

Turbulence Suppression and Shear Flow Dynamics During Transitions to Enhanced Confinement Regimes*

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Understanding the bifurcation processes that lead to enhanced confinement regimes is crucial to predicting their dependencies on operational parameters and optimizing plasma performance. Recent advances in measuring local turbulence characteristics at high time and spatial resolution across the core and edge plasma have dramatically improved our understanding of the transition mechanisms. For example, new control capabilities and operational parameters demonstrate how such plasma properties as core rotation, working-ion mass, scrape off layer flows, safety factor profile, and the equilibrium magnetic field geometry can dramatically influence transition behavior. This presentation will discuss recent advances in the understanding of transition mechanisms, including the edge and core fluctuation and flow behavior, before, during, and after the L-H transition, and during Internal Transport Barrier formation. Unprecedented details of the turbulence dynamics near transitions are now available through new and improved fluctuation diagnostics, such as: Beam Emission Spectroscopy, Doppler Reflectometry and Correlation ECE. A unifying feature of edge (L-H) and core (ITB) transitions is that turbulence and transport reduction occurs as locally measured shearing rates (dv_{θ}/dr) in the turbulence flow field increase and exceed locally measured turbulence decorrelation rates, as determined through 2D fluctuation measurements of amplitude, decorrelation rates, equilibrium and time-varying (zonal) shear flows, and correlation lengths. Novel analysis techniques can also probe the nonlinear interactions between turbulence and shear flows. Observed features show consistency with the ExB shear model, as well as with simulations of core turbulence dynamics. New insights into the mechanisms that affect local turbulence suppression and consequent performance improvement are providing valuable information to guide predictions of the L-H power threshold and expected confinement in ITER and other future experiments.

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Bias-driven confinement transitions in the Large Plasma Device

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Azimuthal flow is driven in the edge of the Large Plasma Device (LAPD) through biasing a section of the vacuum vessel relative to the plasma source cathode. As the applied bias exceeds a threshold, a transition in radial particle confinement is observed¹, evidenced by a dramatic steepening in the density profile, similar to the L- to H-mode transition in toroidal confinement devices. The threshold behavior and dynamic behavior of radial transport is related to flow penetration and the degree of spatial overlap between the flow shear and density gradient profiles. An investigation of the changes in turbulence and turbulent particle transport associated with the confinement transition is presented². Two-dimensional cross-correlation measurements show that the spatial coherence of edge turbulence in LAPD changes significantly with biasing. The azimuthal correlation in the turbulence increases dramatically, while the radial correlation length is little altered. Turbulent amplitude is reduced at the transition, particularly in electric field fluctuations, but the dominant change observed is in the cross-phase between density and electric field fluctuations. The changes in cross-phase lead to a suppression and then apparent reversal of turbulent particle flux as the threshold is exceeded. In order to help gain understanding of these observations, the 3D Braginskii fluid turbulence code BOUT is being used to model cylindrical LAPD plasmas. Comparisons of LAPD turbulence data with these simulations are underway and initial results will be presented.

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²T.A. Carter and J.E. Maggs, Phys. Plasmas 16, 012304 (2009)

Benefits of an extended low shear region for the confinement of tokamak plasmas

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Because internal transport barriers (ITBs) reduce or even quench the turbulent transport within the inner plasma region improving energy confinement in the plasma core which should yield high fusion gains, they have become an essential ingredient of advanced scenarios in which the tokamak could operate as an economic steady-state fusion reactor. Besides an increasingly detailed empirical and experimental knowledge, their theoretical modelling remains incomplete.

Recently, the crucial influence of the role played by the magnetic shear, or equivalently by the safety factor profile, has been experimentally evidenced. It has been shown to be a control parameter in the triggering of ITBs. This serves here as an invitation to focus on a purely magnetic, simplified, approach to investigate which characteristics of the safety factor profile are favourable to build robust ITBs [1]. The Hamiltonian representation of magnetic field lines is used through symplectic maps, such as the symmetric tokamap and its bounded version. It is shown that the existence of a region of vanishing shear is a decisive ingredient that drastically improves confinement. This is all the more beneficial as the radial extent of the low shear region is large, irrespective of the safety profile being monotonic or having reversed-shear. Localized current drive is suggested as a practical way to exploit this feature to build transport barriers. Consequences of this study in terms of equilibrium pressure profiles are presented.

[1] L. Nasi and M.-C. Firpo, 2009 *Plasma Phys. Control. Fusion* **51** 045006.

The H-mode Power Threshold in Hydrogen, Deuterium and Helium Plasmas in DIII-D*

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Determining the H-mode power threshold and validating H-mode threshold scaling relations are very important issues for next step fusion devices, such as ITER. In particular, investigating key physics issues in hydrogen or helium plasmas is vitally important for the first operational phase of ITER, which is planned to be with hydrogen or helium plasmas, and in which access to H-mode is critical for testing relevant hardware and control systems prior to the activated deuterium phase. The H-mode power threshold has been determined for plasmas heated by neutral beam injection (NBI) and/or by electron cyclotron heating (ECH) and as a function of the applied torque. Results will be presented for hydrogen, deuterium and helium plasmas for plasma configurations in the favorable ion grad B drift direction. These experiments have shown that the power required to induce the transition from L-mode to H-mode (the L-H transition) is strongly dependent on the injected neutral beam torque. Overall, the H-mode threshold power in hydrogen is approximately a factor of 2 greater than in deuterium plasmas at comparable torque. Interestingly, the threshold power for hydrogen discharges with full counter current beam injection is found to be roughly the same as the threshold power for deuterium discharges with co-current beam injection.

The effects of varying the heating methods by using either NBI or ECH or a combination of both were also determined. For hydrogen and deuterium plasmas, the H-mode power threshold using ECH (or a combination of ECH+NBI) is 20–40% lower than that for discharges using NBI alone at zero applied torque (i.e., with balanced beam injection).

Changing the plasma geometry by decreasing the vertical distance between the X-point and the lower divertor surface from 26 cm to 10 cm led to a significant (~25–30%) reduction in the threshold power. The trend of increasing threshold power with increasing injected torque is still present. Analysis is underway to determine the cause of this reduction in threshold power, which may be related to the plasma flows at the plasma edge and the scrape-off layer.

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First Results of ELMy H-mode Experiments on HL-2A Tokamak

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H-mode discharges have been achieved in HL-2A by combining the auxiliary heating of NBI ($P_{\text{NBI}} < 0.8$ MW) and ECRH ($P_{\text{ECR}} < 1.2$ MW) with 2nd harmonic X-mode, which are strongly dependent on the optimized discharge conditions, including the total power of the auxiliary heating, good wall conditioning and divertor configuration, titanium gettering in divertor chamber, SMBI fuelling and density feedback, suitable density range, etc. The Type III ELMs with typical frequency of ~ 400 Hz can be sustained more than ten times of energy confinement time with enhanced confinement factor $H_{89} > 1.5$. The H-mode duration is usually determined by auxiliary heating one.

Figure 1 shows a discharge of H-mode with Type-III ELMs in HL-2A. The divertor configuration is used after a discharge startup soon to decrease the radiation power. After NBI heating with the stable power about 700 kW is turned on at $t = 480$ ms, plasma stored energy gradually rises in the timescale of energy confinement time and then begins to drop a little, which means the discharge to enter L-mode. After the ECRH with an averaged power of 830 kW is added at $t = 670$ ms, D_{α} emissions in main or divertor chamber clearly rise and then dramatically drop, following the H-mode appearance with Type III ELMs. The plasma density, radiation power and energy still continuously increase in energy confinement time just after H-mode transition. The H-mode is ended with a time delay of ~ 5 ms after the auxiliary power is turned off.

The optimized parameter ranges of H-mode discharges are investigated after it is observed. The initial plasma density is a rather important parameter, which is limited in $(1.4-1.8) \times 10^{19} \text{ m}^{-3}$ due to the use of ECRH method. The ECRH power will be reflected if density $n_e > 2.2 \times 10^{19} \text{ m}^{-3}$. The generation of H-mode discharges mainly depends on total heating power, which is almost independent of heating methods. The longest H-mode sustains for 650 ms, it is only limited by the heating duration. The SMBI fuelling is superior to gas puffing because the former has less recycling than the latter. Further investigation on H-mode in HL-2A with ECRH power up to 3 MW is to be done.

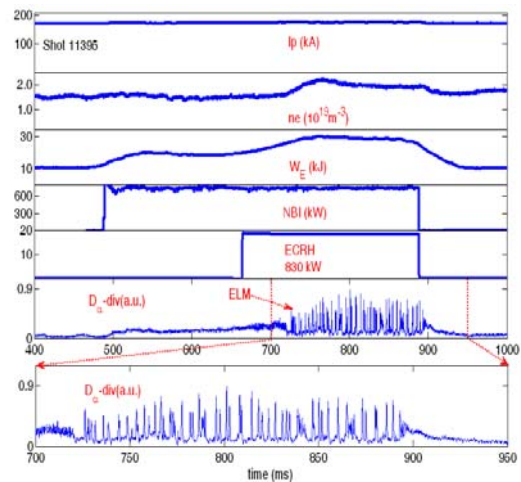


Figure 1. A primary discharge of H-mode with Type-III ELMs in HL-2A.

The waveforms from top to bottom are the plasma current, line-averaged density, stored energy, NBI and ECRH power, D_{α} emissions in the divertor chamber.

Improved L-Mode plasmas with decoupled energy and particle edge barriers in Alcator C-Mod

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The “improved L-mode” plasma confinement regime potentially offers both an attractive operating regime and new insights into transport barrier physics. As reported on ASDEX Upgrade [1], the regime occurs on Alcator C-Mod in the ‘unfavorable’ magnetic configuration, with the ion $\mathbf{B} \times \nabla B$ drift pointing away from the active x-point when, as is well known, the power threshold for the L-H mode transition is higher than in the ‘favorable’ configuration with drifts toward the x-point. At intermediate powers, in many cases edge temperatures gradients steepen, to levels approaching those in H-mode, indicating a clear energy transport barrier. Unlike the classic L-H transition, however, the change is gradual, apparently not a bifurcation, and does not exhibit the usual sharp drops in fluctuations, D_α etc. [2]. Density gradients remain low as in typical L-modes, indicating little reduction in edge particle transport, and indicating an atypical decoupling of the energy and particle transport channels. In recent C-Mod experiments, the improved L-mode regime has been extended from transient periods to a quasi-steady operational regime, with energy confinement approaching that in H-modes. This and the addition of new diagnostics, in particular Charge Exchange Recombination Spectroscopy, have enabled more complete measurements of barrier profiles and fluctuations. Notably, it is found that an E_r well develops in the Improved L-mode, but that it is shallower and has lower shear than that in H-modes, which exhibit both a particle and energy transport barrier. Possible implications of these results for the physics of energy and particle transport suppression and barrier formation will be discussed.

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[3] R. M. McDermott, B. Lipschultz, J. W. Hughes *et al*, Physics of Plasmas **16** (5) 056103 (2009).

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Edge radial electric field structure on JT-60U and its connection to H-mode characteristics

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Charge-eXchange Recombination Spectroscopy (CXRS) measurements with high-spatial and temporal resolutions have enabled the first evaluations of the radial electric field in the JT-60U tokamak peripheral region. We revisited to measure the edge impurity ion dynamic with new CXRS in the hot ion H-mode regime at the high magnetic field of $B_T \sim 4\text{T}$ having two steps transition where a jump of ion temperature gradient precedes a jump of impurity poloidal rotation [1]. In this study, two discrete phases with different magnitude of radial electric field in the H-phase have been observed; one is the “intermediate” H-phase having a large ion temperature gradients without significant poloidal rotation of impurity species (and with moderate magnitude of radial electric field), and the other is the “complete” H-phase characterized by a large radial electric field. The most important feature is that there is a bifurcation branch in terms of the E_r transition between two discrete H-phases (so-called H-H transition), which indicates not only the direction towards moderate to large E_r -well but also the direction towards large to moderate E_r -well.

In the hot ion H-mode regime, no abrupt change in the edge temperature (excepting for continuous increase with time similar to the diamagnetic stored energy) are seen at the L-H transition, exhibiting a smooth transition within a time-scale of ~ 50 ms. However a detailed comparison of the edge temperature, density and E_r structures between L- and H-phases results in a distinct features as the both temperature and density gradients buildup associated with the formation of the E_r -well of ~ 40 kV/m near the location at the steep gradient, indicating a clear pedestal structure. A faster and deeper drop in the D_α emission within less than a few millisecond is found during a stationary ELM-free H-phase. It is observed that a rapid change in the E_r -well structure toward more negative by approximately a factor of two, exhibiting the E_r -well of ~ 80 kV/m (or more negative). These observations, made in discharges with various externally applied torque in direction towards co- and counter-parallel to the plasma current using tangential-NBI plus no significant external applied torque using balanced tangential-NBI and/or perpendicular-NBI, provide for important and new information on the transition phenomenology in the H-mode discharge.

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Microwave Reflectometry Measurements of Core-Edge Turbulence Near the L-H Transition in NSTX

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Recent upgrades to the microwave reflectometry hardware on NSTX have allowed simultaneous measurements of rapid changes in both the electron density profile and the associated turbulence characteristics. The frequency-modulated continuous-wave (FMCW) reflectometer probes a density range of $0.21\text{-}3.5\times 10^{13}\text{ cm}^{-3}$, with a corresponding spatial coverage extending from the plasma core to near the LCFS during the typical L-mode phase of a discharge. This system now has a repetition rate of $7\text{ }\mu\text{s/sweep}$, which allows the diagnostic to measure turbulence levels and radial correlation lengths with time resolutions close to or better than $\sim 100\text{ }\mu\text{s}$, in addition to the evolution of the background density profile. The correlation reflectometer is operated as two poloidally separated channels with identical microwave frequencies for estimating flow velocities. Frequencies can be either fixed or scanned to access densities in the range of $1.0\text{-}2.0\times 10^{13}\text{ cm}^{-3}$. During the L-mode phase, a clear demarcation between the larger edge and smaller core turbulence usually exists. Closer to the L-H transition, intermittent drops in the edge turbulence appear and are strongly correlated with a local steepening of the edge density gradient. Simultaneous increases in the edge flow are also seen. This cycle repeats itself several times before leading to the final transition into H-mode. Details of the density profile and core-edge turbulence dynamics for L-H transitions under a wide variety of discharge conditions will be presented. Comparisons with theory will be discussed.

Observation of the edge radial electric field and plasma rotation evolution in the counter-NBI assisted *LH* transition in low density plasmas in the TUMAN-3M

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Abstract

LH transition at very low density has been observed in the experiments on counter-current Neutral Beam Injection (NBI) in the TUMAN-3M tokamak [1]. The transition has been found at target average density as low as $0.5 \cdot 10^{19} \text{ m}^{-3}$, which is by a factor of 2.5 lower than the *LH* transition density boundary in ohmic and co-current NBI heated plasmas. Model predicting generation of a negative radial electric field E_r , which is thought to help *LH* transition during counter-NBI has been developed. The model conjectures development of the E_r and toroidal rotation V_ϕ in the presence of large ion orbit losses in the counter-NBI scheme.

In the recent experiments the measurements of the edge radial electric field and plasma potential fluctuations by electrostatic probes have been performed. Paper reports emergence of a negative E_r of $\sim 4 \text{ kV/m}$ inside LCFS at the transition time. Potential fluctuations are found to drop simultaneously. The above observations support the assumption of E_r significance in the *LH* transition at low density through the turbulence stabilization mechanism by $E \times B$ sheared flow.

Doppler spectroscopy was used to measure toroidal rotation evolution during the *LH* transition. Spectral shift of B^{3+} impurity has shown an increase in the V_ϕ of $16 \pm 6 \text{ km/s}$ after counter-NBI switch on. The measured V_ϕ agrees with the above model estimations.

Reference

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New analysis of H-mode transition by Reynolds number based on the gyrocenter shift and comparison with NSTX results.

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Abstract:

A new concept of turbulence transport and diffusion coefficient are derived from the microscopic ExB drift at tokamak boundary by characterization of the gyrocenter shift induced by ion-neutral collisions. It is found that when the viscosity force of the ion-neutral collision is counted, the plasma Reynolds number of the poloidal ion flow in the vicinity of separatrix vary over the critical value between turbulent and laminar flows depending on the plasma parameters such as temperature, neutral density and density fluctuation level, which explains the mechanism of H-mode transition [1]. In this presentation, the concept of gyrocenter shift with formation mechanism of radial electric field [2][3] and preliminary result of NSTX H-mode study based on the gyrocenter shift will be included.

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[3] K.C. Lee, Physical Review Letters, Vol-99, 065003 (2007)

Overview of L-H Power threshold studies in NSTX

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We present a summary of results from recent L-H power threshold (P_{LH}) experiments in NSTX. First it was observed that P_{LH} was $\sim 50\%$ lower at low triangularity than medium and high triangularity, with the latter two having comparable P_{LH} . Second it was found that use of thick lithium wall coatings reduced P_{LH} by 50% as compared with discharges with thin or no Lithium coatings. Third, P_{LH} was found to increase strongly with plasma current for sustained H-modes. Fourth, the application of non-axisymmetric $n=3$ fields was found to increase P_{LH} by $\sim 70\%$. Fifth, comparable P_{LH} was found using either RF and NBI heating, suggesting that rotation was not playing a big role in setting P_{LH} . Finally P_{LH} was found to be a minimum near double-null configuration, and tending to increase as the plasma was shifted more strongly toward lower-single null configuration. All of these experiments were conducted with the ion grad-B drift in the favorable direction toward the lower X-point. The details of these observation and comparisons between the profile evolution and simulations will be presented.

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Effects of Pellet Injection on Plasma Properties in ITER Standard *H*-mode Scenario

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Abstract

Impact of increasing nuclear fusion performance in ITER via pellet injection method is investigated using the 1.5D BALDUR integrated predictive modeling code. In these simulations, the behavior of pellet in the plasma is described using the Milora-Foster model [1]. The plasma core transport is described by a combination of an anomalous transport calculated from the theory-based MMM95 model and a neoclassical transport calculated from the NCLASS model. In addition, the boundary condition is provided by a predictive pedestal model based on theoretical pedestal width scalings (either magnetic and flow shear stabilization width scaling, or flow shear stabilization width scaling, or normalized poloidal pressure width scaling) and ballooning mode pressure gradient limit. In this work, it is found that utilizing pellet injection results in a complicated plasma scenario, in which an impact of pellet on the plasma depends sensitively on the pellet's parameters such as pellet's size, pellet's velocity and pellet's frequency. It is also found that applying pellet injection can result in an increase of plasma density in ITER, but does not result in a peaking of plasma density at the center. Instead, the pellet forms a peak in the outer region near the plasma edge, at which the peak location depends on the pellet's velocity. For example, when a pellet with size of 0.4 cm, velocity of 2 km/s and frequency of 2 Hz is utilized for 20 sec, the plasma performance, evaluated in term of Fusion Q, increases up to 12-31%, depending on the pedestal model used. A Pellet with sufficiently large size or high frequency can result in an enormous degradation of plasma performance due to significant reduction of plasma temperature.

[1] W. A. Houlberg *et al.*, 1988 Nucl. Fusion **28**, 595

Transport Properties of Internal Transport Barriers in JET/JT-60U Identity Experiments

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A variety of triggering mechanisms and structures of internal transport barrier (ITB) has been observed in various devices or depending on operation scenarios. Thus identity experiments on ITB in JT-60U and JET have been performed to shed light on the physics behind ITBs. Because of their similar size, the dimensionless parameters between both devices are the same except the Mach number due to the different Neutral Beam Injection (NBI) configuration. These experiments were performed with near identical magnetic configurations, heating waveforms and normalized quantities such as safety factor, magnetic shear, normalized Larmor radius, normalized collision frequency, beta, temperatures ratio. Similarities of the ITB triggering mechanism and the ITB strength have been observed when a proper match is achieved of the most relevant profiles of the normalized quantities [1]. This paper will report on the detail comparison of transport properties of ITBs obtained in these JET/JT-60U identity experiments.

In the series of experiments, ITBs were produced with various target q profiles, such as reversed magnetic shear (RS) with $q_{\min} = 3$ or 2, or weak (optimized) magnetic shear with $q(0) \sim 2$, by adjusting the start time of the main heating. The toroidal rotation profiles were scanned in the case of RS with $q_{\min} = 3$ in order to find the closest match in rotation. The combination of tangential NBI was changed from balance to co-current dominant injection in JT-60U, whereas the toroidal field ripple at JET was varied from 0.08% (lowest) to 0.3% (similar to JT-60U), then to 0.8% (highest) in order to vary the toroidal rotation and therefore get closer to the Mach number observed in JT-60U.

The first results of transport analysis using the JETTO code show that ion thermal diffusivity profiles for both devices are very similar in the case of RS with $q_{\min} = 3$. The paper will discuss the results of transport analyses, which are the non-linear gyro-kinetic stability analysis and first principle transport modeling, to examine the effects of magnetic shear and ExB shear models.

NSTX reversed-shear internal transport barriers

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In the NSTX, internal transport barriers (ITBs) are observed in reversed (negative) magnetic shear discharges where diffusivities for electron and ion thermal channels and momentum are reduced [1]. Neutral beam heating can create ITBs in both electron and ion channels, but High Harmonic Fast Wave (HHFW), can create electron thermal ITBs without momentum input. The electron ITB location correlates well with the location of minimum magnetic shear determined by Motional Stark Effect (MSE) [2] constrained equilibria, while the ion ITB better correlates with the location of maximum $E \times B$ shearing rate. Statistical studies show that the maximum observed electron temperature gradients are a strong function of the magnetic shear, with a threshold condition in magnetic shear for electron thermal ITBs. A high-k microwave scattering diagnostic [3] has measured reduced local density fluctuations at wavenumbers characteristic of electron turbulence [4] for discharges with strongly negative magnetic shear compared to weakly negative or positive magnetic shear. The onset and growth of fluctuations has been observed immediately following a change in the local magnetic shear, resulting in the relaxation of the local electron temperature gradient and a displacement of the electron ITB location. High-k fluctuations have been observed in several interesting regimes, including a bursty regime at intermediate shear that regulates the maximum electron transport. These results are consistent with non-linear gyrokinetic simulations predictions showing the reduction of electron transport in negative magnetic shear conditions despite being linearly unstable [5]. Linear gyrokinetic simulation results for NSTX show that while measured electron temperature gradients exceed critical linear thresholds for ETG instability, grow rates can remain low under reversed shear conditions up to high electron temperatures gradients.

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[3] D.R. Smith, E. Mazzucato et al., RSI **75**, 3840

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A Simple Dynamical Model of Flux-Driven Turbulence and Profile Evolution

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In this paper we present studies of non-local, flux driven turbulence and profile evolution using a simple model consisting of coupled: a.) non-linear reaction-diffusion equation for the turbulence intensity field which includes $E \times B$ shearing effects on intensity scattering cross-phases and turbulence drive; b.) heat transport equation which supports transport bifurcations and which incorporate intensity driven turbulence transport and neoclassical transport. This system extends previous modeling of nonlinear intensity equations⁽¹⁾ coupled to heat transport⁽²⁾. The model is used in a series of basic studies motivated, in part, by recent full-f global gyro-kinetic simulation results⁽³⁾.

We study temperature profile evolution in the presence of turbulence produced in the near-edge region, which subsequently spreads inward and which may interact with both heat pulses and with locally driven core turbulence. All turbulence is flux driven. Several rather basic results emerge. These are: a.) propagation of intensity and heat pulse differs fundamentally, in that the speed of the former grows and then decays as the heat flux is increased, while the latter grows and then saturates at a value set by neoclassical transport. This distinction may be used as a critical test of non-locality effects in cold pulse propagation experiments; b.) the speed of inward propagating of turbulence produced by a strong edge source (i.e. T_i pedestal broader than the density pedestal) is surprisingly sensitive to the strength of the heat flux Q . We show that the turbulence propagation speed of fast increases with Q and then decreases, following the formation of internal transport barrier. This suggests that the ITB location is ultimately determined by both heat flux and near edge conditions, and that the ITB works as much by keeping turbulence out as by keeping heat in! c.) We demonstrate that collisions of in \rightarrow out and out \rightarrow in pulses⁽³⁾ triggers local profile steepening, and (in some cases), ITB formation. Moreover, the interaction point varies with the heat flux Q .

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GPI Measurements of Edge and SOL Turbulence Across the L-H transition in NSTX

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Edge turbulence across the L-H transition has been measured using the gas puff imaging (GPI) diagnostic over a 2-D region ~ 20 cm poloidal by ~ 20 cm radial at the outer midplane edge and scrape-off-layer (SOL) of NSTX. An improved GPI camera system is capable of imaging up to 300,000 frames/sec for over 50 msec at $4 \mu\text{s}/\text{frame}$ with a ~ 1 cm spatial resolution.

The GPI system shows a clear reduction in the SOL turbulence fluctuation levels over a period ~ 20 - $100 \mu\text{s}$ during the L-H transition. The cross-correlation data from the GPI diagnostic has been analyzed to determine the time- and space-dependent radial and poloidal correlation lengths L_r and L_p and flow speeds V_r and V_p across the transition. From these measurements the local dimensionless poloidal flow shear $S=(dV_p/dr)(L_r/L_p)\tau$ can be estimated by averaging the turbulence flow speed over a suitable space and time range. In the near-SOL this shear ranges between ± 2 (with a relatively wide scatter), but there does not yet appear to be a clear correlation between the magnitude of S and the local fluctuation level across the transition. An alternative explanation for the decrease in SOL turbulence at the transition would be a non-local effect propagating outward from the region a few cm inside the separatrix, where the GPI can not measure. Therefore a comparison will be made between the turbulence seen by GPI and by the UCLA edge reflectometry diagnostic to determine whether the transition begins inside or outside the separatrix, and how the turbulence changes propagate during the transition.