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TURBULENCE SUPPRESSION AND TRANSPORT BARRIER FORMATION IN JET AND ASDEX UPGRADE

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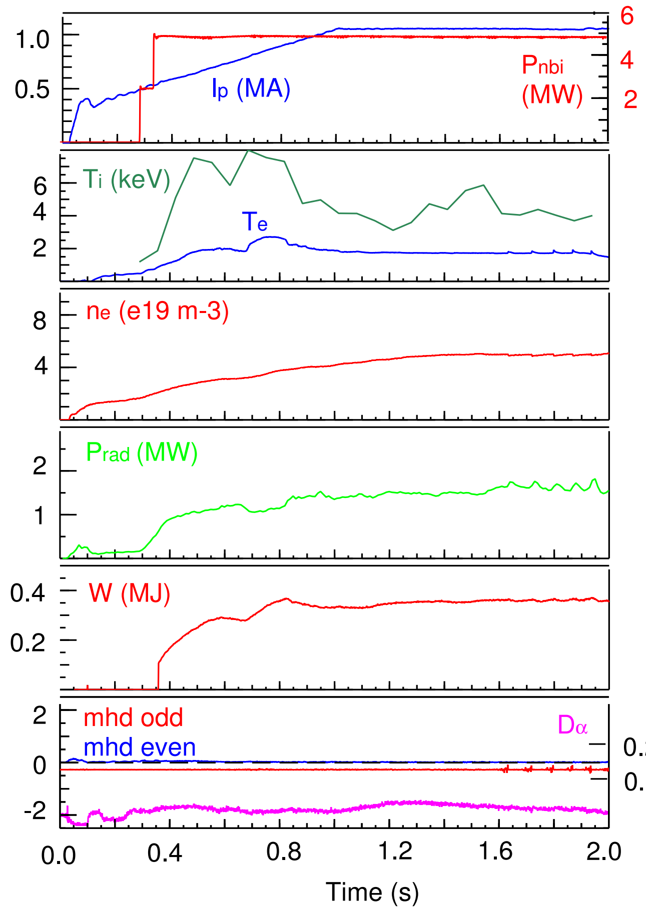
1. Introduction

In this paper we present the latest results on density turbulence measurements in ASDEX Upgrade (AUG) during the formation of Internal Transport Barrier (ITB) with L-mode edge and with enhanced H-mode. A case study is presented for each discharge type and then compared with corresponding JET results. Since the JET results have been previously reported [1] they are not repeated here. Note that the selection of AUG discharges is based on the availability of good turbulence measurements and not necessarily for best plasma performance.

2. Diagnostics

The turbulence measurements were made on AUG using a multichannel profile reflectometer operating in fixed frequency mode [2] and a 2 channel fluctuation reflectometer. All the core channels are O-mode covering a density range of 0.4 - 6.5 × 10^{19} m^{-3} with half the channels using low field side launch from hog-horn antennas and half on the high field side. All systems use single ended detection (i.e. $A\cos\phi$ signal) with a data acquisition rate of 500kHz for 1.6s (profile) or 8s (fluctuation systems).

Fig.1: Time traces of a) I_p and P_{nbi} b) T_i & T_e, c) n_e line ave. d) Radiated power, e) Stored energy, f) mhd signals & D_α for shot 13553 (2.6T/1MA/s).



3. AUG ITB with L-mode edge

Fig.1 shows the temporal evolution of the main plasma parameters for a 2.6T, ~1MAs^{-1} discharge (shot 13553) with an inner limiter configuration. 5MW of NBI is applied during the I_p ramp to form an ITB at ρ ~ 0.6 (poloidal flux coordinate) with an L-mode edge. The discharge is similar to those described in reference [3]. Fig.2 shows radial profiles of T_i (CXRS), T_e (ECE), n_e (Thomson scattering) and q when the ITB is strongest at t = 0.78s. Unfortunately there is no MSE data for this shot so the q profile is taken from a very similar discharge - indicating reversed magnetic shear. For this shot T_i (8keV) > T_e (3keV) with a central density of n_e ~ 6 × 10^{19} m^{-3}.

During the brief ITB phase several reflectometer channels are in close radial proximity to the barrier and show a fall in the level and spectral composition of the density turbulence.

Fig.2: Radial profiles of T_e (ECE) T_i (CXRS), n_e (Thomson) and q (with MSE from 12224) at t=0.787s in shot 13553.

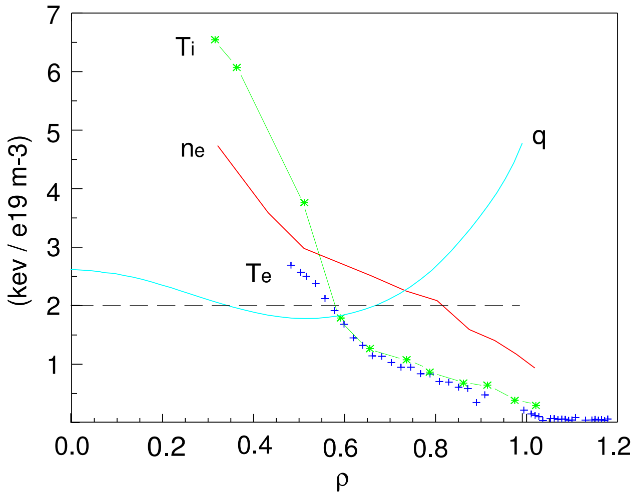
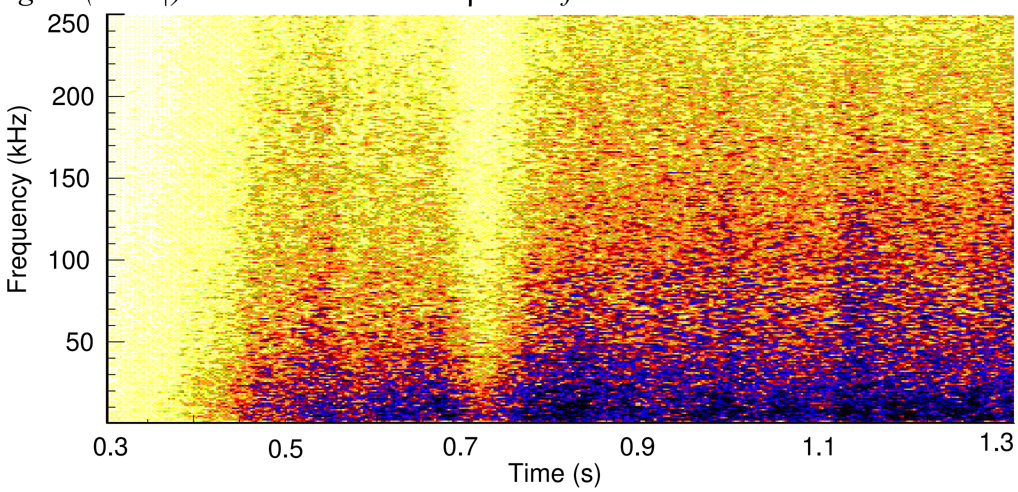


Fig.3 shows a spectrogram of fluctuations in the reflectometer signal (Acosϕ) for a 46GHz channel on the plasma high field side. The channel begins to reflect around t ~ 0.35s at ρ ~ 0.4 with the cut-off layer moving out to ρ ~ 0.6 between 0.5 and 0.9s and then slowly out to ρ ~ 0.9 after 1.0s. The fall in the high frequency components at 0.7s correlates both spatially and temporally with the ITB forming in T_i, T_e and v_{rot}. Fig.4 shows a contour plot of the toroidal rotation velocity (in kms^{-1}) from CXRS. The crosses mark the location of the ITB foot (from T_e) which coincide with regions of enhanced rotation/shearing. Corresponding reflectometer channels which remain in the core at ρ ~ 0.4 and edge ρ ~ 1.0 show no fall in fluctuation level. Measurements from other discharges with cutoff layers sweeping through the ITB confirm that the drop in signal fluctuations is highly localized to the barrier gradient region.

Fig.3: Spectrogram of fluctuations from 46GHz high-field-side reflectomter channel signal (Acosϕ) at normalized radius ρ ~ 0.6 for shot 13553.



The density profile is not well resolved by the Thomson scattering diagnostic (the only available profile diagnostic at this time) however the data from the line averaged density (DCN interferometer) - together with other examples [3] - suggest there is no strong steepening in the density gradient. This means that the reflectometer fluctuations represent a true drop in density turbulence level and are not an artifact of the density gradient changing greatly. More fundamentally this also implies there is no particle barrier, only thermal barriers at the ITB.

4. Improved H-mode

A double transport barrier offers the possibility of even greater confinement properties. In AUG an H-mode discharge with "ITB like" core has received much attention and development [4]. Here the NBI power is stepped up in 2 stages (2.5MW during the I_p ramp & 5MW in the I_p flat top) to allow the formation of an H-mode edge barrier. These discharges are more difficult to diagnose with O-mode reflectometry because of higher plasma densities and large radial movement in the cutoff layers.

Fig.4: Contour plot of toroidal rotation velocity (CXRS) v. normalized radius and time for shot 13553.

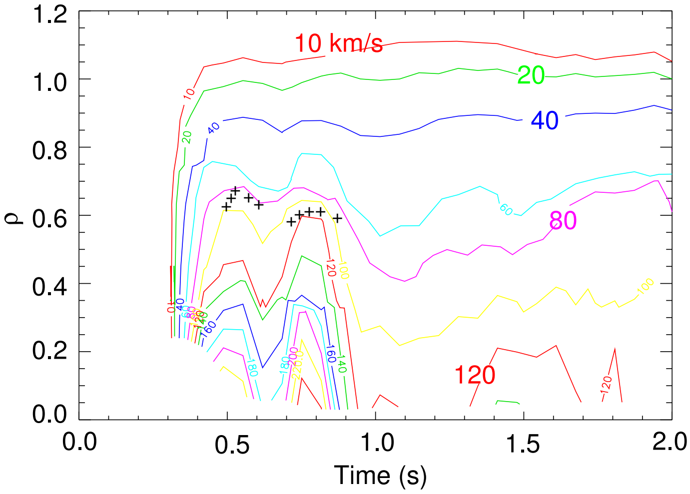


Fig.5: Spectrogram from 49GHz low-field-side reflectometer channel during shot 13356.

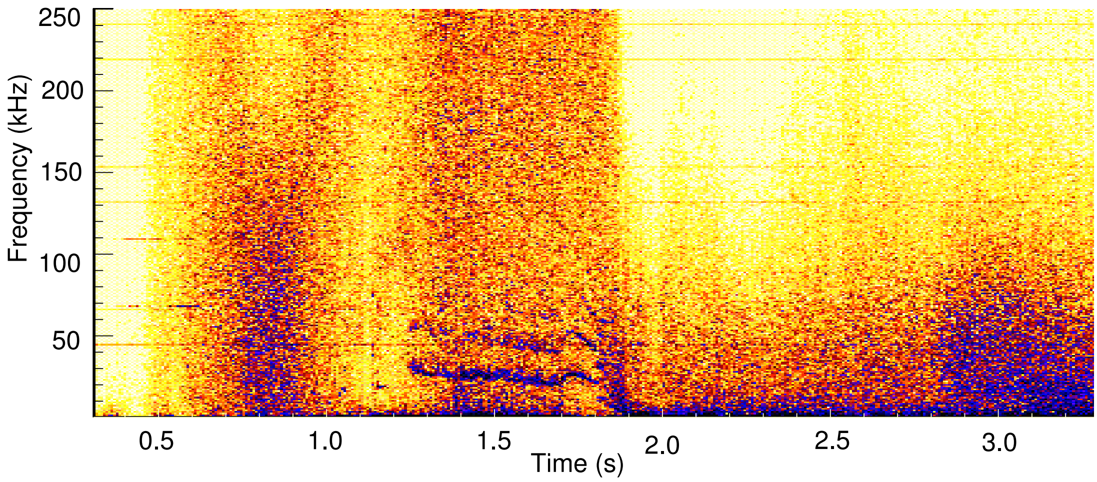


Fig.5 shows a spectrogram from a 49GHz low field side reflectometer channel for a 2.5T / 1MA discharge (shot 13356). Interestingly this discharge begins with a inner limiter L-mode phase, $t < 1.1s$, which generates a (weak) ITB at $\rho \sim 0.4$ expanding to $\rho \sim 0.6$ between $t \sim 0.7$ to 1.1s. As the reflectometer cutoff layer sweeps through the ITB region there is again a fall in the high frequency turbulence. However the high frequency fluctuations rise in the edge during this time - most likely due to a reduced dge rotation velocity. With the 2nd NBI power step (with a lower single null X-point) an H-mode edge forms ($t \sim 1.2s$: fig.6), T_i, T_e, n_e, stored energy etc. rise but with enhanced performance above the standard H-mode. Note there is also strong fishbone activity and type I ELMs. These shots appear to show an "ITB like" core, but this may only be an artifact of profile resiliance. Unfortunately high densities restrict core reflectometer measurements, however, this particular shot was selected for another reason, at $t = 1.89s$ the (2,1) neoclasical tearing mode locks, the central T_i & T_e both collapse to ≈4keV, the rotation and density also collapse and the temperatue profiles flatten around $\rho \sim 0.6$, fig.7. With the density collapse the cutoff layer in fig.5 moves from $\rho \sim 0.85$ to ~0.6 and there is a dramatic fall in the high frequency turbulence.

Fig.6: Time traces of a) I_p and P_{nbi} b) T_i & T_e, c) n_e line ave. d) Radiated power, e) Stored energy, f) mhd, g) D_α for shot 13356 (2.5T/1MA).

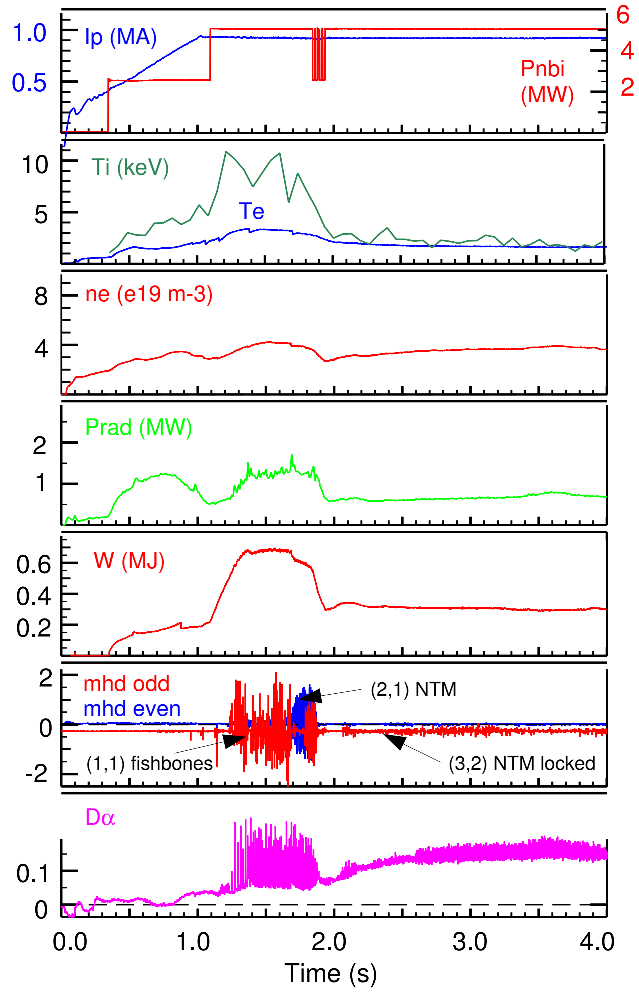
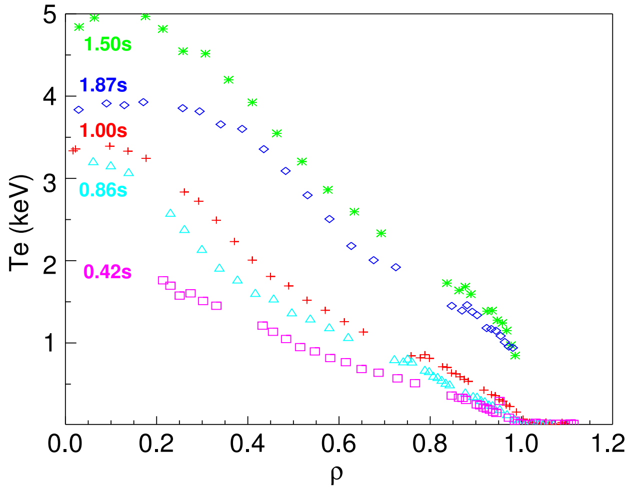


Fig.7: Radial profiles of T_e (ECE) at t = 0.42, 0.86, 1.00, 1.50 & 1.87s in shot 13356.



As the density slowly rebuilds, moving the cutoff back out to ρ ~ 0.8 at t ~ 3.0s, there is a consequent rise in turbulence. Although the large radial cutoff layer movement complicates the spectral evolution, it confirms the suppression of the high frequency turbulence in the initial ITB region - and gives the radial profile of the turbulence during the H-mode.

5. Comparison with JET ITB

The localized suppression of high frequency turbulence (f > 50kHz) in the ITB gradient region is a feature common to both AUG and JET ITBs [1], as is the coincidence of the strong toroidal rotation-shearing and the location of internal and edge transport barriers. In JET it is difficult to maintain edge and core barriers simultaneously. Data however suggests that to maintain two barriers may require two regions of shear rotation. One major difference between the JET and AUG L-mode shots is in the behavior of the low frequency fluctuations. In JET there was clear suppression of f < 20kHz across the core to the ITB foot correlated with a fall in ion thermal conductivity. In the latest AUG shots there is no corresponding suppression. This may be due to several reasons: different machine sizes (AUG: R_0/a = 1.65/0.5m, JET: 3.4/1.0m) and the dependencies of fluctuation wavelengths, or the q profiles, or specific diagnostic sensitivities. Possibly the lack of core suppression in these shots may account for their poor performance compared to previous [3]. A fuller interpretation must await further transport analysis.

References

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