The Third IAEA Technical Meeting (IAEA-TM) on the Theory of Plasma Instabilities will take place from 26 March to 28 March 2007 at the University of York in the U.K.; it will focus on the confinement and stability of burning plasmas. The meeting will be hosted by the Plasma Physics Group in the Department of Physics. After a kick-off meeting in 1999, previous meetings in this series were held at Kloster Seeon in 2002, and at Trieste in 2005.

**Objectives**

The Third IAEA-TM on Theory of Plasma Instabilities will provide a forum for open discussion on theoretical and computational physics issues of relevance to burning plasmas. The meeting will cover linear and non-linear theory of large and small scale plasma instabilities, including turbulence, magneto-hydrodynamic (MHD) effects and integrated modelling. All physics issues of relevance to the performance of burning plasma devices will be covered, but special attention will be paid to the modelling and prediction of instabilities generated by fast alpha particles and their role in the plasma confinement. This subject is of significant importance for the ITER project and for the performance of future fusion power plants. The meeting will aim to identify directions for future fusion research in preparation for ITER and fusion power plants.

**Topics**
(1) Overview

- State of the art, and needs for ITER and fusion power

(2) Improved Performance

- Comparison between turbulence/stability calculations and experiments
- New theoretical paradigms including statistical approaches
- Transport barrier dynamics including pedestal formation
- Active control of transport barriers in future devices
- Control of plasma instabilities (ELMs, NTMs, etc)

(3) Turbulence and Nonlinear Instabilities

- Direct numerical simulations and analytic theories elucidating turbulence saturation and transport mechanisms
- Nonlinear theory of meso-scale self-organized structures (zonal flows, streamers, ...)

(4) Energetic Particle Physics

- Alpha particle induced collective instabilities
- Nonlinear theory/simulation of Alfvénic instabilities
- Energetic particle effects on MHD instabilities (eg sawteeth, NTMs, ELMs)
- Relation between radial electric field and energetic particle dynamics

(5) Interaction of Macroscopic Instabilities and Transport Process

- Recent progress on neoclassical tearing mode physics
- Theories on ELM dynamics, ELM classification
- Theories on disruptions and resistive wall modes,
- Physics basis for integrated modelling

Comments and corrections are welcome -- please email Local Organiser Roddy Vann. A disclaimer applies to the entirety of this site.
INVITED ABSTRACTS
Status of Gyrokinetic Transport Modeling for ITER\textsuperscript{1}

J. Candy\textsuperscript{a}, R.E. Waltz\textsuperscript{a} and M.R. Fahey\textsuperscript{b}

\textsuperscript{a}General Atomics, P.O. Box 85608, San Diego, CA 92186-5608
email: candy@fusion.gat.com

\textsuperscript{b}Oak Ridge National Laboratory, P.O. Box 2008, Oak Ridge, TN 37831-6016

We report on the status of gyrokinetic transport modeling relevant to ITER plasmas. This includes

- the specification of reference local parameters for facilitation of linear and nonlinear benchmark simulations (including electromagnetic fluctuations, plasma shape and electron collisions),

- a summary of nonlinear gyrokinetic calculations (both local and global) of particle and energy transport (including helium ash) for typical scenarios,

- a brief discussion of turbulent alpha-particle transport,

- steady-state profile prediction using iterated gyrokinetic simulation with realistic thermonuclear and other sources.

The last topic refers to a project funded through the US Department of Energy's \textit{Scientific Discovery through Advanced Computing} (SciDAC) program. Results are based on linear and nonlinear GYRO\textsuperscript{2} simulations.

\textsuperscript{1}Work supported by the U.S. Department of Energy under DE-FG03-95ER54309.
\textsuperscript{2}See http://fusion.gat.com/theory/gyro
Particle simulation of edge pedestal formation and plasma rotation dynamics

C.S. Chang
Courant Institute of Mathematical Sciences, New York University, and
Department of Physics, KAIST, Korea

Gyrokinetic particle simulation of edge pedestal formation and plasma rotation dynamics will be presented, and compared with experimental observations. Realistic tokamak edge geometry is used which include separatrix/X-point and material wall from EFIT g-qdisk data. In order to handle adequately the spatially inhomogeneous electric potential in the scrape-off region, the full-f electron technique is used, in addition to the full-f ions. Monte Carlo neutral particles with wall recycling coefficient will be included self-consistently with the plasma kinetics. Ion-ion Coulomb collisions will be particle, momentum and energy conserving. Energy source for the pedestal and scrape-off plasmas is the heat flow from the core plasma, and the particle source is the ionization of the neutral atoms which are either wall recycled and/or gas puffed. The simulation will be self-consistent with the first principles nonlinear neoclassical and (electrostatic so far) turbulence interactions. Plasma ions in the pedestal and scrape-off regions are found to be non-Maxwellian. The density pedestal growth is supplied by the neutral ionization, but the pedestal shape and width are strongly influenced by the finite orbital dynamics in the self-consistently radial electric field, which shows stiff profile due to nonlinear saturation with the ion orbital dynamics. Temperature pedestal growth is supplied by the heat flow from the core and their shapes are strongly influenced by the charge exchange loss, orbit loss, ion-electron heat exchange and the radial transport. The shape of ion temperature is more deterministic than that of electrons due to uncertainty in the electron turbulence heat transport. The equilibrium radial electric field in a strong pedestal induces strong rotational shear in the plasma. Wall interaction of the plasma generates another ExB shear flow in the scrape-off plasma. Neutrals are found to be an important element in the plasma rotation dynamics. If time allows, bootstrap current evolution in with the pedestal, and the effect of magnetic ripple and ergodic field on pedestal dynamics will also be discussed.
FLUID PLASMA STABILITY IN STELLARATORS WITH ANISOTROPIC ENERGETIC SPECIES

W. A. Cooper 1, J. P. Graves 1, M. Jucker 1, K. Y. Watanabe 2, Y. Narushima 2

1 Centre de Recherches en Physique des Plasmas, EPFL, Lausanne, Switzerland
2 National Institute for Fusion Science, Toki, Japan

wilfred.cooper@epfl.ch

Abstract

The energetic ion content in typical high-β LHD discharges accounts for about 1/3 of the total β [1]. Furthermore, because the densities are relatively low ($n_e < 3 \times 10^{19} \text{m}^{-3}$), there is a measurable anisotropy in the plasma pressure [2]. Local and global fluid MHD stability in anisotropic pressure plasmas can be investigated with the Kruskal-Oberman energy principle [3] (ignoring the kinetic energy integral) and with the rigid hot particle energy principle of Johnson et al. [4]. These energy principles have been adapted in the TERPSICHERE code. A heliotron configuration that models LHD with finite parallel anisotropy driven by neutral beams with a total $\beta \simeq 3.9\%$ (unstable according to ideal MHD) shows that the Kruskal-Oberman based theory predicts stability when $\beta_h/\beta \geq 1/3$, where $\beta_h$ corresponds to the beam ion $\beta$ value. The rigid hot particle model requires $\beta_h/\beta \geq 1/4$ to obtain stability. Large perpendicular anisotropy driven by ICRH may lead to more interesting results because the MHD equilibrium properties become more highly distorted.

References

MHD and Gyro-kinetics in Plasmas Around Black Holes.
Steven Cowley, CMPD, UCLA, Los Angeles and Imperial College, London

The black hole at the center of our galaxy, Sagittarius A*, is swallowing a very hot disc of plasma. This plasma is believed to be unstable to MHD instabilities that remove angular momentum from the disc allowing the plasma to flow into the black hole. One of the puzzles about these discs is the energetics. The instabilities convert gravitational energy into turbulent motion which is then dissipated as heat. However, many discs are rather dim suggesting that the electrons are not heated enough to radiate. Thus almost all of the turbulent energy must be converted into ion heat. The plasma physics of the instabilities and the turbulence they drive is in many respects similar to tokamak turbulence. Specifically it is collisionless, highly magnetized and elongated along field lines. I will describe the instability that drives the turbulence. I will also present simulations of the turbulent heating using gyro-kinetic codes developed for fusion. These results show that only in very extreme circumstances are the ions heated more than the electrons. Finally I will discuss how this work has illuminated issues in tokamak instabilities.
In this lecture, I will survey issues in transport physics for ITER. Attention will be focused on issues which are critical to achieving and maintaining a burning plasma. Special attention will be focused on:

i.) mesoscale dynamics and the breaking of gyro-Bohm scaling,
ii.) electron thermal transport in ITB’s,
iii.) momentum transport and spontaneous rotation,
iv.) transport barrier formation and dynamics,
v.) density profiles and the inward pinch.

The talk will be theoretical in orientation, and be in the style of a forward-looking overview, rather than a conventional review.
Interaction of scrape-off layer currents with magnetohydrodynamical instabilities in tokamak plasmas

R. Fitzpatrick

Institute for Fusion Studies, University of Texas at Austin, Austin TX 78712, USA.

Unusually strong non-axisymmetric currents have recently been detected flowing in the scrape-off layer (SOL) of DIII-D discharges (H. Takahashi, E.D. Fredrickson, M.J. Schaffer, M.E. Austin, T.E. Evans, L.L. Lao, and J.G. Watkins, Nucl. Fusion 44, 1075 (2004)). These currents seem to be associated with magnetohydrodynamical (MHD) activity within the plasma. However, the exact nature of this association has yet to be established.

A simple theoretical model, which describes how current eddies can be excited in the scrape-off layer of a large aspect-ratio, low-beta circular cross-section tokamak by time-varying magnetohydrodynamical instabilities originating from within the plasma, is developed. According to the model, the response of the SOL to the varying magnetic fields associated with an MHD instability is similar to that of a thin resistive wall, except that the effective time-constant of the wall depends strongly on the helicity of the instability. Furthermore, due to sheath physics at the limiter, the magnitude of the current which can circulate in the SOL cannot exceed the so-called ion saturation current.

The model is used to study the interaction of SOL currents with tearing modes and resistive wall modes in a typical tokamak plasma. SOL currents are found to be fairly effective at braking the rotation of tearing modes, and to have a significant destabilizing effect on resistive wall modes.
The quest to understand the turbulent transport of particles, momentum and energy in magnetized plasmas remains a key challenge in fusion research. A basic issue being still relatively poorly understood is the turbulent ExB advection of charged test particles with large gyroradii. Especially the interaction of alpha particles or impurities with the background turbulence is of great interest.

In order to understand the dependence of the particle diffusivity on the interaction mechanisms between FLR effects and the special structure of a certain type of turbulence, direct numerical simulations are done in artificially created two dimensional turbulent electrostatic fields, assuming a constant magnetic field. Finite gyroradius effects are introduced using the gyrokinetic approximation which means that the gyrating particle is simply replaced by a charged ring. Starting from an idealized isotropic potential with Gaussian autocorrelation function, numerous test particle simulations are done varying both the gyroradius and the Kubo number of the potential. It is found that for Kubo numbers larger than about unity, the particle diffusivity is almost independent of the gyroradius as long as the latter does not exceed the correlation length of the electrostatic potential, whereas for small Kubo numbers the diffusivity is monotonically reduced.

The underlying physical mechanisms of this behavior are identified and an analytic approach is developed which favorably agrees with the simulation results. The investigations are extended by introducing anisotropic structures like streamers and zonal flows into the artificial potential, leading to quantitative modulations of the gyroradius dependence of the diffusion coefficient. Analytic models are used to explain these various effects.

After having developed a general overview on the behavior in simplified artificial potentials, test particle simulations in realistic turbulence created by the gyrokinetic turbulence code GENE are presented. They are compared to the previous results which enable us to understand the interaction between the wide number of effects present at the same time in realistic turbulence.
Integrated simulation of ELM crash with dynamic response of SOL-divertor plasmas

N. Hayashi, T. Takizuka, T. Ozeki, N. Aiba, N. Oyama

Japan Atomic Energy Agency, 801-1 Mukouyama, Naka, Ibaraki 311-0193, Japan

Edge localized mode (ELM) induces sometimes very large heat load to divertor plates and causes the reduction of plate lifetime. Analyses from multi-machine experiments showed that the ELM energy loss decreases with increasing the collisionality [1]. Although effects of the bootstrap current and the scrape-off-layer (SOL) transport on the ELM energy loss have been discussed, the physical understanding and quantitative evaluation are not fully accomplished so far. The integrated code is one of the effective tools to study the self-consistent ELM behavior [2]. Previous codes dealt with the ELM behavior without the dynamic response of SOL-divertor plasmas. The SOL-divertor plasmas, however, play important roles in the ELM behavior by changing the boundary condition of the pedestal transport. An appropriate SOL-divertor model is required for the integrated code. The simple point model for SOL-divertor plasmas can reproduce experimental results fairly well in a very short computation-time, and is suitable for coupling with core transport codes. From these points of view, we have developed an integrated code TOPICS-IB [3] with a dynamic five-point model [4] and a stability code for peeling-ballooning modes, MARG2D. TOPICS-IB is based on the 1.5D core transport code TOPICS extended to the integrated simulation for burning plasmas. The present five-point model can reproduce well static and dynamic features obtained by particle and fluid simulations [4]. TOPICS-IB successfully simulates a series of transient behaviors of an H-mode plasma; the pedestal growth, an ELM crash and the recovery of pedestal. At the ELM crash, the increase of SOL temperature mitigates the radial edge gradient and lowers the ELM energy loss. The collisionality dependence of the ELM energy loss was found to be caused by both the edge bootstrap current and the SOL transport. In the previous simulation, the ELM energy loss was less than 10 % of the pedestal energy because the mode structure was localized in a pedestal region with a steep pressure gradient [3]. In the present paper, we study effects of pressure profile and plasma shape. The different pressure gradient inside the pedestal top (due to the different transport model) and the different plasma shape can broaden the mode structure and enhance the ELM energy loss. The resultant ELM energy loss will be compared with that in experiments.

How well does MHD theory explain observed tokamak stability?

T C Hender
Euratom/UKAEA Fusion Association, Culham Science Centre, Abingdon, OX14 3DB, UK

This talk will review our understanding of the broad range of observed tokamak instabilities in both the ELMy H-mode and advanced scenarios - both areas of successful comparison between stability theory and experiment, and areas where further developments are needed, will be highlighted.

In some areas MHD theory provides a precise quantitative understanding of tokamak stability - for example axisymmetric stability codes replicate reality so well that they can be used in the development of vertical controllers for experimental application, and $\beta$-limit calculations are routinely used in the design of new experiments. In most other areas our level of understanding is rather more qualitative, but nevertheless provides very important insight for operational optimisation of stability boundaries. A complete understanding of sawteeth remains elusive regardless of probably being the most studied tokamak instability – the key issue of how partial reconnections occur remains to be conclusively explained. Despite this, predictions of sawtooth periods using the so-called ‘Porcelli model’ and their dependence on current drive, are quantitatively good. Disruptions are another area which has been studied for many years, but the complexity and variability of the event has made quantitative understanding impossible in most cases. In this area specific questions such as, ‘why does toroidal peaking of halo currents occur?’ are probably more amenable to quantitative progress. The study of ELMs, using linear edge stability codes, seems in good agreement with observations, though it is important to take account of separatrix effects. The focus for ELMs is now on nonlinear understanding, as this relates to the key issue of ELM heat loads on divertor and first wall surfaces. The expected main performance limiting instabilities for ITER of neoclassical tearing modes (NTMs), in the baseline ELMy H-mode scenario, and resistive wall modes (RWMs) in advanced scenarios, are presently areas of active study. The key issue for the NTM is developing a model for the small island stabilizing terms and the seeding processes. For the RWM the ‘kinetic model’ seems to be fairly successful in explaining the experimentally observed damping, but further development is probably required. So overall there has been considerable success in developing an understanding of MHD stability in the tokamak, but there remain areas, which will be important for ITER, where further progress is needed.

This work was partly supported by the UK Engineering and Physical Sciences Research Council and by the European Communities under the contract of Association between EURATOM and UKAEA. The views and opinions expressed herein do not necessarily reflect those of the European Commission. This work was partly conducted under the European Fusion Development Agreement.
Waves in shear flows exhibit highly complicated behavior in both space and time, which appears transient and asymptotically grows or decays with algebraic power of time. The decomposition into eigenmodes is generally difficult due to the presence of the continuous spectrum and the nonorthogonal property of eigenmodes of non-Hermitian operators. In particular, the degeneracy of some spectra into the continuous spectrum requires mathematically nontrivial consideration. Although one can expect the resonant interaction among the eigenmodes, the spectral resolution of the continuous spectrum is not yet understood for general non-Hermitian operators.

In this talk, we introduce a basic model which mathematically represents the degeneracy of point (i.e. discrete) and continuous spectra. This situation occurs in various hydrodynamic and magnetohydrodynamic waves. In fluid mechanics, vorticity fluctuations convected by shear flow embody a continuous spectrum, which transforms into the Doppler-shifted Alfvén continuous spectrum in the case of plasmas. The acoustic waves and the (subcritical) Kelvin-Helmholtz and interchange modes play the role of point spectra that are possible to be degenerated into the continuous spectrum. The solution of our model indicates that there are some varieties of such wave-wave interaction. Depending on the structure of the non-Hermitian operator, the wave corresponding to the point spectrum exhibits any one of (a) exponential growth, (b) the Landau damping and (c) algebraic growth and saturation. Another possibility is (d) algebraic growth of a local mode corresponding to the continuous spectrum.

It is interesting to observe these phenomena in terms of the wave energy. As in the case with many Hamiltonian systems, the exponential growth occurs if the sign of the wave energy for the point spectrum is opposite to that for the continuous spectrum. The same sign leads to the Landau damping. The case (d) occurs if the continuous spectrum has ‘zero’ energy. The case (c) is attributed to the noncanonical property of our Hamiltonian system.
Turbulent transport associated with zonal flow and GAM near critical gradient

Y. Kishimoto\textsuperscript{1)}, K. Miki\textsuperscript{1)}, N. Miyato\textsuperscript{2)}, J.Q. Li\textsuperscript{1)}, J. Anderson\textsuperscript{1)}
\textsuperscript{1)} Graduate School of Energy Science, Kyoto University, Uji, Kyoto 611-0011, Japan,
\textsuperscript{2)} Japan Atomic Energy Agency, Naka, Ibaraki-ken 311-0193, Japan
E-mail contact of main author: kishimoto@energy.kyoto-u.ac.jp

To understand the transport dynamics near critical gradient regime at which turbulent fluctuations and associated degradation of confinement are triggered is of great importance in properly optimizing plasma profiles and achieving high performance. It is known that weak perturbation significantly affects the dynamics in marginal state due to the critical nature of nonlinear system. Nonlinear up-shift of critical gradient due to the quench of unstable linear modes by zonal flows is one of typical phenomena [1]. An intermittent dynamics was observed in ITG turbulence transport near critical gradient due to the presence of micro-scale ETG driven zonal flows [2]. Recently, geodesic acoustic mode (GAM), which is a branch of zonal flows in toroidal plasmas, has been extensively studied since it significantly changes the characteristics of zonal flow and then the transport [3].

Here, as an example of critical gradient phenomena, we discuss a new type of intermittent dynamics of transport associated with the emission of geodesic acoustic mode (GAM) coupled with zonal flow generation based on global gyro-fluid ITG turbulence simulations. The intermittent bursts are triggered by the onset of spatially propagating GAMs when turbulent energy exceeds a critical value. The stationary zonal flow gradually increases over many periods of quasi-periodic intermittent burst and then turbulent fluctuation is quenched, leading to a nonlinear up-shift of the linear critical gradient, i.e. the Dimits shift [1]. The gradual increase of the zonal flow results from the accumulation of non-damped residual part in each cycle of the burst.

A minimum model including the GAM dynamics can successfully reproduce the intermittent bursts and transport quench observed in the simulation. We have also theoretically investigated the effect of zonal flow on the ITG threshold based on quasi-linear and modulational instability and found that the nonlinear up-shift of the critical gradient is proportional to \( k_{\perp}^2 - q_x^2 \phi_{ZF} \), where \( k_{\perp} \) and \( q_x \) are the wave number of turbulence and zonal flow, respectively.

Damping Rates of Global Alfvén Waves in Tokamaks

Ph. Lauber*, S. Günter*, S. da Graça †, A. Könies*,
S.D. Pinches‡, M. Brüdgam*

*Max-Planck-Institut für Plasmaphysik, EURATOM Association, Garching, Germany
†Max-Planck Institut für Plasmaphysik, EURATOM-Association, Greifswald, Germany
‡Centro de Fusão Nuclear, IST, Instituto Superior Técnico, Lisboa, Portugal

The ability to predict the stability of fast-particle-driven Alfvén eigenmodes in burning fusion plasmas requires a detailed understanding of the dissipative mechanisms that damp these modes. In order to address this question, the linear gyro-kinetic, electromagnetic code LIGKA[1] is employed to investigate their behaviour in realistic tokamak geometry. Recently, the model and the implementation of LIGKA were extended in order to capture rigorously the coupling of the shear Alfvén wave to the drift and sound waves. This coupling becomes important for the investigation of modes like the cascade modes that chirp from the geodesic-acoustic frequency up to the TAE frequency. Especially interesting in this context is the transformation of the Cascade mode into a TAE mode: non-local continuum damping and also radiative damping that depend strongly on the details of the $q$-profile, can increase the mode damping considerably at the transition point. This may explain, why the experimental mode signal as measured by magnetic pick-up coils or reflectometry often vanishes at a critical value for $q_{\text{min}}$.

Furthermore, reflectometry measurements provide information about the radial Eigenfunction structure[2]. Therefore, the gyrokinetic results can be directly compared to ASDEX-Upgrade measurements for both radial envelope and phase.

Effects of tangential neutral beam injection on the internal kink and quasi-interchange modes

*Institute for Nuclear Research, Kyiv 03680, Ukraine
**Princeton Plasma Physics Laboratory, P.O. Box 451, Princeton, New Jersey 08543

It is known since experiments on JET in 1988 that the trapped energetic ions can stabilize sawtooth oscillations [1]. More than 10 years later experiments on JT-60U have shown that the circulating particles can stabilize sawteeth, too [2].

The purpose of this work is to consider physical mechanisms responsible for the stabilization of sawtooth oscillations by the circulating energetic ions. Two cases are considered. First, when the magnetic shear in the plasma core is sufficiently large, so that $1 - q_0 \gg \varepsilon_s$ ($q_0$ the on-axis safety factor, $\varepsilon_s$ the inverse aspect ration at the $q = 1$ surface), in which case sawtooth crashes are associated with the internal kink mode. Second, a plasma with the shearless core surrounded with the region with the large shear. Such a plasma is prone to the quasi-interchange mode. The second case is typical for spherical tori and will also take place in the “hybrid” ITER operation scenario.

The work includes an overview of relevant publications on this topic [3-7] and new results.

In particular, an important role of the fast ion precession in determining the stability of both ideal and reconnecting kinks is emphasized. Because the precession of well-circulating ions is very sensitive to various factors, it is calculated numerically for a realistic geometry. In addition, a new kinetic term is found, which was missing in previous theories. This tem is stabilizing (destabilizing) for the counter- co-(injection).

For the shearless-core plasmas, margins of stability of the quasi-interchange mode in the absence of the energetic ions have been found in Refs. [8,9]. In the present work, the stability of the quasi-interchange mode in the presence of the circulating energetic ions is investigated self-consistently, without a priori assumption that the eigenfunction of the $m = 1$ radial displacement amplitude has the “top hat” structure. In this regime kinetic contribution from energetic ions is much smaller than fluid one. The latter includes stabilizing contribution to toroidal coupling between $m = 1$ and $m = 2$ poloidal harmonics and the finite-orbit-width term, which depends on the direction of injection. Efficient stabilization of the quasi-interchange mode is found for the balanced and co-injection, while the counter-injection is slightly destabilizing. It is also demonstrated that the energetic ions may considerably change the radial structure on the mode.

References

Measurements and understanding of confinement of fast particles and instabilities driven by fast particles are crucial for successful operation of next-step burning plasma machines. Energetic ion confinement and losses and energetic ion-driven instabilities were investigated in experiments on JET and on MAST with a wide range of new diagnostics, in conventional and shear-reversed plasmas, exploring a wide range of effects.

In JET experiments, renewed X-mode reflectometry, FIR interferometry, new lost ion scintillator and Faraday cups, complementary to Mirnov coils, O-mode interferometry, gamma-ray and NPA diagnostics, provide a consistent set of data on fast ion evolution in the presence of fast-ion driven instabilities. The higher quality new data on, e.g. “tornado” modes in monster sawtooth discharges and on Alfvén Cascades (ACs) in reversed-shear discharges, reveal more comprehensively and with a better time resolution the effects of fast-ion driven instabilities on fast ion losses and confinement. Higher sensitivity and better time resolution of interferometry techniques now allowing detection of ACs in JET plasmas with more than 30 MW of input power made possible to employ Alfvén spectroscopy based on ACs in such discharges. The renewed X-mode reflectometry provides now information on the AC localisation region, allowing determination of the q_min evolution in space and time and facilitating the development of ITB scenarios. Alfvén spectroscopy aiming at kinetic information on electron and ion pressures, as well as the use of sub-Alfvénic NBI for exciting ACs is reviewed.

TAEs, ACs, high-frequency modes, and chirping modes are excited by super-Alfvénic NBI in MAST discharges. The super-Alfvénic NBI makes MAST a good test bed for testing diagnostics for Alfvén instabilities. MAST is now equipped with magnetic coils with frequency range up to 5 MHz, soft X-ray camera with frequency range up to 250 kHz, and multi-channel (in energy and in lines-of-sight) NPA. The roles which the various types of energetic particle driven modes play at different values of thermal plasma beta are reviewed. In order to further investigate the effects of very high beta on Alfvén instabilities, such as the suppression of core-localised TAEs by plasma pressure gradient, new TAE antennas are being installed in MAST. Progress in deploying the TAE antennas for detection and evaluation of TAE-resonances will be reviewed.

Modelling of energetic ion-driven instabilities with the HAGIS and CASTOR-K codes will be presented.

*Work conducted partly under EFDA and partly funded by the UK EPSRC and by Euratom.*
Scale merging in edge and SOL turbulence

P. Tamain\textsuperscript{1}, Ph. Ghendrih\textsuperscript{1}, E. Tsitrone\textsuperscript{1}, Y. Sarazin\textsuperscript{1}, V. Grandgirard\textsuperscript{1}, X. Garbet\textsuperscript{1}, E. Serre\textsuperscript{2}, G. Ciraolo\textsuperscript{2}, P. Beyer\textsuperscript{3}

\textsuperscript{1} Association Euratom-CEA, CEA Cadarache, F-13108 St. Paul-lez-Durance, France
\textsuperscript{2} MSNM-GP, Université Paul Cézanne, Technopôle de Château-Gombert, F-13451 Marseille Cedex 20, France
\textsuperscript{3} PIIM, Université de Provence, Technopôle de Château-Gombert, F-13451 Marseille Cedex 20, France

Recent work on edge turbulence in 2D models have indicated that avalanche like transport events, or fronts, play a major role in the SOL transport. This theoretical analysis shows that scale separation between equilibrium and fluctuations does not hold, a feature that is also referred to as scale merging. Furthermore, the very fast cross-field transport governed by these local events is not compatible with the flute assumption that is generally used in the 2D models. Experimental investigations back this analysis and show that the separatrix region, between open and closed magnetic surfaces, plays a specific role in this transport mechanism. A 3D code, including SOL and edge physics in full torus geometry has been developed. This electrostatic turbulence code includes all the large scale flows and currents and provides therefore the appropriate geometry to tackle such a boundary layer problem in particular in the context of scale merging. The issues that will be addressed by this presentation are the physics of front transport in this region, the turbulence spreading between the edge and SOL regions as well as the flow transport between these two regions.
Plasma instabilities driven by fast particles and with fast frequency-sweeping signatures are relevant for their impact upon energetic particle transport and as a diagnostic for internal plasma modes. In this context, the modes' frequency change is fast in the sense that it is not attributable to changes in background plasma parameters (in contrast to, for example, so-called Alfvén cascades or RSTAEs). A review of both analytic and computational modelling of these frequency-sweeping modes will be given. Observations of frequency-sweeping modes will be discussed in the context of these theoretical models.

Recent theoretical advances have indicated that even in a strongly driven system, these frequency-sweeping modes arise from the evolution of phase space structures which continuously relax the particle distribution towards marginal stability at a rate much faster than the classical collision rate. This relaxation results in a much less virulent particle distribution, which is favourable for plasma stability. A second area of work will be presented which provides a quantitative description for a generic nonlinear mode destabilisation mechanism – if one of the aforementioned phase space structures approaches the location of an otherwise linearly stable mode, it may destabilise the mode and itself be further accelerated through phase space, its transport thereby being considerably enhanced.

Future work that needs to be addressed to develop a predictive capability, e.g. for ITER, will be discussed.
Global gyrokinetic simulations have been carried out to investigate both turbulent and neoclassical transport properties for experiments of axisymmetric devices. This study contributes several interesting footnotes to the observation that the ion transport is at neoclassical levels in the National Spherical Torus Experiment (NSTX). Nonlinear turbulence simulations using the General Geometry GTC code show that ion temperature gradient, (ITG), driven turbulence has significant fluctuation amplitude, but drives insignificant ion energy transport in NSTX (about neoclassical level, sometimes even below neoclassical level). This distinguished feature is particularly in contrast to anomalous transport in other machines, such as DIIID, where ITG turbulence is shown to drive large transport (10 x neoclassical level), even though the mean turbulence fluctuation levels for the two machines are actually comparable. It is also found that self-consistent equilibrium EXB flows, which are determined by neoclassical dynamics and calculated by GTC-Neo, a global PIC simulation code, can strongly stabilize ITG modes. Ion-ion collisions are shown to enhance ITG driven thermal transport, but not significantly. Studies to identify the source of the anomalous electron transport in NSTX plasmas are underway. Ongoing investigations with GTC are focusing on high-k fluctuations associated with trapped electron modes, and trapped electron effect on ITG turbulence in the NSTX discharges.

Work supported by U.S. Department of Energy and SciDAC GPS Center.
Contributed Papers
Interest in the micro-tearing instability has revived recently as a possible explanation for the high electron heat transport present in spherical tokamak experiments such as NSTX and START. Numerical simulations using the microstability code GS2 have revealed a number of spherical tokamak plasmas are susceptible to (linear) tearing parity instabilities with length scales of a few ion Larmor radii perpendicular to the magnetic field lines. This micro-tearing mode is studied in greater detail here to uncover its key characteristics, and compare it with existing theoretical models of the phenomenon. Importantly, the instability is found to be driven by the free energy in the electron temperature gradient, as described in the literature. However, our calculations suggest the destabilising mechanisms proposed by previous theoretical models are not relevant to the micro-tearing instabilities we have simulated in the ST. Instead, the instability is destabilised by interactions with magnetic drifts, and the electrostatic potential. Its prevalence in spherical tokamak plasmas is found to be due to the higher value of plasma beta and also the larger ratio of $\omega_{de}/\omega_e$. Nonlinear simulations of this instability have also been attempted, but at the time of writing, convergence has been elusive. However, these results have shown the importance of implementing a correction to the Lorentz collision operator used in GS2 which is proportional to $k^2_{\perp}$.

**Acknowledgement:** This work was funded in part by the United Kingdom Engineering and Physical Sciences Research Council and by the European Communities under the contract of Association between EURAROM and UKAEA. The views and opinions expressed herein do not necessarily reflect those of the European Commission.
Scrapeoff layer turbulence simulation using four field model and role of ion temperature
N. Bisai and IPR team
Institute for Plasma Research
Bhat, Gandhinagar 382 428
India

Neutral beam heated tokamak plasma may have higher ion temperature than electron temperature in scrapeoff layer (SOL) region. In this case, ion temperature can modify the SOL sheath dynamics mainly by increasing ion loss into the limiter/divertor plate. It can also increase total diamagnetic drift current. As the sheath dynamics and diamagnetic current have a direct influence on the plasma stability, the SOL plasma turbulence and transport will be altered. In this work, for the first time, we have studied the SOL turbulence and transport including ion temperature dynamics. Our model consists of flux driven two dimensional (2D) density, potential, electron and ion temperatures (fourfield) fields based on interchange instability. The four fields have been solved numerically. Simulation shows that plasma sustains higher ion temperature than the electron temperature in the turbulent saturated state. Ion temperature fluctuation is also higher compared to the electron temperature. Statistical properties of density, potential, particle, and energy fluxes and a comparison with experimental results are presented. A specific attention has been given to identify the effect of ion temperature in this region by comparing the numerical simulation results with the three field model (density, potential, and electron temperature) results. It is found that ion temperature reduces the SOL width and is closer to the experimentally observed value. It also reduces zonal flows, and amplitudes of inward particle and electron energy fluxes.
Probabilistic transport model for transitions to improved confinement regimes in fusion plasmas

Sebastián Bouzat and Ricardo Farengo

Centro Atómico Bariloche (CNEA) e Instituto Balseiro. (8400) Bariloche. Argentina

In recent years, several one dimensional models based on concepts such as self organized criticality, superdiffusivity, and continuous time random walk, have been developed to study anomalous phenomena observed in fusion plasmas. Recently, the probabilistic transport model introduced in [1] was shown to provide a consistent description of transitions to improved confinement regimes when appropriate particle step probability distributions are considered [2]. In this contribution we summarize and extend the results in [2] by providing additional information on the spatial structure of the density profiles, and its relation to the enhancement of fluctuations and confinement time observed when the source intensity is increased. We also analyze the use of different functional forms for the psd. The model is formulated in terms of a generalized master equation for a field $n(x,t)$ representing the particle or energy density of the plasma:

$$\frac{\partial n(x,t)}{\partial t} = S(x) - \frac{n(x,t)}{\tau_D} + \frac{1}{\tau_D} \int_{0}^{1} P(x,x',n(x'),n''(x')) n(x',t) dx'.$$

Here, $x$ represents a Cartesian coordinate along a minor diameter of a toroidal reactor, $S(x)$ the distribution of the fuelling, and $\tau_D$ the waiting time for the particles jumps. The function $P$ is the psd. In the present proposal $P$ includes two critical mechanisms, acting respectively on the first and second spatial derivatives of the density. These mechanisms allow switching between three different transport channels: one, corresponding to classical diffusion and the other two to different faster transport mechanisms (possibly scale free). The dependence of the transport properties on the second derivative models the appearance of a sheared radial electric field that causes a reduction of transport. The results of the model reproduce the enhancement of confinement time and the appearance of fluctuations (associated to edge localized modes) that take place during transitions, when the fuelling rate is increased. The main conclusions refer to the relevance of introducing the dependence of the psd on the second spatial derivative of $n(x,t)$, and to results being qualitatively independent of the particular functional forms considered for the psd on the three different transport channels.

Alfvén Cascades are shear Alfvén type perturbations in tokamak plasmas with non-monotonic safety factor profiles. They typically exhibit an upward (rather than downward) frequency sweeping as the minimum value of the safety factor decreases in time during the discharge. The preferred direction of sweeping indicates existence of a radial potential well for the upward sweeping eigenmodes, as opposed to a potential hill for the downward sweeping perturbations. The hill-to-well transition appears as frequency rollover in Alfvén Cascade observations in JET plasmas, in which the “hill” modes occupy a broad frequency band, which shrinks occasionally to a narrow spectral line. In this work, we interpret recent JET data on such a rollover in low-frequency Alfvén Cascades in terms of Alfvén Cascade Quasi-modes that arise on the potential hill and stay there transiently prior to damping at the Alfvén continuum resonance. We calculate the lifetime of Quasi-modes and compare relative roles of three factors that determine their minimum frequency: geodesic acoustic coupling, pressure gradient effect, and energetic ion effect. We find that energetic ions with large orbits can alter the minimum frequency significantly in discharges with high power ICRH and NBI.
A key issue for ITER is the extrapolation of the onset threshold and control requirements for the Neoclassical Tearing Mode (NTM). However, the behaviour of this instability remains challenging to understand, with many uncertainties in the theory governing this instability, in particular to understand which theoretical models are dominant, and to quantify them. These difficulties are exacerbated in the prediction of ITER, which requires extrapolation in two key variables — \( \rho^* \) and rotation — that are fundamental to the behaviour of much of the underlying physics. Of concern is that ITER will not benefit from the stabilising influence of high plasma rotation driven by the strong neutral beam momentum injection used in most present devices.

The main elements of uncertainty come in the ‘seeding’ and threshold physics of the mode. For example, if the seeding is due to magnetic coupling then differential rotation between resonant surfaces would play a strong role in influencing NTM \( \beta_N \) threshold. But island growth rates due to a \( \beta \) related pole in delta prime would be rotation independent. Similarly, if the threshold for island growth was dominated by ion polarisation current effects, then a strong dependence is expected on island rotation in the ExB frame, which would not be seen if finite island transport effects dominate. The developments in the theory, and their implications, will be reviewed in the paper.

Experiments can distinguish between these effects. For example, DIII-D scans of neutral beam momentum show a strong dependence of 2/1 NTM onset \( \beta_N \) values on torque injected (figure). Of note is that \( \beta_N \) thresholds continue fall as rotation and rotation shear in the counter direction increases. The behaviour is most consistent with changes in ion polarisation current physics influencing the rise in \( \beta_N \) required to ‘seed’ an NTM via the delta prime model. It is also consistent with results showing how error fields lower \( \beta_N \) thresholds for NTMs: in such cases the mode is often borne rotating indicating that this is not a simple error field penetration. Instead the error field acts to change the plasma rotation, influencing the underlying meta-stability of the NTM, indicating the role of the ion polarisation current term in governing behaviour.

These are crucial issues for ITER, particularly for high \( \beta_N \) scenarios such as the hybrid regime, as thresholds for the most serious 2/1 NTM are expected to fall as small island size stabilisation effects decrease as \( \rho^* \) approaches ITER values — as recently identified on DIII-D and now being tested at lower \( \rho^* \) on JET. These considerations may also have wider implications in the interpretation of tearing mode limits to other scenarios, such as the advanced tokamak.

In this paper we will review the overall status of the theoretical picture, comparing with new experimental results, in order to consider what are the appropriate models dominating behaviour, and the implications for extrapolation to ITER.

This work was jointly funded by EURATOM, the UKAEA EPSRC, and US Department of Energy, and was partially conducted in the framework of the European Fusion Development Agreement. *see appendix of M.L.Watkins et al., Fusion Energy 2006 (Proc. 21st Int. Conf. Chengdu) IAEA.*
On the Theory of Two Fluid Viscoresistive Ballooning Modes

A.J. Carter\textsuperscript{1,2} and H.R. Wilson\textsuperscript{1}

\textsuperscript{1}Department of Physics, University of York, Heslington, York, YO10 5DD
\textsuperscript{2}EURATOM/UKAEA Fusion Association, Culham Science Centre, Abingdon, Oxon, OX14 3DB

We present an extended analytic treatment of linear ballooning modes retaining the effects of viscosity, diamagnetism and heat conduction. In our model we work in ballooning space and evaluate Braginskii’s equations\textsuperscript{[1]} without assuming any geometric ordering to obtain six coupled differential equations (following \textsuperscript{[2]}). After taking a cold ion limit we show that the resulting equations may be analysed using a two-scale analysis for large values of the ballooning coordinate, and proceed to develop these averaged equations. The physical problem is closed by asymptotically matching the dissipative regime to a linear\textsuperscript{[3]} or non-linear\textsuperscript{[4]} ideal magnetohydrodynamic model at smaller values of the ballooning coordinate.

The resulting equations must be evaluated numerically, which is work in progress. Filamentary structures are observed during MAST L–modes\textsuperscript{[5]}, the implications of our theory for explaining these features will be discussed.

Acknowledgements

This work was funded jointly by the United Kingdom Engineering and Physical Sciences Research Council and by the European Communities under the contract of Association between EURATOM and UKAEA. The views and opinions expressed herein do not necessarily reflect those of the European Commission.

References


The control of sawteeth is likely to be of critical importance for baseline scenario operation of burning plasmas as large amplitude sawteeth have been shown to result in the triggering of neo-classical tearing modes, which in turn can significantly degrade confinement. The stabilising effects of alpha particles in burning plasmas are likely to exacerbate this, so recent experiments have identified various methods for amelioration. For example, reversed toroidal field operation demonstrates that shorter sawtooth periods than those in Ohmically heated plasmas can be achieved in JET [1], MAST [2] and TEXTOR [3] by using neutral beam heating (NBI).

In order to understand sawtooth stabilisation, the interaction of MHD and fast particle effects must be considered. Appropriate tools for studying these effects are the MISHKA-F MHD stability analysis code, which includes toroidal flows and ion diamagnetic drifts [4], and the HAGIS code [5], which calculates the effects of both trapped and passing energetic particles with anisotropic distribution functions. HAGIS has been extended to calculate the fast particle contribution to the change in potential energy of the $n=1$ internal kink mode, thought to be responsible for sawtooth oscillations. It is found that whilst the energetic trapped particles are always stabilising [6], passing particles can be destabilising [7]. The code has also been extended to include the effects of sheared toroidal flow. This causes both a change to the electric potential experienced by the particles and alters the frequency of the particles in resonance with the mode, which results in a significant change in the stabilising effect of the trapped particles, in agreement with analytic theory [8].

The effects of NBI, ICRH and fusion alpha particles on sawtooth stability will be discussed using this model.

This work was funded in part by the United Kingdom Engineering and Physical Sciences Research Council and by the European Communities under the contract of Association between EURATOM and UKAEA. The views and opinions expressed herein do not necessarily reflect those of the European Commission.

Rotation Shear and Stability

J W Connor and T J Martin

EURATOM/UKAEA Fusion Association, Culham Science Centre, Abingdon, Oxon OX14 3DB, UK

Abstract
The stability of short wave-length drift instabilities in toroidally confined plasma is conventionally analysed using the ballooning transformation. This reduces the two-dimensional stability problem to the solution of two consecutive one-dimensional equations. The first, the lowest order in n (n is the toroidal mode number), equation produces a local eigenvalue that is a function of radius, x, due to profile variation and also has a periodic dependence on a parameter k, representing a radial wave-number. Usually one finds that profile variation defines a radial position where the growth rate is a maximum. In next order one finds that this position determines the mode’s radial location and that the parameter k is such as to maximise the growth rate. However, if the effects of sheared plasma rotation, dΩ / dq, dominate other profile variation, one finds the growth rate is smaller and, instead, involves an average over a period of k. This is a reversion to an essentially cylindrical situation, where toroidal coupling effects between adjacent resonant surfaces are eliminated. In this paper we consider a generic drift wave model that generates a local eigenvalue having quadratic radial variation of frequency, ω, and growth rate, γ, and periodic variation with k. We derive an analytic dispersion relation; although requiring numerical solution, this shows there is a continuous evolution between these two limits as dΩ / dq increases, the transition being quite sharp for high n. The transition can be associated with a critical rotation shear, dΩ n / dq ~ O(1/n). The detailed character of the results depends on which of the radial variations, ω(x) or γ(x), dominates. However one can conclude in general that the most unstable modes do correspond to an average over k of the conventional ballooning mode and are hence more stable, thus reducing transport. The stability of MHD ballooning modes in the presence of rotation shear is also discussed.

Acknowledgements
This work was funded by the UK Engineering and Physical Sciences Research Council and by the European Communities under the contract of Association between EURATOM and UKAEA. The views and opinions expressed herein do not necessarily reflect those of the European Commission.
Flux driven kinetic transport is analysed for deeply trapped ion turbulence with the code GYSELA in a reduced version. The whole distribution function, $f$, is simulated with a 3 dimensional model (energy, radius and angle). In the present simulation, the system is driven by a volumetric and constant source of heat. The latter is localised towards the core and such that it leads to an up-shift in temperature but does not generate particles or perturbs other fluid moments. When governed by a heat source, interchange instability gives rise to intermittent transport: temperature is characterized by a very bursty behaviour with a skewed PDF ($r=r_0$, $<T>_t=1.09$, variance=3*10^{-3}, skewness=1.09). For comparison, this response is very different from that analysed with a system governed by two boundaries at given constant temperatures ($r=r_0$, $<T>_t=1.02$, variance=4*10^{-9}, skewness=2.81). Intermittency is observed in phase-space. Furthermore, intermittency also yields specific signatures such as the occurrence of high order moments of $f$, independently of the local density and temperature. In this context, we analyse the departure of the distribution function from a gaussian, at different points of the phase-space. Superimposed to these short time scale fluctuations, one finds a low frequency regime where an interplay between zonal flows and turbulence occurs. During such prey-predator cycles one finds a regime with a strong increase of the zonal flows and a quenching of the turbulent energy. As a consequence, the core temperature rapidly increases while the edge temperature decreases. The end of this transport-less regime is governed by the onset of turbulence that governs large relaxation events and a strong modification of the zonal flows.
Influence of magnetic shear on impurity transport

H. Nordman, T. Fülöp, P. Strand

Department of Radio and Space Science,
Chalmers University of Technology and Euratom-VR Association
Göteborg, Sweden

The magnetic shear dependence of impurity transport in tokamaks is studied using a fluid model for ion temperature gradient (ITG) and trapped electron (TE) mode driven turbulence. It is shown that the impurity transport is very sensitive to the magnetic shear in regions close to the TE mode stability threshold, corresponding to the inner core region of tokamak plasmas. Further away from marginal stability, in particular for ITG dominated cases, the shear dependence is weaker. The steady state impurity profiles in source-free plasmas are found to be considerably less peaked than the electron density profiles and only weakly dependent on magnetic shear. Comparisons between anomalous and neoclassical transport predictions are performed for ITER-like profiles, and it is concluded that the magnetic shear dependence of the impurity flux, which is observable only in the inner core region, is dominated by anomalous effects.
Reduction of Ionization Instability in Micro Hall Accelerator

Takeshi Furukawa

Aviation Program Group, Japan Aerospace Exploration Agency (JAXA)
6-13-1 Osawa, Mitaka, Tokyo, JAPAN
Tel: +81-422-40-3533, Fax: +81-422-40-3536

Abstract: With a view to realizing a micro hall accelerator for micro/nano satellite, a reduction technology of plasma magneto-hydrodynamic (MHD) wave turbulence was estimated using numerical analysis. At high-voltage mode of DC regime, plasma MHD wave turbulence of various frequencies is observed. Large-amplitude discharge current oscillation in the tens of kHz “low-frequency oscillation” among them has been a serious problem that should be solved to improve the operational stability and the propulsion system durability. So the dependencies of the propulsion performances including amplitude/frequency of low-frequency oscillation on various operational parameters are clarified in this research. Besides, a new physical parameter “average length of ionization-zone” which we propose, can be varied by neutral particles velocity and is correlated conversely with amplitude. To increase neutral species velocity-inlet in acceleration channel by preheating propellant through circulate propellant inside thruster can bring about the lower amplitude of low-frequency oscillation. At the same time it causes cooling propulsion, and the higher thrust and specific impulse with hardly changing thrust efficiency. Also, spatiotemporal variations of plasma properties and electromagnetic field were obtained in acceleration channel at the peculiar times in low frequency oscillation. This knowledge would be useful for proposing ideal design and parametric conditions of micro micro hall accelerator as a promising high-performance propulsion device in space missions requiring for high-reliance.

Keywords: Electric Propulsion, Plasma, Numerical Analysis, MagnetoHydroDynamics(MHD)

![Fig.1. Schematic view of micro hall accelerator for analysis (left). Fig.2 Dependencies of maximum, minimum, average and amplitude of discharge current, and average length of ionization-zone, and thrust and thrust efficiency on neutral species temperature.]

![Fig.3 Time evolutions of low frequency oscillations for varied discharge voltage in numerical analysis.(left) Fig.4 Spatial distributions of electron temperature and plasma density in acceleration channel at the peculiar times I-IV of discharge current oscillation in Fig.3.](image)
A low beta and high aspect ratio Double Tokamak collider (DTC) is taken into consideration for low frequency stabilization process with toroidal coordinates playing the vital role as the configuration is governed by the transport phenomena which subsides the effect on the unstable mode. The present study is to stabilize such system if density gradient $\nabla n$ plays against the gravity in the upward direction thereby causing the R-T instability. Here the conductivity causes the implosion in the system which can be stabilized by the sheared flow and finite conductivity. Above study is done theoretically to obtain the growth for the stabilizing process. The growth for the stabilizing process is obtained. The transport phenomena decreases by $(2\delta - 2\varepsilon + \sin \varepsilon)^{1/3}$ over the what one considers in classical Tokamak case.

PACS No.: 52.35Py, 52.35 -g, 52.25
A model for field error penetration is developed that includes the effects of both resonant and non-resonant perturbed 3-D magnetic fields. The non-resonant components give rise to a neoclassical toroidal viscous force that damps toroidal flow, while the effect of the dominant resonant perturbation is to produce a localized electromagnetic torque at the rational surface. The neoclassical toroidal viscous force acts throughout the plasma cross-section (unlike the localized electromagnetic torque) and attempts to keep the plasma rotating toroidally at a level comparable to the ion diamagnetic fluid velocity. A model toroidal momentum balance equation is used that accounts for the competition between the neoclassical and electromagnetic forces as well as a phenomenological cross-field viscous force. This equation is solved by a WKB-type procedure in the vicinity of the rational surface in a limit where neoclassical viscosity exceeds the perpendicular viscosity in the bulk plasma. The dominant effect of the neoclassical viscosity is to alter the global velocity profile shape and to effectively “enhance” the cross-field viscosity. Torque balance at the rational surface is governed by a competition between the electromagnetic torque and the neoclassical modified cross-field viscous torque. Using a semi-collisional model to account for the layer response, a criterion for the critical resonant error-field amplitude in the presence of non-resonant field errors is predicted. The theory indicates that the critical error field amplitude increases with plasma density when neoclassical physics is included; this result is in qualitative agreement with empirical scaling.
The ITER tokamak will operate in a regime where pressure gradients may likely drive instabilities such as neoclassical tearing modes (NTMs) in the core and edge localized modes (ELMs) in the pedestal region. Important requirements for simulating such instabilities using macroscopic plasma fluid codes include physically correct forms for the parallel heat flows and stresses. Previous work has approached the parallel closures problem in the plasma core and edge using distinct, nearly-collisionless and collisional theories, respectively. For growing NTMs in the plasma interior, however, parallel transport in the vicinity of magnetic islands is most likely moderately collisional. This is due to the fact that rapid parallel equilibration leads to long temperature gradient scale lengths along the magnetic field. Furthermore, although appropriate near the bottom of the pedestal region, a collisional plasma assumption for the top of the pedestal in ITER is not valid. In this talk, we present recent advances in calculating parallel closures for arbitrary collisionality. These closures stem from a solution of a lowest-order drift kinetic equation that includes time dependence, free streaming and particle trapping in general magnetic geometry, and an exact treatment of the linearized, Coulomb collision operator. In addition to writing the parallel closures formally in terms of integrals of thermodynamic drives along particle characteristics, we discuss a numerical approach to directly solving the drift kinetic equation. Expansion of the distribution function's velocity dependence in orthogonal polynomials permits a massively parallel, numerical solution to separated, reduced kinetic equations in five dimensions, time, particle speed and three spatial variables. Finally, consideration will be given to the implementation of this solution in the plasma fluid code, NIMROD [1,2], with a discussion of future applications to NTM and ELM simulations.


The appearance of transport barriers in plasmas is usually taken to be the result of bifurcations in the transport equations, in which the possible control parameters are the radial electric field in association with shear flow, which may contribute to the reduction or suppression of turbulent fluctuations. On the other hand, such barriers show up globally as modifications in the profile of the safety factor, which is related to the equilibrium solutions. Solano [1] has suggested to study transport barriers under the point of view of the criticality of the Grad-Shafranov equation, and finding the bifurcations in its solutions. Ball et al. [2,3], on the other hand, have studied the problem using economical or minimal models, based on reduced Magnetohydrodynamic (MHD) equations with phenomenological terms, which allow an optimization approach, by controlling such parameters as those related to the power source, damping and shear flow driving rate. Then they study the bifurcations for such model. The purpose of this work is to explore Solano’s idea, but using a modified Grad-Shafranov equation which can properly take into account equilibria with shear flow. Bifurcations of the solutions are studied for different properties of the shear flow.

This work has been partially supported by CONACYT grant U47899-F.

References
Tearing mode stability in a sheared slab model of the tokamak plasma

M. James\textsuperscript{1,2} and H.R. Wilson\textsuperscript{3}

\textsuperscript{1} University of Bristol, H.H. Wills Physics Laboratory, Royal Fort, Bristol, BS8 1TL, UK
\textsuperscript{2} EURATOM/UKAEA Fusion Association, Culham, Abingdon, Oxon, OX14 3DB, UK
\textsuperscript{3} Department of Physics, University of York, Heslington, York, YO10 5DD, UK

The growth of magnetic islands is related to currents flowing parallel to the magnetic field and, for long narrow islands (with the width comparable to the ion Larmor radius), the contribution from the polarisation current can significantly affect the time evolution. The analysis presented here is derived from a numerical solution of the gyro-kinetic equations which confirms, and extends, previous analytic studies [1, 2] of the effect of the polarisation current on the island stability. Accurate determination of the polarisation current’s contribution to the island stability is hindered by the form of the electron density which changes sharply at the separatrix leading to spikes in its derivatives and, consequently, the polarisation current. The importance of this spike has been highlighted [3] and dealt with using both fluid [1] and kinetic [2] descriptions. Through treating the cross-field transport on an equal footing with the parallel streaming [4, 5], the spike can be removed naturally and simulations of this [6] suggest that there is a noticeable effect on the island evolution. We present these simulations as well as preliminary results from a numerical study based on the analytic work of previous authors [5].

References


Acknowledgements

This work was funded by the Engineering and Physical Sciences Research Council and by the European Communities under the Contract of Association between EURATOM and UKAEA. The views and opinions expressed herein do not necessarily reflect those of the European Commission.
The modelling of the formation of transport barrier requires a quantitative prediction as to how much flux is reduced by zonal flows (ZFs). Here, I will consider a few simple turbulence models to discuss the scaling of turbulent transport with (mean or RMS) shearing rate and then to examine the model dependence of such scalings. In particular, I will examine the effects of ZFs with different frequency spectra on turbulent transport, by comparing the results obtained for high-frequency ZFs [1] and those for low-frequency random ZFs [2], and identify different physical mechanisms responsible for the reduction in transport and turbulence amplitude. Furthermore, I will discuss the effects of fluctuating magnetic fields on the transport of particles and momentum in high $\beta$ plasmas, indicating the possibility of quenching turbulent transport without much effect on turbulence amplitude with small normalized flux (the so-called cross-phase) [3].

The core-SOL (Scrape-Off Layer) transition region in tokamaks is of fundamental importance for the transition from L- to H-mode confinement and related phenomena, such as the formation of a pedestal and the ejection of plasma blobs. To date, the different plasma parameters and magnetic topologies in core and SOL preclude not only self-consistent simulations across the core-SOL transition, but also make reliable experimental measurements difficult. This motivates the study of such phenomena in basic experiments. In many basic devices, a transition between a core-like and a SOL-like region can be achieved by exploiting properties of the plasma production mechanism and/or introducing limiters. Although such experiments cannot reproduce the extreme gradients occurring in tokamaks, they satisfy the most important assumptions in present models and are therefore relevant for the validation and benchmarking of tokamak simulation codes.

On the toroidal experiment TORPEX, a core-SOL transition is achieved by limiting the rf plasma production to the region $r < 0$. At the core-SOL transition at $r \sim 0$, a drift-interchange instability gives rise to a vertically propagating large-amplitude wave. The shapes of the wave crests are highly fluctuating and asymmetric. Particularly large wave crests penetrating into the region $r > 0$ break into parts, which give rise to plasma blobs propagating radially far into the SOL. The data has striking similarity with tokamak edge data in many aspects, such as the resulting skewness profile across the core-SOL transition.

On the linear experiment CSDX, a core-SOL transition arises at the position of the helicon antenna. A significant change of the mode structure is observed across the core-SOL transition. The radial extension of the SOL modes varies explosively, but, in contrast to the toroidal case, no blobs that completely detach from the core region are observed.

A pattern recognition approach is used to analyze the presented turbulence imaging data, which greatly increases the amount of statistical information extracted. Strategies to apply this approach to numerically generated data are outlined, with the aim of improving experimental comparisons to, and validation of, various theoretical models of this transition region.
Enhanced confinement observation in the presence of negative currents at the edge of the S.I.N.P. tokamak

Ramesh Narayanan

Saha Institute of Nuclear Physics
1/AF Bidhannagar
Kolkata-700064

Recently, an enhanced confinement regime has been observed in the S.I.N.P. tokamak. This regime has been realized by tuning the Vertical Magnetic Field ($B_v$) so as to fast ramp-up the current initially, resulting in the formation of hollow current density profiles. The subsequent current decay has been observed to drive negative edge currents within the discharge column, which subsequently help in a transition to an improved confinement properties regime. The observation of the edge negative currents has been made using Internal Langmuir Magnetic Probes (ILMP) and an Internal Rogowskii Coil (IRC) [R. Narayanan and A.N. Sekar Iyengar, RSI, 77, 33503 (2006)].

These experimental results in the light of recent observations of central zero current density in JET [N.C. Hawkes et al, PRL, 87, 115001 (2001)] and JT-60U [T. Fujita et al, PRL, 87, 245001 (2001)] has an important impact on the present fusion research. These experimental results provide experimental verifications, that of generating negative currents within the discharge column. These negative currents can, in turn, effectively lead to an L-H transition of the plasma column.

This paper will present the experimental results of this enhanced confinement discharge and a plausible model for the same.
Shear Alfven wave dynamics in gyrokinetic tokamak plasmas

Y. Nishimura, Z. Lin, and L. Chen
Department of Physics and Astronomy, University of California, Irvine CA, 92697 USA
Email: nishimuy@uci.edu

W.X. Wang, T.S. Hahm, and W.W. Lee
Princeton Plasma Physics Laboratory, Princeton NJ, 08543 USA

Electromagnetic gyrokinetic particle simulation in toroidal geometry is developed based on a fluid-kinetic hybrid electron model using the GTC code [1]. The hybrid model solves the adiabatic response in the lowest order fluid equations and solves the resonant interaction in the higher order kinetic equations, based on an expansion of the electron responses using a small parameter of the square-root of the electron-ion mass ratio while preserving the linear and the nonlinear wave-particle interactions. The Alfven wave propagation in a fully global gyrokinetic particle simulation is investigated. In the long wave length magnetohydrodynamic (MHD) limit, shear Alfven wave oscillation, continuum damping, and the appearance of the frequency gap [2] in toroidal geometries are demonstrated. The wave propagation across the magnetic field (the kinetic Alfven wave) [3] is examined by comparing the simulation results with the theoretical dispersion relation. Furthermore, finite-beta stabilization of the ion temperature gradient (ITG) mode and the onset of kinetic ballooning mode (KBM) [4] (or the Alfvenic ion temperature gradient (AITG) [5, 6] mode) are investigated. Preliminary nonlinear simulation results are discussed.

References
Linear gyro-kinetic calculations of toroidal momentum transport in a tokamak due to the Ion Temperature Gradient mode

A.G. Peeters

University of Warwick, Coventry CV4 7AL, United Kingdom

It is shown from a symmetry in the gyro-kinetic equation that for up down symmetric tokamak equilibria and for \( u_\phi \gg \rho v_{thi}/r \) (where \( u_\phi \) is the toroidal velocity, \( v_{thi} \) is the thermal ion velocity, \( \rho \) is the Larmor radius, and \( r \) is the radius of the flux surface), the transport of parallel momentum can be written as the sum of a diffusive and a pinch contribution with no off-diagonal terms due to temperature and pressure gradients. The measured parallel velocity gradient in ASDEX Upgrade [O. Gruber, H.-S. Bosch, S. Günter et al., Nucl. Fusion 39, 1321 (1999)] is insufficient to drive the parallel velocity shear instability. The parallel velocity is then transported by the ion temperature gradient mode. The diffusive contribution to the transport flux is investigated using a linear gyro-kinetic approach, and it is found that the diffusion coefficient for parallel velocity transport divided by the ion heat conductivity coefficient is close to 1, and only weakly dependent on plasma parameters.

Furthermore, the pinch of toroidal momentum will be discussed. Such a pinch can lead to a radial gradient in the toroidal velocity even without momentum input. This is of importance especially for a reactor where the torque on the plasma due to the neutral beam heating is expected to be small.
Basic plasma physics experiments in toroidal geometry offer the possibility of investigating the properties of low frequency instabilities in well-diagnosed scenarios. The development of instabilities, from a linear to a nonlinear character, and the related turbulence and its implications for anomalous particle transport, are investigated on TORPEX, a toroidal device with toroidal magnetic field $\leq 100$ mT and a small vertical component ($\leq 4$ mT). Plasmas from noble gases are produced and sustained by low field side injection of microwaves ($P \leq 20$ kW) with $f=2.45$ GHz, in the EC frequency range. Density and potential fluctuations are measured over the whole plasma cross-section, and their properties investigated for a large range of variation of control parameters, including the ion mass, the neutral gas pressure and the vertical magnetic field. For the different experimental scenarios, the maximum of fluctuations is measured where the pressure gradient and the magnetic field gradient are co-linear. From the comparison of the measured spectral properties, including the dispersion relation in the directions perpendicular and parallel to the magnetic field, with a kinetic dispersion relation for drift waves in slab geometry, the observed instabilities are identified as drift-interchange. The spectrum exhibits coherent features where the unstable modes are excited. At this location, the bicoherence spectrum is dominated by nonlinear interactions between the fundamental and higher order harmonics. The degree of turbulence increases as the modes are convected away from their source region by the underlying $\mathbf{E}\times\mathbf{B}$ drift, the spectral regions between harmonics are progressively filled in and nonlinear interactions between modes are measured in an extended frequency range. The quadratic non-linear coupling coefficients and the energy transfer function are estimated at different locations over the plasma cross-section. Features such as the characteristic scale range involved, the spectral index and the direction of energy cascade are consistent with a nonlinearity induced by the $\mathbf{E}\times\mathbf{B}$ convection of density fluctuations. In real space, large-scale coherent structures are detected in the fluctuating density, originating in the region of high fluctuation level and propagating in the $\mathbf{E}\times\mathbf{B}$ direction. The relation between statistical space-time properties of the structures and local spectral properties of fluctuations will be discussed.
Effects of Impurities on Electron Temperature Gradient Modes

M. Reshko¹,², C. M. Roach², J. W. Connor², R. J. Hastie² and the MAST Team.

¹ Department of Physics, University of York, Heslington, York, YO10 5DD
² Euratom/UKAEA Fusion Association, Culham Science Centre, Abingdon, Oxon, OX14 3DB

The persistence of large anomalous electron heat transport in regions of improved ion confinement sometimes observed in tokamak plasmas suggests that the electron-temperature-gradient-driven drift waves may be the antecedents of the small-scale turbulence and associated energy flow. Whereas most previous studies of these modes were carried out for a two-species plasma, in this paper we retain impurities and examine their effect using gyrokinetic theory. We derive a dispersion relation and solve it analytically in the strong ballooning limit, while also obtaining numerical solutions with the GS2 code. The inclusion of adiabatic impurities is found to have a strong stabilising effect on the electron temperature gradient modes.

This work was funded jointly by the UK Engineering and Physical Sciences Research Council and by the European Communities under the contract of Association between EURATOM and UKAEA. The views and opinions expressed herein do not necessarily reflect those of the European Commission.
Dissipative instabilities in a flowing system have been widely discussed in the literature, and is being sought to be applied to explain various phenomena in fusion plasma. The instabilities are accompanied by plasma heating and diffusion and can also greatly enhance plasma transport across magnetic-field lines [1]. Physical nature of these instabilities actually is coupled with that of resistive wall modes. Physics of instabilities in flowing systems is elaborated and it may seem that one fail to encounter a variety of that with new physics. This investigation presents new type of dissipative streaming instability.

Strong dissipation changes physical nature of streaming instabilities [2]. Instability becomes of dissipative type, caused by excitation of the beam wave of negative energy. Another type of streaming instability caused by excitation of the negative energy beam wave also is known in theory. With increase in beam intensity space charge fields set an upper limit on beam current that can be transmitted through given vacuum electrodynamic system. In systems of uniform transversal geometry overlimiting e-beam instability is due to modulation of the beam density in media with negative permittivity [3]. Influence of dissipation on this instability was considered in [4]. But in no-uniform-cross-section plasma-filled systems overlimiting e-beam instability is also due to growing of the negative energy beam wave [5].

Superposition of the two processes that lead to excitation of the beam wave with negative energy leads to new type of dissipative streaming instability. Its growth rate has previously unknown, inverse proportional dependence on dissipation. The influence of dissipation on excitation of the beam wave with negative energy is elaborated in detail as well as the transformation of the instability to that of dissipative type. Growth rate of the instability is obtained for arbitrary level of dissipation. An approach is developed that enables to investigate the dynamics of the instability development. The space-time evolution of the instability is governed by partial differential equation of second order independently on geometry and specific parameters. Basic parameters of the instability indicate that its role can be important for understanding of the processes in fusion plasma.

5. E.V. Rostomyan. *Europhysics Letters* (is accepted for publication).
Edge stability in MAST
S. Saarelma\textsuperscript{1}, A. Kirk\textsuperscript{1}, H. Wilson\textsuperscript{2} and the MAST team\textsuperscript{1}
\textsuperscript{1} UKAEA Fusion Association, Culham Science Centre, Abingdon, UK
\textsuperscript{2} University of York, Heslington, York, YO10 5DD, United Kingdom

One of the major problems in ITER and other large future tokamaks are the Edge Localised Modes (ELMs) that transport particles and energy in bursts from the plasma edge to the divertors. If the ELMs are large, they can cause unacceptable erosion of the divertor plates. To avoid the erosion the ELM phenomenon has to be understood and ways to either reduce the ELM size, mitigate their effects or suppress them completely have to be found.

The stability analyses using ELITE for the MAST tokamak show that the plasma is close to the peeling-ballooning stability boundary before an ELM crash. We also show that when approaching a true X-point configuration, the peeling component of such an instability is stabilised while the ballooning component stays unstable. Therefore, the ELMs in diverted plasmas are unlikely to be triggered by pure peeling modes.

It has been observed that increasing $\beta_p$ enables accessing small ELM regimes [1]. We show that increasing the core pressure, and, thus, $\beta_p$ while keeping the edge pressure profile fixed has a stabilising effect on the ELM triggering peeling-ballooning modes.

In MAST, where plasma rotates at a relatively fast speed due to the combination of small volume and high beam power, the edge stabilisation by the toroidal rotation plays a role in the ELM triggering. Between ELMs, the rotation profile has a strong gradient close to the plasma edge. During an ELM the profile flattens. In stability analyses, we find that strongly sheared rotation stabilises the edge modes and only when the destabilising force from the pressure gradient and current exceeds the stabilising force from the rotation, instabilities are triggered. The growing instability ties up the flux surfaces and flattens the rotation profile further destabilising the mode and triggering an ELM. This ELM triggering mechanism is only significant in tight aspect ratio tokamaks with strong beam heating. With low rotation speeds or large aspect ratio, the effect of the rotation shear stabilisation becomes insignificant.

This work was partly funded by Euratom and the UK Engineering and Physical Sciences Research Council. The views and opinions expressed herein do not necessarily reflect those of the European Commission.
A new formulation describing convective cells in magnetized plasmas driven by longitudinal current density is presented. The equilibrium state is regarded as a stationary incompressible flow in a uniform longitudinal magnetic field. A solution to the equilibrium flow, leading to a uniform vorticity, is shown to exist in terms of periodic functions in a cylindrical geometry. The uniform vorticity, in turn, is seen to drive a constant longitudinal current, thus giving rise to convective cells. The relation of the convective cells to macroscopic plasma instabilities is discussed.
An \(m/n=1/1\) internal mode instability in lower hybrid current driven (LHCD) plasmas has been observed previously on the HT-7 tokamak [Youwen SUN, et al, Plasma Phys. Control. Fusion 47, (2005) 745]. This mode appears during the sawtooth ramp, saturates, damps and finally disappears before the subsequent sawtooth collapse and before the appearance of the precursor oscillations. It is named “mid-oscillation” for distinguishing from the precursor oscillation and the post cursor oscillation. It usually does not triggering the sawtooth crash, and its nonlinear evolution quite resembles the resistive tearing mode. The effect of the barely trapped suprathermal electrons may be ignored due to the relatively low threshold LHCD power for exciting the mid-oscillation [Youwen SUN et al, Phys. Plasmas 12, 092507 (2005)].

This mode is most likely destabilized by the current density gradient at the rational surface. Hence, the final stabilization of mid-oscillation before the subsequent sawtooth crash may be caused by the flattening of the local current density profile. It is proposed in this paper that the flattening of the local current density profile is caused by the locally enhanced radial transport of the suprathermal electrons driven by LHCD due to existence of the mid-oscillation. Based on the local transport model [Z. Chang and J. D. Callen, Nucl. Fusion 30, 219 (1990)], it is obtained that the density of the fast electrons will decrease inside the rational surface while increase a little outside it due to the mid-oscillation when the LHCD deposits the rational surface. Therefore, the current density profile will flatten near the rational surface, and the mid-oscillation may become stable again in this condition. This is in agreement with the experimental observation, in which it was found that the mid-oscillation occurred when the LHCD deposited in the central region, and only a precursor oscillation appeared when the deposition location move outwards [Youwen SUN, et al, The 5th General Scientific Assembly of Asia Plasma & Fusion Association, Jeju, Korea, August 29-31, 2005, TO1]. The numerical calculation shows that the time scale of the evolution of the current density profile is also the same order as the characteristic time of the evolution of the observed mid-oscillations.
Modelling of particle and energy losses by type I ELMS and their mitigation with external magnetic field perturbations

M.Z. Tokar¹, T.E. Evans², A. Gupta¹, R. Singh³, P. Kaw³, and R.C. Wolf¹

¹Institut für Plasmaphysik, Forschungszentrum Jülich GmbH, Association FZJ-Euratom, 52425, Jülich, Germany; ²General Atomics, San Diego, California 92186-5606, USA; ³Institute for Plasma Research, Bhat, Gandhinagar-382428, India

A model to assess the particle and energy losses caused by type I Edge Localized Modes (ELM) is proposed. It is based on the assumption that the increase in transport caused by ELMs is due to flows along magnetic field lines perturbed by ballooning-peeling MHD modes. The model reproduces well the experimentally found variation of losses with the plasma collisionality $\nu^*$, namely the weak dependence of the particle loss and significant reduction of the energy loss with increasing $\nu^*$. It is demonstrated that the electron parallel heat conductivity is normally dominant in the energy loss.

The effect of magnetic field perturbations from external resonant coils on the particle and energy transport in the edge transport barrier is analyzed. In recent experiments on DIII-D and JET such coils have been verified as an effective tool for mitigation of losses due to ELMs. The observed reduction of the density in plasmas of low collisionality is explained by the charged particle flows along field lines which are inclined in the radial direction even between ELM bursts. The increase of the electron and ion temperatures in the barrier is interpreted by the reduction of perpendicular neoclassical transport with decreasing density and kinetic non-local effects in the heat transport along perturbed field lines. The found modification of the pressure gradient implies the stabilization of peeling-ballooning MHD modes responsible for type I ELMs.
Diamagnetic drifts play an important role in the evolution of magnetic islands when $\beta > \rho_\star$. In particular, they are responsible for the propagation of the magnetic islands through the plasma. This propagation gives rise to a polarization current that is thought to be responsible for the threshold against neoclassical tearing modes. Of course, diamagnetic drifts also give rise to microinstabilities and thus to turbulence that interacts with the magnetic islands. We have investigated the role of the polarization current under both laminar and turbulent conditions.

Under laminar conditions three regimes can be distinguished depending on the width $W$ of the island compared to the gyroradius $\rho_s$ and to the acoustic width $\rho_sL_s/L_n$ where compressibility becomes important ($L_s$ and $L_n$ are the shear and density scale-lengths). Numerical and analytic calculations show that the polarization drift is stabilizing in all three regimes. The amplitude of the polarization current exhibits a peak at the transition between the compressible and incompressible regimes. The electron temperature gradient is also found to have a stabilizing influence for $\eta_e > 0$.

To investigate the interaction of turbulence with a magnetic island we have extended the Hasegawa-Wakatani model to include the effects of an island and of the associated magnetic shear. In the absence of island the fluctuations are most intense in the hydrodynamic channel where the resistive drag causes the electron response to be non-adiabatic. When the island width exceeds the width of the hydrodynamic channel the region of non-adiabatic behavior is broadened, as eddies show a tendency to propagate along the separatrix. The turbulent fluctuations are found to exert a drag on the island, slowing and even weakly reversing the propagation velocity so that after saturation the island is drifting slowly in the ion diamagnetic direction.

This work was supported by US DoE contract No. DE-FG03-96ER-54346 and by the Center for Multiscale Plasma Dynamics under contract No. DE-FC02-04ER54785.
A gyrokinetic investigation of ion temperature gradient (ITG) modes and collisionless trapped electron modes (TEMs) is presented for the stellarator Wendelstein 7-X (W7X) [G. Grieger et al., Plasma Physics and Controlled Nuclear Fusion Research 1990 (International Atomic Energy Agency, Vienna, 1991), Vol. 3, p. 525]. The employed geometry consists of a flux tube based on Clebsch-type coordinates and generated by a vacuum magnetic equilibrium. The study of the ITG mode - assuming both adiabatic and full electron dynamics - reveals that in W7X different microinstabilities may coexist. Special attention is paid to the relative separation of regions with a large fraction of magnetically trapped particles and those of bad curvature. This feature results in a weaker destabilization for both ITG and TE modes, as compared to a large aspect ratio tokamak. In addition, the W7-X configuration manifests strong zonal flows with associated low radial transport.
In the LHD experiments, observed density profiles are usually hollow, for example, in a configuration with R=3.75m. On the other hand, in the neoclassically optimized configuration with R=3.53m, it is found that the density profile tends to be peaked. Here we investigate the neoclassical (NC) and anomalous quasi-linear (QL) particle fluxes, in order to discuss the above tendency of the density profiles observed in two LHD configurations whose magnetic axis in vacuum are R=3.75m and R=3.53m.

Three density profiles are assumed as in Fig.(a); peaked (circles), squares (hollow) and intermediate (triangles). The temperature is assumed as $T=T_0(1-\rho^2)$ with $T_0=1[\text{keV}]$. Also $B_0=1[\text{T}]$ is assumed. The NC particle fluxes for these density profiles are shown in Fig.(b). It can be seen that the NC particle flux is almost independent of density profiles, while it shows strong configuration dependence. The latter can be explained by the strong change of effective helical ripples. The weak dependence on the density profiles, or $1/L_n$ on the NC particle flux in the $1/nu$ regime can also be explained by the dominant role of $1/L_T$. Next the QL particle flux is plotted as a function of $1/L_n$, which is calculated by GOBLIN code based on the linear gyrokinetics. Here electrostatic assumption is used, and the instability can be identified as ITG mode. As is contrast to the neoclassical case, it strongly depends on $1/L_n$; the sign is changed as $1/L_n$ becomes negative. Here we consider the particle balance equation, $\partial n/\partial t + \nabla \cdot \Gamma = S$, where $S$ is particle source. In the gas puff plasmas, the source is deposited only near the edge, so that in the steady state in the core, radial component of flux should be zero; $\Gamma^{NC} + \Gamma^{QL} = 0$. Since the positive tendency of $\Gamma^{NC}$ is robust, when $\Gamma^{NC}$ is large, the negative $\Gamma^{QL}$ is needed. This will impose the density profile to be hollow, from Fig.(c). In the case of R=3.53m, the QL flux itself should be zero because the NC flux is sufficiently reduced. From Fig.(c), this can be realized at some positive value of $1/L_n$. In this case, the density profile will be imposed to be peaked, as is usual in tokamak case.

![Figure: (a)Assumed density profiles, (b) Neoclassical particle flux in R=3.75m(solid) and R=3.53m(dashed) LHD configurations, and (c) quasi-linear particle flux in R=3.75m.](image)
We investigate the effects of plasma instabilities generated in a 3D reconnecting current sheet (RCS) with normal and anomalous resistivity on particle acceleration and their effect on the reconnection electric field by means of the test particle simulations for different magnetic topologies. The effects of the electric field induced across the RCS by fully separated beams are also evaluated for different RCS thicknesses.