011)], and Jenkins & Kruger [Phys. Plasmas **19**, 122508 (2012)].

‡http://w3.pppl.gov/cemm

Poster

A framework for moment equations for magnetized plasmas*

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Abstract

We present mathematical formalism to solve a system of general moment equations [J.-Y. Ji and E. D. Held, Phys. Plasmas **13**, 102103 (2006); **16**, 102108 (2009)] for magnetized plasmas. Using a perturbative expansion based on large cyclotron frequency, we write the ith order equation for rank-l tensor moments, $\mathbf{b}\check{\times}\mathsf{M}^l_{(i)} = \mathsf{G}^l_{(i)}$, where $\check{\times}$ denotes the generalized cross product and $\mathsf{G}^l_{(i)}$ contains the $(i-1)$st order moments, $\mathsf{M}^l_{(i-1)}$. We then obtain the general solution (homogeneous solution+particular solution) of the ith order moment equation. The homogeneous solution is proportional to $M^l_{(i)\|}\mathsf{P}^l(\mathbf{b})$, where $M^l_{(i)\|}$ is the parallel moment and $\mathsf{P}^l(\mathbf{b})$ is the harmonic tensor [$\mathsf{P}^0(\mathbf{b}) = 1,\ \mathsf{P}^1(\mathbf{b}) = \mathbf{b},\ \mathsf{P}^2(\mathbf{b}) = \mathbf{bb} - \frac{1}{3}\mathsf{I}$, etc.]. This generalizes the the CGL (rank-2) tensor to an arbitrary rank-l tensor. The parallel moments, $M^l_{(i)\|}$, are determined from the parallel component of the $(i+1)$st equation, $\mathsf{G}^l_{(i+1)\|} = 0$. Starting from $i = 0$ with $\mathsf{G}^l_{(0)} = 0$, we obtain $\mathsf{M}^l_{(0)}$, which is the homogeneous solution with $M^l_{(0)\|}$ being determined by $G^l_{(1)\|} = 0$. Then for $i = 1$, we obtain $\mathsf{M}^l_{(1)}$, the particular solution (explicitly expressed in terms of $\mathsf{G}^l_{(1)}$ i.e., $\mathsf{M}^l_{(0)}$) plus the homogeneous solution (with $M^l_{(1)\|}$ determined by $G^l_{(2)\|} = 0$). We can continue this procedure to obtain $\mathsf{M}^l_{(2)}$ and higher orders. Our formalism can be applied to plasmas of general collisionality and magnetic geometry with accurate collision operators. We also compare our perturbed moment equations with moments of the drift kinetic equation (DKE) by rewriting Hazeltine's DKE in the perturbation theory.

* Work performed in conjunction with the Plasma Science and Innovation (PSI) Center and the Center for Extended MHD Modeling (CEMM).

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Poster

Linear and nonlinear studies of edge harmonic oscillations with the NIMROD code

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It is desirable to have an ITER H-mode regime that is quiescent to edge-localized modes (ELMs). ELMs deposit large, localized, impulsive, surface heat loads that can damage the divertor. One such quiescent regime with edge harmonic oscillations (EHO) is observed on DIII-D, JET, JT-60U, and ASDEX-U [1]. These ELM-free discharges have the edge-plasma confinement necessary for burning-plasma operation on ITER. The EHO is characterized by small toroidal-mode numbers ($n \approx 1$-5); measurements from beam-emission spectroscopy, electron-cyclotron emission, and magnetic probe diagnostics show highly coherent density, temperature and magnetic oscillations. These measurements show that the EHO is a saturated macroscopic mode with perturbations peaking at the magnetic separatrix. The particle transport is enhanced compared to discharges without EHO, leading to essentially steady-state profiles in the pedestal region. Finally, the operation regime of the QH-mode is dependent on the rotation profile, and QH-mode discharges are produced with an applied torque through either co- or counter-neutral-beam injection and/or neoclassical toroidal viscosity from plasma interaction with non-resonant magnetic fields [1]. We investigate a reconstruction from DIII-D shot 14098 during a period of broadband-wavenumber EHO and compare our results to the known phenomenology.

The linear growth rates as computed with a resistive-MHD model have a ballooning-like toroidal-mode spectrum that does not explain the low wavenumber phenomena of EHO. Given the importance of the flow profile to the experimental observations, we include the reconstructed flows in our computations. When the flows are included, there is a destabilization of the modes across the toroidal mode spectrum and the mode at marginal stability is lowered from $n=5$ to $n=3$. To be presented is an examination of the effect on linear stability of inclusion of anisotropic thermal conductivity, and two-fluid decoupling and drift stabilization through the use of a generalized Ohm's law. Analytic theory and previous computations predict the inclusion of a full generalized Ohm's law is the growth rate is enhanced at intermediate wave-numbers and cut-off at large wave-numbers by diamagnetic effects [2], and the inclusion of ion gyroviscosity is stabilizing to large wave-numbers [3].

Nonlinear computations initialized with small amplitude waves with a broad-wavenumber spectrum produce and ELM-like dynamics. Preliminary results from nonlinear computations initialized with large low-wavenumber modes from the linear spectrum produce a more quiescent state, however these computations must progress further in time. Results from continuing these computations are presented.

This work is currently supported by the SciDAC Center for Extended MHD Modeling ‡ .

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‡ http://w3.pppl.gov/cemm

Poster

The Energy Transport Shortfall in the H-mode Deep Core and L-mode Near Edge Regions*

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In general, validation studies have shown that the TGLF Gyro-Landau-Fluid transport model [1–4] is accurate in predicting the core density and temperature profiles from a variety of tokamaks. While TGLF has demonstrated good agreement with the core profiles, it has been shown that the TGLF-09 model under-predicts the energy transport in the near edge L-mode (ρ=0.7–0.95) region in the DIII-D and JET tokamaks. Nonlinear GYRO simulations yield the same under-prediction. This has been referred to as the L-mode edge shortfall. It has also been found that TGLF often over-predicts the electron temperature profile in the deep core where no MHD activity is observed. This implies there is often an energy transport shortfall in that region as well. From a turbulence standpoint, the deep core region is simpler than the L-mode edge because only ETG modes are predicted to be unstable. In general, we will re-examine both the L- and H-mode discharges of interest using the latest version of TGLF which was recently upgraded to include an improved model for ExB shear suppression. The errors between the predicted and experimental profiles and temperature gradients will be quantified. Nonlinear GYRO simulations will be used to verify the fluxes from TGLF using the local experimental parameters from representative discharges. Sensitivity studies will be performed including examination of finite orbit width (FOW) effects on the neutral beam heating profile using CQL3D-hybrid-FOW[5] and subsequent impact on our TGLF predictions with an emphasis on the deep core shortfall cases.

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[X] Poster

ADVANCED DIVERTOR CONFIGURATIONS (X-DIVERTOR AND X-POINT DIVERTOR) ON PRESENT TOKAMAK EXPERIMENTS

Advanced divertor configurations are studied for a spectrum of different tokamaks (including superconducting ones) using the CORSICA magnetic equilibrium code. For NSTX and DIIID, which have , very successfully, engineered and run advanced divertors, our efforts consist of understanding the experimental configurations as well as suggesting new configurations. For all machines under study, (NSTX, DIII-D, ASDEX, and SST), X-Divertors (XD)) are designed as perturbations to each's standard divertor, maximizing flux expansion and field line flaring at the target plates without exceeding coil design limits, and using only the existing PF/CS coil configurations, i.e. without special coils near the target plates. Special consideration is given to a new X-Point Divertor for the upcoming Advanced Divertor Experiment (ADX) at MIT. CORSICA simulations are run to explore the parameter space for future PF coil design and optimization.

Type: Poster

Authors: Mike Kotschenreuther, Brent Covele, Prashant Valanju, Swadesh Mahajan, Brian LaBombard

Progress on Nonlinear Sawtooth Simulations using M3D-C1

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Linear and nonlinear, reduced as well as full resistive and two-fluid magnetohydrodynamic simulations of sawtooth instabilities are carried out using the high-order finite element code M3D-C1 [1]. The objective of this project is to take advantage of the high accuracy of M3D-C1 and its ability to use locally refined meshes in order to perform sawtooth simulations at high Lundquist numbers, focusing on the reconnection process. The code's high versatility allows the comparison of reduced, full and two-fluid MHD models as well as cylindrical and toroidal geometries.
Two aspects will be emphasized in the course of the investigations. (1), the results of relatively simple nonlinear reduced MHD simulations in cylindrical geometry are compared to reduced MHD simulations performed by a helical MHD code developed by Q. Yu [2]. In these simulations the occurrence of plasmoids (small additional islands at the $q = 1$ surface) increasing the reconnection rate is observed at high Lundquist numbers [3]. (2), more realistic nonlinear two-fluid MHD simulations in toroidal X-point geometry will be carried out in order to study phenomena such as incomplete sawtooth reconnection, which is often observed in experiments [4].
Initial results include a comparison of linear growth rates of the resistive internal kink instability in cylindrical reduced and full MHD simulations to analytic dispersion relations as well as to results from Yu's helical MHD code. Nonlinear reduced and full MHD simulations in cylindrical geometry at high Lundquist numbers are also presented.

Acknowledgments:
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[4] V Igochine et al, Nucl. Fusion 47, 23 (2007).

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Poster

Validation of MMM7.1 and TGLF Models for Anomalous Thermal Transport

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Predictions of electron and ion temperature profiles are obtained utilizing the Multi-Mode anomalous transport model, MMM7.1 [1], and the Trapped Gyro-Landau Fluid model, TGLF [2]. The simulations are carried out using the new numerical transport solver PT-SOLVER in the PTRANSP Predictive TRANSPort code. The predicted evolving temperature profiles are compared with the corresponding DIII-D experimental data. The discharges simulated in this validation study include Ohmic, L-mode, and H-mode plasmas, plasmas with co- and counter-rotation, and plasmas with internal transport barriers. The boundary conditions for temperature profiles are taken at the plasma edge for the L-mode and Ohmic discharges and at the top of the pedestal for the H-mode discharges. Both the MMM7.1 and TGLF models can compute anomalous thermal, particle, toroidal and poloidal angular momentum transport. The MMM7.1 and TGLF models compute the anomalous transport driven by the ITG, TEM, ETG, KBM and collisional drift modes. The neoclassical thermal transport is calculated using the Chang-Hinton module. The PT-SOLVER is a modular, parallel, and multi-regional solver [4] particularly suited for stiff turbulent transport models such as MMM7.1 and TGLF. Results will be presented illustrating the degree to which the MMM7.1 and TGLF transport models yield temperature profiles that are consistent with the DIII-D experimental data.

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Poster

Progress on a high-order direct q-solver for static axisymmetric equilibria

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Static plasma equilibria in toroidally axisymmetric devices are described by the Grad-Shafranov equation (GSE). In order to solve this equation, two free functions need to be specified. In the original formulation of the GSE, the two free functions are the plasma pressure (p) and the net poloidal current (F). However, in many applications of fusion interest (e.g. studies on MHD instability, microscale turbulence and equilibrium evolution), it is more desirable to specify p and the safety factor (q) instead of p and F. Yet to this date very few high order direct solvers, if any, have the ability to solve the GSE taking p and q as inputs. This is mainly because direct q-solvers encounter convergence issues that are best understood when the GSE is seen as an eigenvalue problem [LoDestro and Pearlstein (1993)].

We have recently developed a new direct q-solver based on the following two main ingredients: 1) a fast, high order direct Grad-Shafranov solver using conformal mapping and integral equation methods on the unit disk [Pataki et al. (2013)]; 2) a flux-conserving formulation [Takeda and Tokuda (1991), LoDestro and Pearlstein (1993)] to express the GSE in terms of p and q and resolve the associated convergence issues. We present initial results obtained with our new solver, and investigate its accuracy and convergence properties.

Electromagnetic effects on high-beta blob transport

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Plasma blobs (or blob-filaments) are coherent turbulent structures usually observed in the scrape-off layer (SOL) of magnetic confinement devices. An individual blob is characterized by its density, which is higher than the surrounding plasmas and its filamentary shape that is stretched along the magnetic field line. Convective transport and deformation due to instabilities of blobs determine the anomalous transport of not only the intermittent edge turbulence, but probably also edge-localized modes (ELMs) crossing the SOL [1]. If the advection time required for a blob to traverse the SOL is shorter than the dissipation time, the inverse of the instability growth rate, the heat loads will directly reach the in-vessel components.

The radial propagation speed of the sheath-limited blob is determined by the balance of the polarization due to the radial effective gravity force, and the sheath current at the parallel boundaries. In low-β ($\beta=8\pi nT/B^2<<m_e/m_i$) plasmas, the deformation of blob structure depends on several electrostatic instabilities such as Kelvin-Helmholtz instability and resistive drift instability [1]. However, in high-β limit ($\beta\geq m_e/m_i$), electromagnetic effects cannot be neglected since the plasma with high-β allows the magnetic field line to be bent; thereby the resistive drift wave is coupled with shear Alfven waves. In addition, parallel ExB drift shear caused by a parallel gradient of density will introduce an electromagnetic instability. This motivates studying the electromagnetic effects on blob transport to explain and predict the characteristics of ELMs and edge turbulent transport projected on high-β devices such as ITER.

In this study, we compare electrostatic and electromagnetic blob models, using three dimensional edge plasma simulation code, BOUT++ [2]. In the electromagnetic regime, the effect of the resistive drift-Alfven waves and parallel ExB shear mode on seeded high-β blob will be discussed. Moreover, by comparing the ExB advection and instability growth rates, impact of electromagnetic effects on plasma heat load on first wall will be presented.

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Poster presentation preferred.

2014 International Sherwood Fusion Theory Conference

Effects of Background-Inhomogeneity-Generated Zonal Flows on Microinstabilities and Plasma Pressure Balance*

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It is found that linearly generated zonal flows due to the extra ion charge density arising from FLR effects and the zeroth-order spatial inhomogeneity [1,2,3],

$$\bar{n}_i(\mathbf{x}) = n_i + \frac{1}{2}\rho_i^2 \frac{1}{T_i}\nabla_\perp^2 n_i T_i,$$

have similar effects as the nonlinear Dimits shift [4] on the retardation of the linear growths of ITG turbulence. However, the nature of the retardation is fundamentally different between the two. While Dimits shift is nonlinearly generated, the shift in the case at hand is linear in nature. Preliminary runs using GTC [5] have confirmed this linear effect on the growths of the instability.

Another topic related to this linearly generated zonal flows due to the zeroth-order spatial inhomogeneity is the relationship between these equilibrium zonal flows and the diamagnetic drifts based on the FLR effects. We have found that the conventional force pressure balance,

$$\sum_\alpha n_\alpha q_\alpha \mathbf{E} + \frac{1}{c}\mathbf{J}\times\mathbf{B} = \nabla \sum_\alpha p_\alpha,$$

where α denotes species, can be modified in the presence of equilibrium zonal flows as

$$\mathbf{J} = \frac{c}{B}\hat{\mathbf{b}} \times \nabla(p_{\perp e} + p_{\perp i}) + e n_i \frac{\rho_i^2}{2}\left[\nabla_\perp^2 \mathbf{v}_{E\times B} + \frac{\mathbf{v}_{E\times B}}{n_i T_i}\nabla_\perp^2 n_i T_i\right]$$

along with those $\mathbf{v}_{E\times B}$'s generated by microinstabilities [6].

*Present work is supported by US DoE Contract No. DE-AC02-09CH11466.

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POSTER PRESENTATION

The Tokamak MHD (TMHD) plasma model

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A plasma model, specific to MHD of macroscopic events in tokamaks, such as disruptions, is presented. These virulent phenomena attracted recently special attention because of their potentially big effect on operation of ITER and the next step devices. The first important characteristic of disruptions is that their time scale is much shorter than the magnetic field penetration time into the plasma. This implies that the plasma dynamics preserves the magnetic fluxes and as a result excites localized currents of two types: surfaces currents at the plasma boundary, and the sheet currents at the resonant magnetic surfaces. The second property is that even the thermal quench (loss of plasma thermal energy), which is the fastest event in disruptions, lasts more than 1 ms in large machines. This implies that the plasma inertia, which is the driving term in numerical simulations, plays a minor role, while the force balance is much more important. The third characteristic of plasma dynamics in tokamaks is that the plasma flow to the wall is unrestricted and conventional hydro-dynamic boundary condition $V_{normal} = 0$ is not applicable for disruptions. In order to utilize these properties

$$\tau_{MHD} \simeq \underbrace{R/V_A}_{<1\ \mu s} \ll \underbrace{\tau_{TMHD}}_{\simeq 1\ ms} < \underbrace{\tau_{transport}}_{\simeq 0.1\ s} \ll \underbrace{\tau_{resistive}}_{\simeq 1\ s}$$

we introduce a notion of Tokamak MHD (TMHD), which describes the macroscopic dynamics of a tokamak plasma as a fast equilibrium evolution with flux conservation, excitation of sheet currents or islands at the resonant surfaces and the surface currents at the plasma boundary and the wall.

The simplest form of macroscopic TMHD is represented and explained in the following table

Eq. of motion	$\lambda\delta\vec{r} = -\nabla p + (\vec{\jmath} \times \vec{B})$	No inertia, no velocity, no time, no Courant limitation on the time step
Ampere's law	$\vec{B} = (\nabla \times \vec{A}), \quad \mu_0\vec{\jmath} = (\nabla \times \vec{B})$	Standard
Faraday's law	$-\frac{\partial \vec{A}}{\partial t} - \nabla\varphi_E + (\vec{V} \times \vec{B}) = \frac{\vec{\jmath}}{\sigma}$	Standard, with a non-standard meaning: it determines the time rate and $\vec{V}$. No boundary condition for V_{normal} is necessary
$\sigma = \sigma(T_e)$	$(\vec{B} \cdot \nabla\sigma) = 0$	Plasma anisotropy, $(\vec{B} \cdot \nabla T_e) \simeq 0$ is explicitly specified
$\vec{V} \equiv \frac{\partial \delta \mathbf{r}}{\partial t}$	$(\nabla \cdot \vec{V}) = 0$	Replaces the equation of state

Existing numerical schemes, which are essentially hydro-dynamics with an additional $\vec{\jmath} \times \vec{B}$ driving term, are not suitable for TMHD. Instead, adaptive grid schemes, capable to reflect the plasma anisotropy, should be created [?]. A simple algorithm, reflecting the nature of TMHD, is suggested in order to overcome the Courant condition restriction to the time step. New Reference Magnetic Coordinates (RMC) are described as an approach of generation of coordinates aligned with 3-D ergodic magnetic field. Numerical examples for 2-D m/n = 1/1 kink mode dynamics is presented.

The basic physics of TMHD has been validated by recent phenomenal success in: (a) Theoretical discovery of Hiro currents (2007), (b) 100 % consistency of theory explanation of plasma current asymmetry with JET data on all its 4854 disruptions, (c) Prediction of Hiro currents in VDE on EAST (2011), and (d) Confirmation of Hiro currents by first measurement on EAST (2012).

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This topic would like to be presented as a poster.

GTC simulation of tearing modes in fusion plasmas

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Abstract

In tokamak discharge, Tearing modes are very important modes which may cause the disruption and sawtooth crash. For these reason, an effective physics model and corresponding simulation code are needed to study these modes. We have modified the massless fluid model [1] used in Gyro-kinetic Toroidal Code (GTC) and developed resistive finite mass eMHD model [2], using the model in GTC, we have successfully recovered linear behavior of the classical resistive tearing mode, and verified the capability of GTC to study this mode. The modified GTC may supply a more powerful implement than the former one for tokamak plasma study.

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Poster Abstract

A critical gradient analysis to better understand measured and predicted plasma responses in the DIII-D tokamak

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Two common, characteristic features of turbulent transport in tokamak plasmas are the existence of a critical driving gradient for onset of the turbulence, and a "stiff" (e.g. strongly superlinear) increase in turbulence flux as the driving gradient exceeds this critical value. In the limit of infinitely stiff transport, these characteristics lead to core profile gradients that are pinned to the critical values. While many physics parameters are important in determining the critical gradient and transport stiffness, it is generally believed that experimentally two of the most important parameters are the magnetic shear $\hat{s}$ and E×B velocity shear. In this study, we present a critical gradient analysis of a recently reported [1] H-mode transport stiffness experiment performed on DIII-D, which quantified the responses of core profiles to increasing neutral beam heating at different levels of injected torque. Transport modeling of these discharges with the TGLF transport model found the best agreement at low injected power and torque. In order to better understand these results, we first compare the measured ion temperature gradient profiles to the critical value for onset of the ion temperature gradient (ITG) instability, which is theoretically predicted to be the dominant instability at most radii in these discharges. The critical gradient profile is calculated via a series of local, linear eigenvalue calculations made with the GYRO code. Once the critical gradient is calculated, we quantify the differences between the experimental and critical gradients $\Delta_{Ti,crit} = \nabla T_{i,exp} - \nabla T_{i,crit}$ in terms of local E×B and magnetic shear as well as heating power at various radii in the plasma. We then characterize the difference between the experimental and TGLF transport solution gradient profiles $\Delta_{Ti,TGLF} = \nabla T_{i,exp} - \nabla T_{i,TGLF}$ as a function of in local heating power, magnetic and E×B shears, and $\Delta_{Ti,crit}$.

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prefer poster

Coupled neoclassical-magnetohydrodynamic simulations of axisymmetric plasmas

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A new code has been written to solve a set of time-dependent drift-kinetic equations (DKE) for the non-Maxwellian part of the electron and ion distribution functions (f_{NMs} for species s) using the full, linearized Fokker-Planck-Landau collision operator. In this initial application, the plasma is taken to be axisymmetric and in a collisionality range from the neoclassical banana regime to the more general $\nu_s L_{\|}/v_{ths} \sim 1$. Each DKE is formulated such that the resulting f_{NMs} carries no net density, parallel momentum, or kinetic energy. Rather, these quantities are contained within the background Maxwellians and are evolved by an appropriate set of extended magnetohydrodynamics (MHD) equations. Computational methods and convergence results will be discussed. The calculated neoclassical conductivity and bootstrap current are benchmarked against theoretical models. Moments of each f_{NMs} are used to provide neoclassical closures to a set of reduced, transport-timescale MHD equations, allowing for self-consistent simulations of the inductive formation of the Ohmic and bootstrap currents. Plans for coupling to M3D-C^1, and extensions to nonaxisymmetric geometries will be discussed. This future work will be ideally suited for coupled neoclassical-MHD simulations of core plasma instabilities (e.g., neoclassical tearing modes).

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POSTER

A 4D map for escape from resonance: negative energy modes and nonlinear instability

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It is well-known for some systems that analysis of the potential energy provides a necessary and sufficient condition for stability, a famous example being the 'δW' energy principle of MHD. This amounts to Lagrange's theorem of mechanics. More generally for any Hamiltonian system, positive definiteness of the Hamiltonian expanded about an equilibrium point provides only a necessary condition for stability, a criterion known as Dirichlet's theorem. The reason that this criterion is not necessary for stability is because of the possible existence of negative energy modes, which are linearly stable modes of oscillation that have negative energy. When such modes are present, the Hamiltonian is in general indefinite (see e.g., Ref. [1]). It has been argued in Refs. [2,3] that although such systems with negative energy modes are linearly stable, they are unstable to infinitesimal perturbations under the nonlinear dynamics. In the present work we study this kind of nonlinear instability with the simplest nontrivial map model.

It is well-known that area preserving maps have been used as models of magnetic field line behavior and chaotic transport in systems with two-dimensional time periodic velocity fields. In such systems, invariant tori are closed curves, which in two-dimensions provide barriers to transport. If an equilibrium point is surrounded by a nested set of such curves, the equilibrium is stable. However, in higher dimensions invariant tori do not provide barriers and allow an avenue for escape that is usually called Arnold diffusion. In this work we study this escape in the context of a four-dimensional map that is designed to mimic the behavior of a system with one positive and one negative energy mode. The map is polynomial, with a cubic degree of freedom that allows for detuning of resonance and a quadratic degree of freedom that allows for eventual escape. A special regular orbit present in the cubic degree of freedom is examined in detail as coupling is activated. A special structure is observed, termed the "triangular torus", and its role in escape is investigated.

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POSTER

Turbulence-driven bootstrap current in low-collisionality tokamaks

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Steady state tokamak operation requires non-inductive current drive of which the bootstrap current is the most economic option. Increasing the bootstrap fraction of the total plasma current relies on high beta and low aspect ratio. This is the prediction of neoclassical transport theory, which calculates the steady state population of trapped and passing particles in the presence of coulomb collisions. Here we report a novel mechanism through which a bootstrap current can be driven even in a purely collisionless plasma. In analogy with the neoclassical mechanism, we show that resonant scattering of electrons by drift wave microturbulence provides an additional means of establishing an equilibrium between trapped and passing electrons. Specifically, collisionless trapped electron modes are shown to provide a robust means of detrapping electrons through: (1) pitch-angle scattering via the precession resonance, (2) radial transport of electrons at fixed pitch-angle. In this latter case, while the electron's pitch-angle is fixed, the location of the trapped-passing boundary in phase space $\lambda_c = B_0/B_{max}(r)$ shifts as the electron is radially transported. To quantify the relative importance of the collisionless and collisional bootstrap current drive, we introduce a mean field formulation in which Coulomb collisions as well as collisionless resonant electron scattering are treated on an equal footing. Employing a linearized Fokker-Planck collision operator, the plasma current in the presence of both collisions and resonant electron scattering is computed as a function of the plasma collisionality and turbulent fluctuation amplitude. We find that the change in the bootstrap current is particularly strong during transient bursts of turbulent transport where fluctuation levels can obtain values a few times greater than that estimated from mixing length theory for a steady-state ITER-like tokamak. This suggests that bursty turbulent transport can change the plasma equilibrium and its micro and macrostability not only through profile relaxation of density and temperature, but also through direct modification of the axisymmetric plasma current distribution via turbulence-induced electron detrapping. *This work was supported by DOE OFES.*

Poster

Theory and Feasible Experiments on D-^{3}He and D-D Burning Plasmas*

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The physics of D-^{3}He and D-D plasmas in which the heating due to the emitted charged particles is prevalent differs considerably from that of D-T burning plasmas for instance for the larger role that energy loss by radiation plays, the lower degrees of collisionality of the involved plasmas, etc. In fact, the features of several important phenomena known from present day experiments with higher degrees of collisionalty cannot be predicted with reasonable reliability. These include magnetic reconnection and spontaneous rotation.

Therefore, in view of the attractive features of D-^{3}He and D-D reactors it is appropriate to devise experiments that can produce and investigate the burning conditions of the relevant plasmas. A set of parameters for the high field Candor experiment designed to operate at peak temperatures around 40 keV with peak electron densities around 2×10^{15} cm^{-3} is proposed. This temperature is chosen to be above that corresponding to the ideal ignition conditions for inhomogeneous D-^{3}He and D-D plasmas.

An important incentive to undertake these investigations is the recent realization that hybrid high fields magnets can be fabricated using two superconducting components: MgB_2 for the "low" field ($\lesssim$ 100 kG) outer part and a high temperature superconductor for the high field inner part. For the inner part of the toroidal magnet a helical configuration of the type proposed originally in Ref. 1 can be envisioned. The main function of this is to contribute to the magnetic flux variation needed to induce the high toroidal currents ($I_p \gtrsim$ 15 MA) that the considered experiments should be able to produce. An evident advantage of an entirely super-conducting machine relative to one like Ignitor, whose core involves copper magnets, is that the length of the pulse and the duty cycle are not limited by the heating of the coils.

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Poster preferred.

Simulation of Field Aligned Blobs in the Scrape off Layer

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Naturally occurring error fields of resonant magnetic perturbations applied for stability control are known to cause chaos at the boundary of tokamaks and stellarators. Additionally a large body of experimental and theoretical evidence has shown that particle transport in the SOL is dominated by the convection of long-lived, rapidly propagating, field aligned plasma filaments often called blobs. We use the BOUT++ code to investigate how resonant magnetic perturbations in the boundary between closed and open flux surfaces change macroscopic observable such as the SOL width. We use a Poincare field-line mapping as a simple computationally method to introduce 3D effects into what is otherwise a series of 2D nonlinear simulations. The field-line map introduces the effect of field-line chaos on the connection length in the outer portions of the pedestal and the SOL. We report on the division of the particle flux into that from the random small-scale fluctuations and that from the coherent blobs that propagate with density enhancements outward and density depletions into the core plasma. Correlations functions are used to quantify mean blob parameters, and PDF's of blob sizes and velocities are computed. The net outward flux is decomposed into that due to turbulence and blobs or coherent structure transport. Variation of experimentally relevant quantities such as the SOL gradient length scale L_n and intermittency of the particle flux $\langle n_e V_r \rangle$ in the SOL are reported as a function of the strength of the magnetic perturbation. Attempts are made to compare the results with experimental observations data on blobs.

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<u>Poster Session Requested</u>

Effect of parallel electron thermal conduction on resistive drift and tearing modes in non-uniform RFP plasmas*

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The simultaneous presence of linear drift-like and tearing instabilities is studied using both two-fluid extended modeling with NIMROD and analytical methods [1]. The primary motivation for these studies is to understand the residual electrostatic transport thought to be present in MST experiments when PPCD techniques are used to reduce tearing mode activity. Linear numerical simulations were performed for plasma slab with cold ions and hot electrons in a doubly periodic box bounded by two perfectly conducting walls. Within this model, configurations with magnetic shear are unstable to current-driven drift-tearing instability. Additionally, there is an unstable pressure-gradient driven mode that is largely electrostatic in nature and is suggestive of a resistive-drift type instability. An analytical model was developed that includes physics of electron-ion decoupling on short scales as well as the effect of diamagnetic flows caused by non-uniform electron pressure profile. The model confirms the coexistence of drift-tearing and resistive-drift modes. Previous analytical studies were performed in the limiting case of infinitively large parallel electron heat conduction. We report now on a more realistic model with large but finite parallel electron thermal conduction. In this case, electron diamagnetic frequency is determined by electron temperature and plasma density gradients on the mode rational surface ($k_{\parallel}=0$) and by plasma density gradient outside of this surface. Preliminary analytical results confirm some reduction of the drift-tearing mode growth rate (consistent with Ref.[2]) but show relative insensitivity of the drift modes to cross-field variations of the electron diamagnetic frequency. Results of NIMROD simulations for different regimes of the electron thermal conduction are reported as well.

*The work is supported by the U. S. DOE and NSF

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Poster

New Features of the Quasi Coherent Mode and Novel Theoretical Model*

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Recent experiments [1] have brought to light of the so-called Quasi Coherent Mode (QCM) that is observed when a special physical regime involving well confined plasmas is generated. This regime is referred to as EDA H-Regime and has been systematically produced by Alcator C-Mod machine. In particular, this mode has been found to: 1) have a phase velocity in the electron diamagnetic velocity both in the laboratory and the plasma reference frames, 2) involve relatively high electron temperature fluctuations, 3) be highly localized radially at the outer edge of the plasma column and extending beyond the Last Closed Magnetic Surface (LCMS).

Therefore, we have developed a novel theoretical model for which: i) the mode driving factors are the plasma resistivity and the local sharp plasma pressure gradient that develops when the plasma enters the EDA H-Regime, ii) taking into account that the rotation transformation $\iota(\psi) = 1/q(\psi) = 0$ on the LCMS, a new kind of mode topology has to be identified, as the "disconnected mode approximation" [2] cannot be applied. This approximation was introduced originally with the collisionless trapped electron mode [3] and applied to ideal MHD ballooning modes [2] excited within the main body of the plasma column where $dq/d\psi$ is finite, iii) the mode localization in the poloidal direction (ballooning) is related to the limited region around the equatorial plane where the pitch of the magnetic field is about constant [4].

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Poster Preferred.

Surface Currents during a Major Disruption

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The surface current on the plasma-vacuum interface during a disruption event involving a kink instability can play an important role in driving current (Halo or Hiro current[1]) into the vacuum vessel. We revisit theoretical calculations of this surface current in recent work[1-3], replacing the idealized step-function background plasma profile with a more realistic profile characterized by strong but finite gradient along the radial direction. Consequently, the resulting "surface current" is no longer a delta-function current density, but a finite and smooth current density profile with internal structure, concentrated within the region with strong plasma pressure gradient. Moreover, this current density profile has peaks of both signs, unlike the delta-function case with a sign opposite to[1-2], or the same as the plasma current[3]. Therefore, the calculation of the halo or Hiro current based on a step-function background plasma profile can also be qualitatively different from that using a more realistic profile. We will compare our analytic results with previous work carried out with delta-function current density profiles, as well as simulation data.

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Poster

Unitary Highly Parallelized Algorithms for Nonlinear Systems

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A unitary qubit algorithm has been developed for the solution of the 3D nonlinear Schrodinger equation (NLS) that shows ideal parallelization to over 750,000 cores. In particular, for the 1D NLS

$$i\,\partial\psi / \partial t \;=\; -\,\partial^2\psi / \partial x^2 \;+ |\psi|^2\,\psi$$

it consists of the following unitary operators (in 1D) on the qubit amplitudes α, β :

$$\begin{pmatrix} \alpha(x,t+\delta t) \\ \beta(x,t+\delta t) \end{pmatrix} = \hat{I}^2_{x\alpha} Exp\left[-\frac{i\varepsilon^2\Omega(x)}{2}\right].\hat{I}^2_{x\beta} Exp\left[-\frac{i\varepsilon^2\Omega(x)}{2}\right].\begin{pmatrix} \alpha(x,t) \\ \beta(x,t) \end{pmatrix}$$

where the interleaved collide (C)-stream (S) operators $\hat{I}_{x\alpha} = \hat{S}_{-\Delta x,\alpha}\hat{C}\;\hat{S}_{\Delta x,\alpha}\hat{C}$. $\hat{S}_{\Delta x,\alpha}$ is a shift of the amplitude α at x to lattice site $x+\Delta x$, while the unitary collision operator $\hat{C}$ is the $\sqrt{SWAP}$:

$$\hat{C} = \frac{1}{2}\begin{pmatrix} 1-i & 1+i \\ 1+i & 1-i \end{pmatrix} \text{ , so called because } \hat{C}^2\begin{pmatrix} \alpha \\ \beta \end{pmatrix} = \begin{pmatrix} \beta \\ \alpha \end{pmatrix}.$$

To recover the nonlinear term in the NLS, one chooses the phase factor $\Omega(x) = |\psi(x)|^2$ and the moments of the mesoscopic qubit representation $\alpha(x)+\beta(x)=\psi(x)$. This algorithm has been benchmarked against exact analytic solutions in both scalar and vector soliton collisions.

Recently, Yepez [1] has developed a quantum lattice gas model for the 1D Dirac particle (mass *m)* which treats exactly the spatial dependence by a single collide-stream unitary operator set $U_S U_C$ where *m* is the mass of the Dirac particle and γ is the usual relativistic factor:

$$U_C = \begin{pmatrix} \sqrt{\gamma^2 - \sin^2(\gamma m)} & -i e^{-im\sqrt{\gamma^2-1}}\sin(\gamma m) \\ -i e^{+im\sqrt{\gamma^2-1}}\sin(\gamma m) & \sqrt{\gamma^2 - \sin^2(\gamma m)} \end{pmatrix}$$

In the non-relativistic limit one can recover the quantum harmonic oscillator for the Schrodinger equation by choosing the particle mass $m \to m[x] \equiv m + \kappa x^2/2$, and $\gamma \to 1$.

The computational intensity of this single collide-stream algorithm is very significantly reduced from that of our earlier multi-collide-stream qubit algorithm. This will then permit a higher order Trotter decomposition of the exponential non-commuting operators [2] and still leave the computational intensity well below our previous algorithm. The accuracy of the two unitary methods witl be contrasted both for the simple harmonic oscillator as well as the 1D NLS soliton collisions.

Work supported by AFOR and NSF.

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[poster presentation]

Intrinsically Quasineutral Formalism for Electromagnetic Plasma Dynamics*

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The assumption of charge neutrality is a very good approximation for a large class of plasma phenomena, with the practical advantage of eliminating the high-frequency plasma waves. It is widely used, but its actual implementation takes different forms depending on a variety of theoretical approaches. This has even caused controversies in some cases. The present work proposes a clear-cut handling of this issue, advocating a system of plasma and electromagnetic field equations where the quasineutrality condition is built-in and satisfied automatically. This is a hybrid fluid-kinetic, fully electromagnetic system, where the ion densities and flow velocities are determined by fluid continuity and momentum conservation equations and the electron density and flow velocity are related algebraically to the ion variables by virtue of quasineutrality. The electric field is determined completely by the electron momentum conservation equation (which is not needed to get the electron flow velocity), the magnetic field is determined by Faraday's law, the electric current is determined by Ampere's law and the electron continuity equation is an identity because the divergence of such current is always zero. The kinetic part of the system determines the closure terms in the fluid equations, which are the pressure tensors and the collisional friction forces. These moments of the distribution functions are weighed by the random particle velocity in the reference frame of the fluid velocity of the species under consideration. Accordingly, the kinetic equations for the distribution functions are expressed in such non-inertial moving frames and, in them, the electric field is eliminated algebraically using the momentum conservation equation of the considered species. This results in kinetic equations whose solutions have the desired properties that their density moments satisfy identically the quasineutrality condition without the need to impose any additional constraint and their random velocity moments are identically zero. This intrinsically quasineutral formalism has been successfully applied to a description of macroscopic physics with length scales larger than the gyroradii in low-collisionality, magnetized plasmas. As special limits, it has been shown to yield the results of kinetic-MHD and of the neoclassical banana regime.

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A churning mode and plasma convection in the vicinity of the poloidal field null*

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A churning mode is a mode of a toroidally-symmetric plasma convection in the vicinity of the poloidal field null [1]. It is driven by the toroidal curvature coupled with the pressure gradient. The toroidal equilibrium conditions cannot be easily satisfied in the virtual absence of the poloidal field – whence the onset of this mode, which "churns" the plasma around the poloidal field null without perturbing a strong toroidal field. We find the conditions under which this mode can be excited in magnetic configurations with first- second- and third-order PF nulls (i.e., in the geometry of standard, snowflake and cloverleaf divertors). The size of the affected zone in second-and third-order null divertors is much larger than in a standard divertor. The proposed phenomenological theory allows one to evaluate observable characteristics of the mode, in particular the frequency and amplitude of the poloidal field perturbations. The mode spreads the tokamak heat exhaust between multiple divertor legs and leads to a broadening of the plasma imprint in each leg. The mode causes a much more intense convection than the plasma drifts in the poloidal plane. A parametric analysis of the heat flux to the divertor plates is performed for large-scale fusion tokamaks and the conclusion is drawn that the presence of the churning mode may provide significant reduction of divertor heat loads.

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Poster

Helicity Conservation and Two-Fluid Relaxation Modeling for Reversed-Field Pinches*

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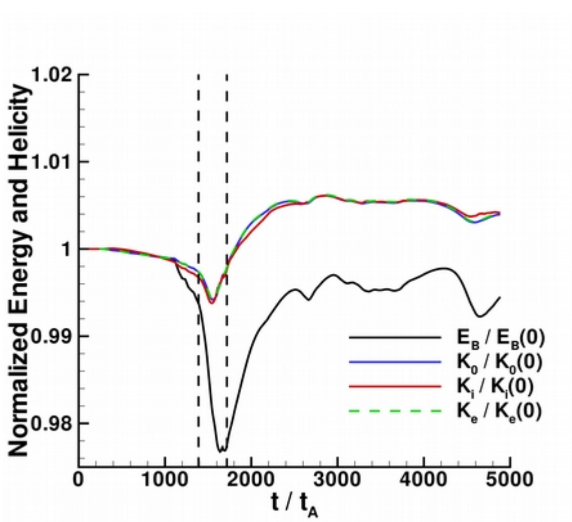
*Work supported by U.S. D.O.E.

We report on NIMROD simulations of two-fluid relaxation relevant to reversed-field pinch discharges. RFPs typically exhibit periodic relaxation events that flatten the parallel current profile. Two-fluid physics is significant on the Madison Symmetric Torus RFP and this has consequences for magnetic relaxation [Kuritsyn et. al. PoP Vol. 16 No. 055903 (2009)]. Two-fluid relaxation theories make use of generalized species helicities and predict a relaxed state with both parallel current and parallel flow spatially uniform [Hegna, PoP Vol. 5, No. 6 (1998)]. Nonlinear NIMROD simulations that include the Hall term in Ohm's law demonstrate significant parallel momeuntum transport coinciding with the current relaxation [King et. al. PoP Vol. 19 No. 055905 (2012)]. However, simulations using the experimentally observed orientation of helicty and flow display a steepening, rather than a relaxation, of the parallel flow profile as the parallel current relaxes.

We compare the results of NIMROD simulations to Hegna's theory. Our simulations at modest Lundquist number (S=20,000) show that magnetic helicity and generalized species helicities are well-conserved relative to the magnetic energy over the relaxation event, as the theory requires. (See Figure.) However, simulations show significant parallel forcing on the ions, which the theory assumes to be small. The source of the forcing and its implications for the parallel momentum evolution are discussed.



Normalized magnetic energy (solid black line) changes by ~2% over the relaxation event (denoted by vertical dashed lines) while the normalized magnetic helicity (solid blue line), ion helicity (solid red line), and electron helicity (dashed green line) change by ~0.5%.

Poster Submission

RF Models for Plasma-Surface Interactions

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Theoretical and computational models have been developed for the accurate computation of sheath potentials near metal and dielectric coated walls. We report on the verification and benchmarking of these models and their implementation in the VSim software. These models enable the physical effects of DC and RF sheath physics to be included in macroscopic-scale plasma simulations without explicitly resolving sheath scale lengths. Consequently, sheath potential and dielectric-modified sheath potential computations can be efficiently carried out and visualized in complex, experimentally relevant geometries such as plasma-facing ITER antenna surfaces. In addition, test-particle capabilities have been developed which correctly track particle passage through dielectric-modified, and conventional, sheaths. New diagnostics track particle and energy fluxes on material interfaces, for use in secondary electron and sputtering yield computations. Thus, the developed tools can be applied to the study of RF sheath-enhanced impurity production in the vicinity of antenna structures. Visualization methods for these capabilities have also been developed and will be illustrated.

POSTER

Super H-Mode: Pedestal Bifurcation to Enable High Performance*

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The EPED model [1,2] predicts the H-mode pedestal height and width based upon two fundamental and calculable constraints: 1) onset of non-local peeling-ballooning (P-B) modes at low to intermediate mode number, 2) onset of nearly local kinetic ballooning modes (KBM) at high mode number. The model calculates both constraints directly with no free or fit parameters, using ELITE to calculate the P-B constraint, and a "BCP" technique to calculate the KBM constraint [1]. EPED has been extensively compared to observed pedestal structure, finding ~20% agreement between predicted and observed pedestal height in more than 300 cases on 5 tokamaks [1–5].

For shaped tokamak plasmas, the model typically predicts a current-driven mode limited regime at low density, where the pedestal pressure increases with density, transitioning to a predominantly pressure-driven mode limited regime at high density, where pedestal pressure decreases weakly with density. In very strongly shaped plasmas, a bifurcation can occur above a critical density, with a "Super H-Mode" branch at very high pressure, enabling substantial increases in pedestal pressure, and potentially global fusion performance, over the H-mode branch. We present detailed predictions of the Super H-mode bifurcation, together with preliminary observations of Super H-mode on DIII-D which agree with predictions and obtain very high pedestal pressures.

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Poster presentation requested

Development and Verification Tests for Vertical Displacement Studies with NIMROD*

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Disruptions associated with vertical displacement events (VDEs) have potential for causing considerable physical damage to ITER and future tokamak experiments. Quantifying the induced forces and heat loads can be addressed through magnetohydrodynamic-based simulation. [For example, see Strauss, Paccagnella, and Breslau, Phys. Plasmas **17** 082505 (2010).] Here, we report on numerically implicit resistive-wall development and relevant verification tests for the NIMROD code [Sovinec, *et. al.*, J. Comput. Phys. **195**, 355 (2004)]. With the time-scale for VDE evolution being very long relative to ideal MHD evolution [Boozer, Phys. Plasmas **19**, 058101 (2012)], any numerical stability limitations from a resistive wall model would lead to inefficient use of NIMROD's implicit capabilities. An implicit thin-wall computation has, therefore, been developed to couple separate plasma and vacuum regions without numerical stability limitations. Preconditioning of the generalized minimum residuals iterative approach to solving the resulting algebraic system is accomplished region by region, and cross-region contributions to the Krylov-space matrix-vector products are found through 'matrix-free' computation. Verification testing for the resistive wall includes thin-wall diffusion between two regions of vacuum. With external kink being a significant risk during VDE [Zakharov, Phys. Plasmas **15**, 062507 (2008)], we also check the resistive wall mode (RWM) variant of the classic cylindrical external kink [Shafranov, Soviet Physics-Technical Physics **15**, 175 (1970).] Benchmarking the threshold for linear vertical instability applies the 'decay index' criterion for large aspect ratio, uniform-current toroidal equilibria [Mukhovatov and Shafranov, Nucl. Fusion **11**, 605 (1971).]

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Poster session contribution

Authors: J. Andrew Spencer, Evstati G. Evstatiev, and Jin-Soo Kim

Title: ECRH Models for Guiding-Center Orbits in Parabolic Magnetic Mirrors[1]

Abstract: It has long been known that the stochastic electron cyclotron resonance heating (ECRH) is limited by the existence of invariant curves in phase space, and at high energies a Fokker-Planck equation is inappropriate. Fully kinetic integration of electron motion is impractical for time scales of interest to experiment. Two ECRH models for use in particle-in-cell simulations that integrate the guiding-center equations of motion are considered. One is based on the impulsive heating approximation (or kick model) of Lieberman and Lichtenberg[2], while the other, which we modeled, continuously updates the particle's energy due to the wave-particle interaction. The kick model preserves the invariant curves in phase space but fails to reproduce the full kinetic simulations once the heating becomes nonstochastic. The continuous model shows good agreement with the exact, fully kinetic calculations up to long time scales of interest. The continuous guiding-center model requires slightly more computational time than the kick model, but is roughly two orders of magnitude more efficient than the fully kinetic calculations. The results of these simulations will be presented.

Poster: This will be presented as a poster.

[1]This work is supported in part by the DOE-SBIR program.

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Models for energetic particle instability and transport in general toroidal configurations

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The existence of energetic particle (EP) instabilities and the associated enhanced levels of fast ion transport have been well documented in recent years for both axisymmetrical and non-axisymmetical experiments. For current devices the main impact of these instabilities is decreased beam heating efficiency; for future devices, such as ITER and DEMO, EP-dirven turbulence can lead to high heat fluxes on plasma-facing components, decreased ignition margin, and (for reactors) economic impacts due to neutron deficiencies. The understanding and ultimate mitigation of these modes depends on developing a spectrum of models, including both first-principles approaches and lower dimensionality reduced models that can be calibrated against the more comprehensive approaches. Recent applications of the TAEFL gyrofluid model have indicated it can capture much of the required EP physics, yet provide the computational efficiency to be applied in whole discharge modeling. Recent improvements in TAEFL and applications to devices such as ITER, DIII-D, and JET will be discussed. Also, new strategies for the analysis of non-local fast ion transport, by coupling the TAEFL mode structures to the DELTA5D Monte Carlo particle orbit code, will be described. Finally, techniques for analyzing EP modes in non-axisymmetic systems, such as stellarators, RFPs, and 3D tokamaks using gyrofluid approaches have been developed.

Acknowledgement: This research has been sponsored by the US Department of Energy under Contract DE-AC05-00OR22725 with UT-Battelle, LLC.

Properties of the Gyro-kinetic Turbulence Electric Field Spectrum with Mean Field Parallel and ExB Velocity Shear *

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The time and flux surface averaged spectrum of electric potential fluctuations is studied for a large set of non-linear gyro-kinetic turbulence simulations in tokamak geometry with the GYRO code [1]. It is found that the finite toroidal mode number part of the 2-D spectrum can be well fit by a simple Lorentzian shape with fitting parameters that are only weakly dependent on the plasma conditions. In the presence of mean field velocity shear, the potential spectrum for finite toroidal mode number fluctuations becomes asymmetric in the radial wavenumber space. This is true for both mean field parallel velocity shear and shear in the mean field ExB Doppler shift. The spectral shift however has different properties for the two mechanisms. The parallel velocity shear causes a shift but not a reduction in the peak value of the spectrum. The ExB shear reduces the peak of the potential spectrum by an amount that depends upon the radial wavenumber shift. Hence only the shear in the ExB Doppler shift, which breaks the radial parity of the flux tube, causes transport suppression. These two different behaviors can be reproduced with a simple model of the saturation mechanism. The shifted potential spectra are shown to have a form that depends only on the shift and not directly on the plasma parameters. The verification of this "spectral shift" model [2] for a large number of cases is presented. The zonal flows (axisymmetric radial electric field fluctuations) are shown to be topologically distinct from the mean field in a flux tube simulation. Only the mean field ExB velocity can break the radial parity of the flux tube and cause net momentum transport. The turbulence driven zonal flows have a symmetric spectrum in the radial wavenumber even when the finite toroidal wavenumber spectrum is not. It is found that the zonal electric field energy is a decreasing fraction of the total turbulent electric field energy as the mean field ExB velocity shear is increased. It is also found that the intermittency of the fluctuation intensity is reduced by ExB velocity shear.

*This work supported in part by the U.S. Department of Energy under DE-FG03-95ER54309.

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Poster session requested

Gyrokinetic simulation of the tearing mode instability*

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Abstract

A recently developed split-weight perturbative particle simulation scheme for finite-β plasmas in the presence of background inhomogeneities which analytically separates the additional adiabatic response of the particles associated with the quasi-static bending of the magnetic field lines [1] has been generalized to the sheared magnetic field geometry. The new scheme has been implemented in a 2D particle-in-cell code in slab geometry with drift-kinetic electrons and gyrokinetic ions. The electrons pitch-scattering collision operator has also been implemented to study collisionless as well as collisional tearing, and drift-tearing instabilities. In this paper the results of linear simulations of tearing and drift-tearing modes for realistic mass ratio $m_i/m_e = 1837$ and different values of plasma β, electron-ion collision frequency, density and temperature gradients are presented and compared to the solution of the eigenvalue equation [2].

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Form of presentation requested: **Poster**

Presentation Type: **Theory/Computation**

* Research supported by the U. S. Department of Energy.

Implicit δf Lorentz Ion Orbit Averaging and Sub-Cycling

Benjamin Sturdevant and Scott E. Parker

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A second order implicit Lorentz ion drift/gyrokinetic electron model has been developed to study low-frequency quasi-neutral plasmas[1,2]. However, in the presence of a strong guide field the ion gyro-frequency can limit the applicability of such a model. For example, in the tokamak edge region, gradient scale lengths are short and a full Lorentz ion model may be a viable alternative to gyrokinetics, but is limited due to the time step required to fully resolve the ion gyromotion. Utilizing both orbit averaging and sub-cycling along with GPU acceleration may allow utilization of the Lorentz ion model in well-magnetized low-frequency applications. Sub-cycling and orbit averaging techniques are both based on advancing particles over several micro time steps for each macro time step over which the fields are advanced. The two methods differ in that sub-cycling uses only the most current particle data to provide information on the sources for the field equations, whereas orbit averaging uses temporally averaged source data. Both methods are well-suited for the use of GPUs to accelerate the particle advances. Orbit averaging has also been shown to reduce the number of particles needed for accurate simulations, leading to a savings in computational cost. The aim of this research is to develop numerically stable and accurate sub-cycled and orbit averaged schemes which can be used in an implicit, fully electromagnetic delta-f code. Optimal uses of GPUs will also be explored to reduce the wall time of our simulations. An orbit averaged delta-f implementation, using a simplified field model, has been shown to successfully simulate finite Larmor radius (FLR) effects on ion acoustic waves for macro time steps much larger than cyclotron time scales. Further work will be done to determine optimal numerical parameters for the method, in particular, the ratio of macro to micro time step sizes, and tests will also be performed to simulate nonlinear effects on Landau damping. Modifications of the method will be explored for the inclusion of a fully electromagnetic field model along with additional considerations which arise due to the method being implicit.

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Poster

Studying changes in electron temperature fluctuations across the ohmic confinement transition using nonlinear gyrokinetic simulation

C. Sung, A. E. White, N. T. Howard, D. Mikkelsen[1], J. Rice, M. Reinke, C. Gao, P. Ennever, M. Porkolab, R. Churchill, C. Theiler J. Walk, J. Hughes, A. Hubbard, M. Greenwald and C-Mod team

PSFC, MIT, [1]PPPL

Despite years of research, the physics responsible for the ohmic confinement transition, from LOC to SOC, remains a mystery. Although it has been proposed that this transition arises when the plasmas changes from Trapped Electron Mode (TEM) dominant in the LOC regime to Ion Temperature Gradient (ITG) dominant in the SOC regime, experimental and simulation evidences supporting this hypothesis are often conflicting. On Alcator C-Mod, a new Correlation Electron Cyclotron Emission (CECE) system was used to measure changes of local electron temperature fluctuations in the near-edge region (r/a~0.85) across the ohmic confinement transition. The CECE measurements show a decrease in the relative electron temperature fluctuation level across the transition from LOC to SOC, which would be consistent with a shift from TEM to ITG dominant turbulence. To better interpret the changes in turbulence and transport across the LOC/SOC transition, extensive non-linear gyrokinetic simulations (GYRO) were performed to compare with experiment. These simulations, coupled with recent upgrades to GYRO's [Holland *et al*. PoP - 2009] CECE synthetic diagnostic, allow for a thorough validation of the gyrokinetic model at the near-edge. We will present and discuss the results of this validation study, which include an extensive sensitivity study and comparisons with experimental heat fluxes and temperature fluctuation levels.

Poster Session

Plasma dielectric response in inhomogeneous magnetic field near electron cyclotron resonance*

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Abstract

Conductivity kernel of hot plasma in RF field in the electron cyclotron frequency range is calculated on axis in mirror magnetic configuration. The calculation is done by integrating linearized Vlasov equation along the unperturbed particle orbits assuming the right-handed circular polarization (resonant with electrons) of RF field. This study addresses questions of RF wave propagation and absorption in magnetic configurations with inhomogeneities along magnetic field lines such as Mirror machines, Tokamaks, Stellarators, etc.

By applying the drift approximation for particle orbits the integration over the phase angle in velocity space is done analytically and the calculation of the kernel at each point is reduced to 2-D integration in velocity space and to integration in time. These calculations are still numerically intensive such that getting result with a good accuracy required runs on NERSC supercomputer.

When the test point is located far from the resonance point the conductivity kernel is a function localized near the test point with range in the parallel direction limited by a few v_T/ω . This localization is due to the phase mixing in the velocity and time integrals. In this case the inhomogeneity of the magnetic field only slightly modifies the plasma conductivity kernel when compared with the kernel of plasma in homogeneous magnetic field. When the test point is located not far from the point of the electron cyclotron resonance, the conductivity kernel is localized not only near the test point but also it has a second peak at the location of the resonance. This second peak is due to contributions from particles crossing the cyclotron resonance where the phase mixing is suppressed. Thus in this case the plasma spatial response (spatial dispersion) is additionally widened by the distance from the test point to the cyclotron resonance point. Such double peaked structure of the conductivity kernel is recovered in the accurate kinetic model of plasma response.

This novel property of the plasma conductivity kernel near the cyclotron resonance in inhomogeneous magnetic field could change the predictions for waves dispersion based on more simple models of hot plasma. Results of simulations of propagation and absorption of right-handed wave launched in the Mirror magnetic field in our model will be presented.

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Stabilization of the Vertical Instability by Non-axisymmetric Coils*

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In a published Physical Review Letter [1], it was shown that one can improve axisymmetric stability by placing a set of parallelogram coils above and below the plasma oriented at an angle to the constant toroidal planes. The physics of this stabilization can be understood as providing an effective additional positive stability index. The original work was based on a simplified model of a straight tokamak and is not clearly applicable to a finite aspect ratio, strongly shaped plasma such as in DIII-D. It is also well known that the plasma response can be quite large, either amplifying or suppressing the vacuum fields, and even possibly reversing the vacuum fields. Taking account of these effects in an analytic extension to the model is quite impractical. Thus, to treat these properly, a numerical approach is clearly needed. Numerical calculations were performed to provide a proof of principal that 3-D fields can, in fact raise the elongation limits as predicted. A four field period trapezium shaped coil set was developed in toroidal geometry and 3-D equilibria were computed using VMEC for DIII-D with these coils specified, and trapezium coil currents of 10 kA, 100 kA, and 500 kA. The growth rates were computed as a function of the conformal wall position with TERPSICHORE for the $n = 0$ family symmetry-preserving family, (*i.e.* $n = 4k$, for $k = 0, \pm 1, \pm 2, \pm 3, ...$). The results show an insignificant improvement in the stabilizing wall location for the lower coil current cases, of the order of 10^{-3} and less. In contrast, the marginal wall position is increased by 7% as the coil current is increased to $500\,\mathrm{kA}$. The results fully confirm the main prediction from the original study in Ref. 1 in a real geometry case. While the effect is relatively small for coil currents below 100 kA, there is a significant change in the stability between the 100 kA and 500 kA cases. In DIII-D the shift in marginal wall position of 7% would correspond to being able to move the current wall outward by 5 to 10 cm. While the predicted effect on the axisymmetric stability is real, it appears to require higher coil currents than could be provided in an upgrade to existing facilities. Additional optimization over parameters such as the pitch of the coils, the number of field periods, the internal inductivity ℓ_i, plasma β, q_{95}, and the presence or absence of negative central shear, would mitigate this.

*This work supported in part by the General Atomics Internal Research & Development funding and the U.S. Department of Energy under DE-FG02-95ER54309, and DE-AC02-09CH11466.

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Poster presentation requested

Non-spectral Landau-fluid model for non-collisional and weakly collisional parallel electron transport*

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Abstract

The Landau-fluid model [1] allows an approximate representation of parallel electron kinetics within the familiar framework of fluid equations. The closure of the fluid moment equations requires the calculation of fluxes that can be expressed as non-local spatial integral operators. The key component for construction of the closure operators is the sgn(k)=k/|k| operator, where k is the parallel wave number in Fourier space. Thus, implementation of these operators is natural for calculations with a spectral code but nontrivial for a configuration-space-based code. Recently, an efficient non-spectral method for non-local closure operators was proposed and numerically implemented [2]. In the present work, following the approach in [3,4], we generalize the non-spectral non-local heat flux to include electron collisions. This results in a representation of the parallel electron dynamics that captures the physics of parallel electron heat flux ranging from the collisionless electron free-streaming regime to the collisional Spitzer parallel heat conduction regime. Comparison of the present model of the parallel electron heat flux with a rigorous solution of the kinetic equation based on moment expansion [5,6] for different collisionality regimes is presented and potential applications to boundary plasma modeling are discussed.

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APPLICATION OF X-DIVERTORS WITH COMPREHENSIVE DESIGN CONSTRAINTS IN DEMO/REACTORS

X-Divertor (XD) are designed, respecting realistic engineering constraints, for future DEMO/REACTORs using the CORSICA magnetic equilibrium code. All PF coils are located exterior to the vacuum vessel and TF coils, and each coil current is reduced to within a fraction of the plasma current. For the Korean DEMO study, both a vertical maintenance shaft and neutral beam port have been incorporated harmoniously into XD PF coil design. High triangularity has also been achieved, with $\delta > 0.6$. High flux expansion and field line flaring, quantified by the Divertor Index (DI), at the outer target plate suggest the possibility of controllable divertor detachment, dramatically reducing heat flux at the plate while maintaining core plasma integrity.

Type: Poster
Authors: Prashant Valanju, Brent Covele, Mike Kotschenreuther, Swadesh Mahajan

Non-neoclassical poloidal flow induced by micro-turbulence

W.X. Wang, S. Ethier, B. Grierson, P.H. Diamond (UCSD), T.S. Hahm (SNU, Korea), F.L. Hinton (UCSD), J. Chen, Z. Lu (UCSD)

Princeton Plasma Physics Laboratory, Princeton, NJ, USA

Recently, significant anomalous poloidal flow has been observed for both bulk ions and impurities in DIII-D experiments [1, 2]. In ITER burning plasma experiments with little toroidal momentum input, such anomalous poloidal rotation can make significant contribution to $E \times B$ flow shear, and thus strongly impact ITER confinement performance. Typically, anomalous poloidal flow is observed in low collisionality regime with large ion temperature gradients, and scales with the inverse of ion collisionality. Nonlinear gyrokinetic simulations of DIII-D experiments have been carried out to elucidate underlying mechanisms for driving anomalous poloidal flow. Simulation studies with the GTS code include self-consistent neoclassical physics, allowing us to access comprehensive physics of both driver and damping in determining the poloidal flow. It is found that ITG turbulence, while producing experimentally relevant heat transport, can also drive a significant poloidal Reynolds stress in the core region where significant anomalous poloidal flow is observed. The divergence of the Reynolds stress produces a proper torque needed for driving the observed anomalous poloidal flow in the right direction. Specifically, by balancing with the magnetic-pumping-induced viscous damping, the turbulence-generated torque can drive a stationary poloidal flow consistent with the level of observed anomalous poloidal flow in ion collision time scale. Moreover, the fluctuation-induced poloidal Reynolds stress profile shows weak dependence on the ion collisionality in low collisionality regime due to time scale separation between turbulence and collisional zonal flow damping. This result suggests that the observed collisionality scaling of anomalous poloidal flow may result from the viscous damping. Finally, close coupling may exist between poloidal and toroidal flow via strong correlation between poloidal and toroidal Reynolds stress. Work supported by U.S. DOE Contract DE-AC02-09-CH11466. [1] B. A. Grierson et al., Nuclear Fusion 53, 063010 (2013). [2] C. Chrystal, "Testing neoclassical and turbulent effects on poloidal rotation in the core of DIII-D", invited talk, 55th Annual Meeting of the APS Division of Plasma Physics Nov. 11-15, 2013, Denver, Colorado.

Poster

The Effect of Magnetic Fields to the Divertor Sheath

Ying Wang, Xianzhu Tang, Gian Luca Delzanno

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The magnetized sheath plays an important role in the plasma-material interaction near the divertor plates of a tokamak. Plasma induced erosion can seriously limit the wall lifetime. Impurities are released from the wall to the core plasma via physical or chemical sputtering from incident ions and neutrals. It is crucial that we have as correct as possible a description of the divertor sheath in which the magnetic field has only a small angle to the wall. Previous studies [1] show that the sheath dynamics is strongly affected by the three regimes of the plasma Debye length, electron and ion thermal Larmor radii. The ion energy and angular distributions respond to the magnetic field differently for different regimes. In this work, we will present our effort to study the effect of the magnetic field to the divertor sheath through a sheath model based on the Braginskii equations[2]. The discussions will be made in different regimes of the Debye length and the electron and ion Larmor radii. A fluid model of neutrals will be proposed for a collisional, magnetized plasma. The effect of neutrals to the sheath profile will be discussed.

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Nonlinear Generation of Zonal Structures by Toroidal Alfvén Eigenmodes in Gyrokinetic Simulations

Zhixuan Wang[1], Zhihong Lin[1], Wenjun Deng[2], Ihor Holod[1]
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2 Princeton Plasma Physics Lab, Princeton, NJ

It is well-known that zonal electric fields, and corresponding zonal flows, play important roles in the microscopic drift-wave-type turbulences because of its self-regulatory effects. On the other hand, zonal magnetic fields have not been observed in experiment until recently [1]. The zonal magnetic fields may be important for understanding nonlinear dynamics of energetic-particle-driven toroidal Alfvén eigenmodes (TAE), which is crucial among Alfén wave instabilities in fusion plasmas. In theory, Chen showed that zonal magnetic fields would be spontaneously excited by TAEs [2]. But in simulations, Todo only observed zonal structures driven by nonlinear coupling [3].

Gyrokinetic Toroidal Code (GTC) simulation is the first global gyrokinetic simulation to show the self-regulatory effects of zonal flows excited by drift wave turbulence [4]. Then it has been extensively used for numerous studies on interactions between zonal flows and electrostatic turbulence [5,6]. Recently, GTC electromagnetic simulation, treating both EP and thermal plasmas non-perturbatively, have been verified [7] together with two other codes (GYRO and TAEFL) for the reversed shear Alfven eigenmode in the DIII-D experiment (shot # 142111). Some nonlinear studies on the beta-induced Alfvén eigenmode has also been carried out with GTC [8].

In the current work, GTC linear simulation of TAE in this DIII-D discharge agrees well with experimental results. Further simulation result on another DIII-D discharge shows that the EP profile is the main factor deciding whether TAE or RSAE is the dominant instability in the system. Nonlinear simulation recovers Todo's result that zonal fields (electrostatic fields and magnetic fields) can only be driven by TAE nonlinear coupling, but not by TAE spontaneous excitation. Besides that, GTC nonlinear simulations also cover the studies of the nonlinear saturation mechanism, EP profile flattening (EP radial transport) etc. We also observed some nonlinear bifurcation of TAE frequency in our GTC simulation.

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Poster session

FULL PARTICLE ORBIT CALCULATION IN TOROIDAL PLASMAS BASED ON BORIS SCHEME

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Institute for Fusion Theory and Simulation, Zhejiang University

When studying particle dynamics in high frequency electromagnetic waves, such as LHW heating, it is important to integrate full particle orbit accurately to long time scale in Tokamak. Here we derived a formulation under magnetic coordinate based on the Boris Scheme, which can be used effectively to push particles to long time scale. After several hundred gyro-periods, the banana orbit can be observed and the toroidal precession frequency can be measured. The toroidal precession frequency is found to match that from the guiding center simulation. This new method shows better numeric properties than the Runge-Kutta method in terms of conserving particle energy and magnetic moment.

Poster

Representation of an Ideal Magnetohydrodynamic Equilibrium in a Toroidal Domain Near a Magnetic Axis

Harold Weitzner

Courant Institute of Mathematical Sciences

New York University

In a paper submitted to Physics of Plasmas, " Ideal magnetohydrodynamic equilibrium in a non-symmetric topological torus", a variant characterization of the equilibrium relations was developed and applied to study the possibility of low shear equilibrium in a topological torus. It was shown that a formal expansion of the equilibrium in the amplitude of the magnetic field harmonics could be carried to all orders. The magnetic field components could be chosen so that the magnetic resonances, which are present, do not destroy the equilibrium or lead to singularities or surface currents. This process explicitly excluded a region near the magnetic axis. The same representation is used to study the region near a magnetic axis. An expansion is carried out in the distance from the axis. Axes which are either circular or non-circular are considered.

Poster

Multi-channel transport studies in Alcator C-Mod Plasmas: probing the role of ITG/TEM stability crossing in rotation reversals

A. **E. White[1], N. T. Howard[2], M. L. Reinke[3], M. Greenwald[1], C. Sung[1], J. Rice[1], and the Alcator C-Mod Team**

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[3]Univeristy of York, UK

Understanding the coupling of electron, impurity particle, and momentum transport channels is critical for understanding and predicting the performance of ITER, which will feature intrinsically rotating, self-heated plasmas. Gyrokinetic analysis of C-Mod L-mode plasmas with Ohmic and RF heating, show that hollowing of rotation profiles at lower density (rotation reversal) is also not correlated with changes in the dominant turbulence drive from ITG to TEM. In the RF heated plasmas, there is no change of the critical gradient in a/L_{Ti} across the rotation reversal. Sensitivity scans have been conducted in $a/L_{Te,}$ $a/L_{ne,}$ and collisionality to probe the nature of the turbulence. This helps to better understand the limits of identifying the turbulence as dominantly ITG or TEM, and to probe how crossing the boundary between the two types of turbulence impacts the multi-channel transport. Results from linear and nonlinear GYRO simulations of a variety of C-Mod plasmas will be presented.

Poster preferred.

Action principles for reduced fluid models

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Abstract

Fluid models are ubiquitous in the study of plasmas. It is desirable that such fluid models be Hamiltonian in nature, but this property is often lost in the process of deriving them. One way to ensure the Hamiltonian nature of such models is to derive them from action principles, i.e, start from a Hamiltonian parent-model action and make all the approximations and manipulations directly in the action (e.g., [1,2]). In this paper, we derive two well-known fluid models (two-fluid theory and the Lüst equations [3]) from purely Lagrangian methods. We start by giving a brief description of the Lagrangian viewpoint of fluid dynamics and the Euler-Lagrange maps that relate it to the Eulerian one. We proceed by defining an action based on the ion and electron trajectories and finding the resulting equations of motion after variation. Then, we use the Euler-Lagrange map to recover the Eulerian form of the models. In order to obtain Lüst's model, we show that we need to define new variables to express the two-fluid action and to construct non-local Euler-Lagrange maps to recover the correct equations of motion. We enforce quasineutrality and we show that we would need an implicit definition of the new variables in order to drop it.

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POSTER

Potpourri

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Constrained MHD stability. T. ANDREUSSI, F. PEGORARO, *Pisa, Italy* – Following up on previous work [Phys. Plasmas **19**, 052102 (2012); **20**, 092104 (2013)] we present examples of MHD equilibria for which we compare/contrast Lagrangian, Eulerian, and Dynamically Accessible stability. These kinds of stability differ by the constraints employed. Such constraints will be discussed, along with examples ranging from simple convective instability to MRI configurations with flow.

Mock fields and helicity. Z. YOSHIDA, *Tokyo, Japan* – Ideal MHD has magnetic helicity and cross helicity as Casimir invariants of its noncanonical Hamiltonian structure. However, loop integrals such as the Kelvin circulation theorem or local magnetic flux $\oint \mathbf{A} \cdot \mathbf{dr}$ are not manifest in the noncanonical formalism. We show how to recover such loop invariants by using an early idea [PJM, Z. Naturforschung **42a**, 1115 (1987)] and appropriately introducing *mock* fields that do not affect the dynamics but carry Lagrangian information. The construction is general and a series of examples will be given.

Dirac brackets for model construction. C. CHANDRE, E. TASSI, *Marseille, France* – We show how Dirac's theory of constained dynamics can be used to obtain Hamiltonian reduced models, where chosen constraints become constants of motion. To demonstrate the method we show that the Vlasov-Poisson (VP) equations along a constant magnetic field are obtained from the Vlasov-Maxwell system. In this case Dirac's primary constraint is freezing $\mathbf{B}$, while a secondary constraint is $\nabla \times \mathbf{E}$. This corresponds to a critical case where Dirac's matrix of constraints is not invertible. Nonetheless, a novel method exists to explicitly compute the Dirac bracket without additional constraints, leading to the usual Hamiltonian formulation for VP. As another example we derive the Hamiltonian structure of the modified Hasegawa-Mima equation from the ion fluid equations. Casimir invariants, an infinite class of constants of motion, are naturally obtained for this model.

POSTER

Gyrokinetic Simulations of Energetic Electron Driven Alfven Instability*

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The confinement of energetic particles is a critical issue in ITER, since ignition relies on self-heating by the energetic α -particles. The energetic particle, including energetic ions and energetic electrons, can collectively drive shear Alfven instabilities and Energetic Particle Mode (EPM) in toroidal systems, which might induce large transport of energetic particles in burning plasmas. In this work, the linear excitation (by antenna, initial perturbations or energetic electrons) of the energetic-electron driven beta-induced Alfven eigenmode (e-BAE) have been explored through large-scale gyrokinetic simulations using the global gyrokinetic toroidal code (GTC).

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Global Geodesic Acoustic Eigenmode in Toroidal Plasmas

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Geodesic Acoustic Modes (GAM) can be generated by microturbulence, and in turn, regulate the microturbulence in tokamak edge. Since the GAM frequency is proportional to the ion sound speed, it forms a continuous spectrum in the long wavelength limit. When finite ion Larmor radius effects are taken into account, the GAM mode converts to a kinetic GAM (KGAM), which propagates radially outward. With a fixed boundary condition at the last closed flux surface, KGAM eigenmodes with discrete frequencies can form. Such an eigenmode analysis is typically based on the local dispersion relation of KGAM. However, the eigenmode theory has not been verified quantitatively using experimental data.

In a recent experiment on the HT-7 tokamak, two GAM frequencies were observed to coexist at the edge. The initial application of the eigenmode analysis using local KGAM dispersion relation fails to predict the observed frequencies. This discrepancy is believed to arise from the fact that the GAM wavelength is comparable to the scale length of the electron temperature, which invalidates the local KGAM dispersion relation.

In this work, global eigenmode analysis of KGAM has been performed in the gyrokinetic toroidal code (GTC) simulations using the experimental parameters of HT-7. GTC simulations using an artificial antenna find a radially extended KGAM eigenmode with a frequency agree very well (within 5%) with the experimental value. GTC simulations demonstrate that a global eigenmode analysis, rather than that based on the local KGAM dispersion relation, is needed to quantitatively explain the experimental measurements of the KGAM frequencies. GTC simulations of the excitation of the global KGAM eigenmodes by the microturbulence will also be presented.

Poster

NIMROD Simulations of Plasma Response to Resonant Magnetic Perturbations in DIII-D Experiments

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Abstract

Plasma response is believed to be a key element in the suppression and mitigation of edge localized modes by resonant magnetic perturbations (RMPs) in tokamak experiments. We have computed the plasma response to RMPs in DIII-D experiments #126006 and #142603 using the extended MHD models implemented in the NIMROD code. The I-coil vacuum field is imposed as the boundary condition at the tokamak wall location. Plasma responses to RMP are obtained by following the linear and nonlinear evolution of the configuration into steady state subject to the RMP boundary condition. Such a steady state can be only reached if the unstable toroidal component edge localized modes in these discharges are suppressed by physical mechanisms in the MHD model or excluded numerically from the computation. For static equilibriums, NIMROD calculations of linear plasma response to n=3 component of RMP indicate shielding effects that are likely caused by the two-fluid diamagnetic flows. Perpendicular toroidal rotation introduces moderate but less shielding of RMPs than the two-fluid effects alone. Progress on the benchmarking with other 3D codes will be discussed.

*Poster

Spontaneous excitation of convective cells by kinetic Alfv́en waves*

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Abstract

Zonal structures such as zonal flows are known to play crucial roles in dynamically regulating plasma turbulence and thereby transport in tokamak plasmas. The analogues in uniform plasma are the convective cells, which have been extensively studied in the 1970's [1, 2, 3, 4] in the context of cross-field transport [5], especially with regard to potential applications to space plasmas. In particular, it is worthwhile mentioning the extensive studies of convective cells excitation by kinetic Alfvén waves (KAW) in the context of generation of turbulence flows in the upper ionosphere [6, 7].

Previous theoretical analyses often rely on two limiting assumptions: (i) neglecting the finite ion Larmor radius (FLR) corrections to the Reynolds stress; (ii) decoupling between the electrostatic (ESCC, described by $\delta\phi_z$ only) and the magnetostatic (MSCC, described by $\delta A_{\parallel z}$ only) convective cells. Both assumptions, as will be shown in this work, could lead to erroneous conclusions on the spontaneous excitation of convective cells by KAW (See, *e.g.*, the recent analysis and summary of previous literatures on this topic given by [8]).

In this work, we derive the generating equations for ESCC and MSCC and demonstrate that, generally, they are excited by KAW simultaneously. Artificially suppressing MSCC yields the incorrect ESCC dispersion relation, but still the correct qualitative conclusion that ESCC are not spontaneously excited by KAW in the long wavelength limit. However, the analogous assumption that ESCC is suppressed delivers the erroneous MSCC dispersion relation as well as erroneous claim that MSCC can be spontaneously excited by KAW in the long wavelength limit. The general case of coupled ESCC and MSCC is discussed for arbitrary wavelengths.

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