Relationship between divertor collisionality and filament activity measured with reflectometry at ASDEX Upgrade

J. Vicente[1], D. Carralero[2], D.E. Aguiam[1], A. Silva[1], C. Silva[1], P.A. Schneider[2], M.E. Manso[1], L. Guimarãis[1], G.D. Conway[2], the EUROfusion MST1 Team* and the ASDEX Upgrade Team

[1]*Instituto de Plasmas e Fusão Nuclear, Instituto Superior Técnico, Universidade de Lisboa, 1049-001 Lisboa, Portugal*

[2]*Max-Planck-Institut für Plasmaphysik, 85748 Garching, Germany*

Introduction

Filaments of high density plasma play an important role in the cross-field heat and particle transport at the edge and Scrape-off Layer (SOL) of magnetic fusion devices. Their impact in the life-time of plasma facing components, for instance, is of great importance for future fusion devices. It is generally accepted that filaments (polarized electric dipoles in the poloidal plane) extend along the magnetic field lines and can be either connected or disconnected from the target plates depending on competing mechanisms. This establishes two possible filament regimes with different scalings between their perpendicular velocities and sizes. At ASDEX Upgrade (AUG) the collisionality in the divertor Λ_{div} has been suggested to control the transition (at $\Lambda_{\mathrm{div}}=1$) between the two regimes as well as to link with the so-called shoulder formation in the SOL density profiles of L-mode discharges [1]. Here we study these effects during L-mode and H-mode plasmas with strong emphasis on the analysis of reflectometry data.

Reflectometry Techniques

Reflectometry is a radar technique with good time and spatial resolutions that can be used to measure electron density profiles and fluctuations. Electromagnetic waves (O/X modes) are launched into the plasma and reflect at a critical electron density layer that depends on the probing wave frequency F (O-mode), or on both F and the local magnetic field (X-mode). In this study the 1D geometric optics approximation is used, that accounts for the phase shift $\Delta\varphi$ of the reflected wave to be proportional to the radial displacement Δr of the reflecting density layer ($\Delta r=\Delta\varphi c/4\pi F$, c is velocity of light). High radial velocity $V_r=\Delta r/\Delta t$ values due to the fast propagation of filaments, are then used to trace filament activity [2].

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*See http://www.euro-fusionscipub.org/mst1

Reflectometry Systems

Two O-mode systems in frequency bands Q (33-49.2 GHz) and V (49.4-72 GHz) were used operating in fixed frequency, providing both amplitude and phase measurements with 0.5μs time resolution. The minimum probing frequency (33 GHz with cut-off at $n_c=1.35\text{x}10^{19}\text{m}^{-3}$) sets the outer limit of probable plasma regions. A multichannel X-mode swept frequency reflectometer, was recently developed at AUG integrating the design of a new three-strap ICRF antenna [3]. This allows measurements of SOL density profiles up to $\approx 2\text{x}10^{19}\text{m}^{-3}$.

L-mode scans

The two filament regimes were analysed in L-mode plasmas by scanning Λ_{div} across the transition. This was achieved in plasma discharges where the total density was ramped up. Experiments were also performed at toroidal magnetic field $B_t=-2.1\text{T}$ to allow optimized SOL coverage by the new X-mode profile system - profiles were simultaneously obtained by plunging a Langmuir probe (LP) into the plasma, near the mid-plane. Results can be seen in Fig. 1 for two time periods corresponding to $\Lambda_{\text{div}}<1$ and $\Lambda_{\text{div}}>1$, respectively. The profiles from both diagnostics cover regions from the far-SOL up to $\rho_{\text{pol}}\approx 0.98$ and, in general, good agreement is found for $1.00<\rho_{\text{pol}}<1.04$ (separatrix at $\rho_{\text{pol}}=1.00$). It is shown that the gradient scale lengths become larger in the near SOL region with increasing discharge density. A swelling of the profiles is also observed in the far SOL. This is in line with other previous observations that suggested increasing levels of cross-field transport with convective components [4].

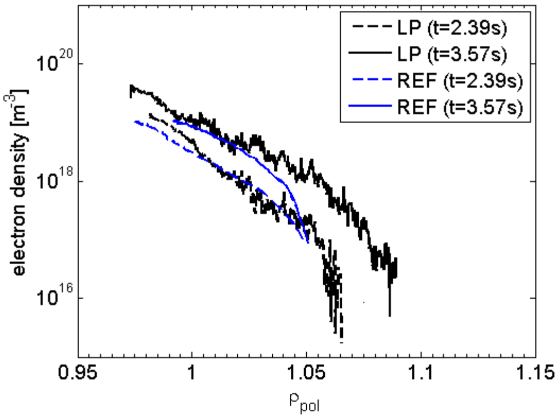

Figure 1: *Density profiles obtained with Langmuir probe (LP) and reflectometry (REF) during an L-mode density scan (AUG #33292).*

Profiles evolve with the density ramp up, and the (fixed) probed layers move to different radial positions. Using the frequency hopping capability of the O-mode system, a set of probing frequencies can be selected to probe the same radial location in different time periods. In Fig.2 it is shown the power spectra of the complex amplitude ($Ae^{i\varphi}$) obtained with the Q-band system in a discharge where frequency hopping (F=33,38 and 43GHz) was employed to probe regions at

$\rho_{pol}\approx 0.99$ across periods of different Λ_{div} values.

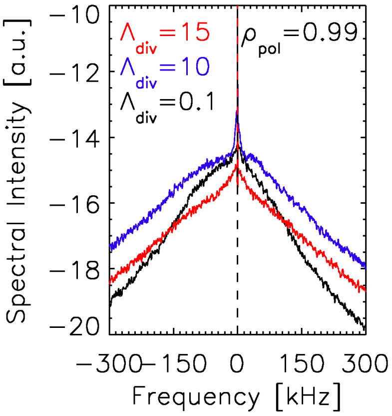

Figure 2: *Power spectra of the complex amplitude obtained with F=33,38 and 43GHz in L-mode plasmas with* $\Lambda_{div}=0.1,10$ *and 15, respectively (AUG #32192).*

Changes in the total reflected power may not be comparable due to different dependencies with *F*, for instance with the poloidal wavelength of density fluctuations at the cut-off. However, neglecting small asymmetries in the spectra (mainly visible in the lowest Λ_{div} period) due to possible Doppler effects, it is observed how the unshifted 0^{th} order reflection broadens with increasing collisionality. This broadening must be due to a transition into stronger scattering. The number of filaments (filament detection frequency) measured at this location does not seem to vary significantly at the Λ_{div} transition, as displayed in the top plot of Fig. 3. In fact, there is a ≈30% decrease in filament detections after divertor collisionality changes from $\Lambda_{div}=10$ to $\Lambda_{div}=15$. It is also observed that, independently of the collisionality, the maximum detection frequency lies just inside the separatrix. For inner regions, $\rho_{pol}<0.95$, filament detections are rare. More data points, in overlapping regions during the two filament regimes, would likely be required to draw additional conclusions. In particular, the lack of data close and outside the separatrix at low Λ_{div} is currently unavoidable with the fixed frequency systems used here.

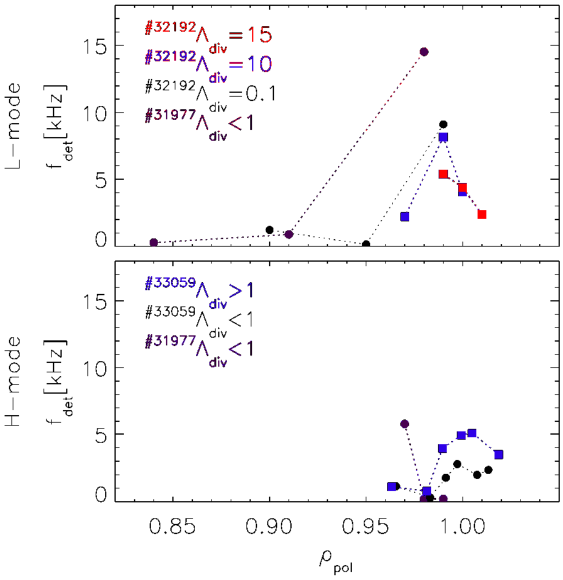

Figure 3: *Filament detection frequencies obtained from fixed frequency reflectometry at different radial positions and* Λ_{div} *values in L-mode (top) and H-mode (bottom) discharges at AUG.*

H-mode scans

To investigate the existence of a similar transition between filament regimes and SOL profiles in H-mode plasmas (presumably controlled by Λ_{div}) a series of experiments were recently conducted (see ref. [5] and subsequent works). It should be noted that only inter-ELM periods are considered here (and far away from the ELM onset) since ELM filaments likely display drive mechanisms and dynamics unrelated with interchange instabilities, as assumed for L-mode. Filament detections obtained with frequency hopping, as performed for L-mode, are displayed in the bottom plot of Fig.3. In this case, detection frequencies close and inside the separatrix are much lower than in L-mode, during low Λ_{div}, and of comparable values during high Λ_{div} regimes. Close and outside the separatrix, the detection profile seems to be flatter than in L-mode and higher with increasing Λ_{div}. The spectral broadening of density fluctuations, as observed in L-mode, is not so clear in the H-mode signals. This can be seen in Fig.4 where also a radially localized mode (close to the separatrix) with frequency $f\approx$80kHz is displayed in the reflected signal. Note that the increased Λ_{div} periods feature type-III ELMs which might display precursors with this characteristic frequency.

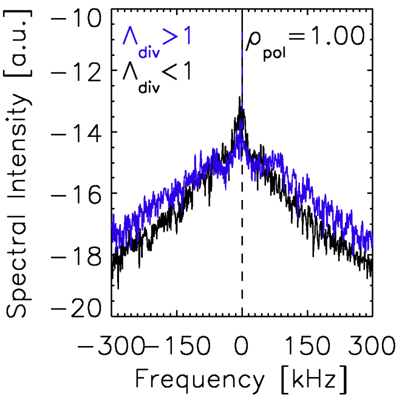

Figure 4: *Power spectra of the complex amplitude obtained with F=41GHz in inter-ELM H-mode plasmas.*

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