Studies of edge MHD modes in H-mode discharges in ASDEX Upgrade using reflectometry

S.da Graça[1], G.D.Conway[2], M.Maraschek[2], A.Silva[1], E.Wolfrum[2], R.Fischer[2], L.Cupido[1], F.Serra[1], M.E.Manso[1], the CFN reflectometry group[1] and the ASDEX Upgrade Team[2]

[1] *Centro de Fusão Nuclear, Associação EURATOM / IST, Instituto Superior Técnico, Av. Rovisco Pais, P-1049-001 Lisboa, Portugal*

[2] *Max-Planck-Institut fuer Plasmaphysik, Garching, Euratom Association, Germany*

1. Introduction

The H-mode regime is of particular importance for ITER due to the improvement of plasma confinement. The scenario is characterized by a decrease of edge turbulence, the formation of an edge transport barrier and the appearance of Edge Localized Modes (ELMs) which lead to a fast loss of energy and particles. Edge MHD instabilities in ELMy H-mode discharges, have been observed in several machines, including "Washboard modes" (WBs) in JET [1] and a quasi-coherent mode (QC) in Alcator C-mod [2]. In ASDEX Upgrade, a similar MHD mode around 90 kHz was previously observed but not extensively studied. In this paper, some properties of these edge MHD modes, their radial structure across the edge and their poloidal velocity are shown.

2. Technique

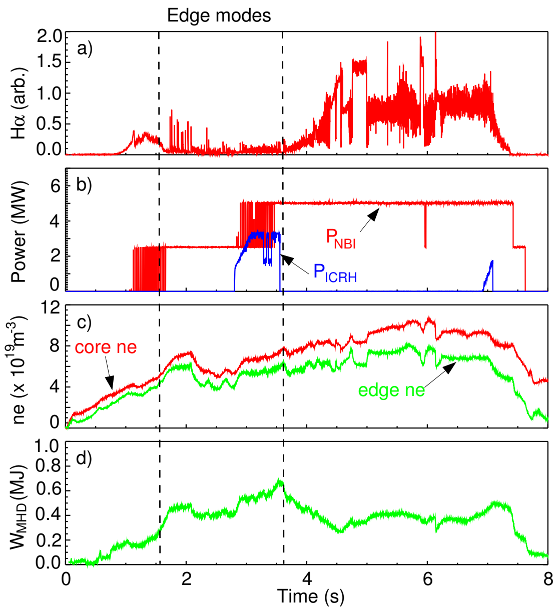

Figure 1: Time traces of (a)H_α, (b) NBI and ICRH power, (c) n_e at edge and core and (d) W_{MHD} for shot #20393.

In ASDEX Upgrade, a dual O-mode channel (Q-band: 33-49.2GHz and V-band: 49-72GHz) fast frequency hopping reflectometer with I-Q detection [3] is dedicated to n_e fluctuation measurements. To obtain the radial structure of coherent modes, the δn_e fluctuation level at each cutoff position is estimated using the 1D Geometric optics (GO) model [3]: $\delta\phi = (4\pi/\lambda)\,(\delta n/n)\,\nabla n^{-1}$, where λ is the vacuum wavelength of the probing wave. This model is strictly only valid for long fluctuation wavelength and small amplitude fluctuations. The antennae separation

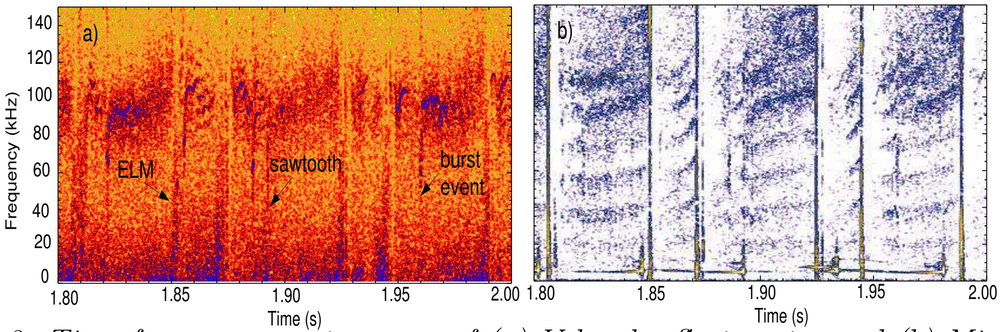

Figure 2: Time-frequency spectrograms of (a) V band reflectometer and (b) Mirnov coil signals for shot #20393.

between Q and V-bands is 32 cm and so the poloidal velocity can be deduced through poloidal correlation.

3. Properties of edge MHD modes

Figure 1 shows time traces of H_{alpha}, NBI and ICRH power, n_e at the edge and core and the stored energy W_{MHD} for the typical H-mode discharge #20393. The vertical lines on the figure indicate the time slot when edge MHD mode are seen. In this case, the disappearance of these edge modes seems to be consistent with the decrease of W_{MHD}.

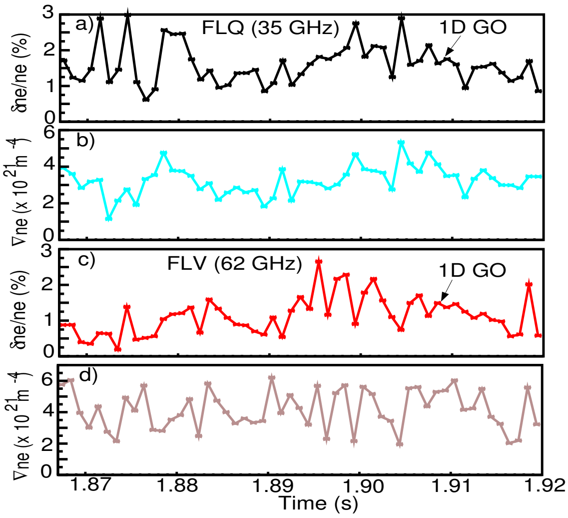

Figure 3: Temporal evolution of (a) density fluctuation level deduced from Q band reflectometer signal, (b)its associated ∇n_e, (c)density fluctuation level from V band reflectometer signal and (d)its associated ∇n_e for shot #20393.

Figure 2 shows the V band channel and magnetic spectrograms for the time window [1.8 s,2 s]. In this discharge, the probing frequencies of Q and V bands are respectively 35 GHz (near separatrix) and 62 GHz (near pedestal top). In the reflectometer spectrogram, edge modes between 70 kHz and 120 kHz are observed between Type I ELMs. These modes can have different behaviour, it could be coherent with several distinct bands or broadband. The magnetic spectrogram shows quite different modes with several "broadband" bands between 35 kHz and 150 kHz. From the mode number analysis using the toroidal and poloidal set of coils on the low field side, it was deduced that all frequency bands rotate in the electron diamagnetic drift direction.

Figure 3 shows the temporal evolution of $\delta n_e/n_e$ calculated using the 1D GO model for Q and V bands as well as the n_e local gradients taking from Lithium Beam density profile diagnostic. The $\delta n_e/n_e$ for Q and V bands are similar and is reduced before and after the ELM event. The disappearance of the edge modes is associated with the decrease of electron pressure and its gradient, and the modes reappears when the pressure and its gradient recover. It seems that the pressure gradient plays a role as a driving force.

4. Radial structure

An H-mode discharge (#20354) similar to the previous one is considered in this analysis. The reflectometer frequency pattern is 7 steps of 6 ms. At least two frequency peaks ($\simeq 85\ kHz$ and $103\ kHz$) are observed on both reflectometer and magnetic signals corresponding to $n \simeq 5$, $m \simeq 16-17$ and $n \simeq 6$, $m \simeq 21-22$ respectively. The poloidal mode number value is underestimated as only coils on low field are used. So, the underestimated q values are $q > 3.34$ (for $f \simeq 85\ kHz$) and $q > 3.4$ (for $f \simeq 103\ kHz$) close to the $q_{95} = 3.47$ value.

Figure 4 shows the $\delta n_e/n_e$ radial structure of edge modes using the 1D GO model and the Lithium Beam density profiles. The $\delta n_e/n_e$ is obtained by filtering signals between 60 kHz and 110 kHz. Data sets of 100 points over 4 ms are considered in order to calculate an average standard deviation of $\delta n_e/n_e$ and its statistical error. The maximum $\delta n_e/n_e$ is approximatively 4.4 % at $\rho_{pol} = 0.994 \pm 0.003$. The large density fluctuation level is due to the large gradient at the edge. At $\rho_{pol} \simeq 0.994$, the corresponding value of q from CLISTE is 4.16. It seems that the maximum of the radial structure is consistent with the localization of $q = 4$ (within the error bars) in the q profile from CLISTE equilibrium reconstruction code.

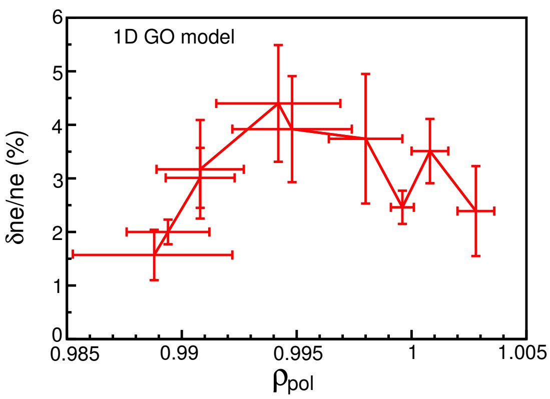

Figure 4: Density fluctuation level profile using 1D Geometric Optics model for shot #20354.

5. Poloidal correlation

In the typical H-mode shot #21131, the probing frequency of Q-band and V-band channels are 49.2 GHz and 49.4 GHz respectively. The 200 MHz frequency difference ensures no cross contamination between the respective receivers but, is sufficiently small to ensure that the two channels reflect from approximately the same density cutoff layer (in particular in the steep gradient region). Both channels register strong spectral peaks with high correlation and clear cross-phase development in the presence of MHD modes. The coherence is obtained by using windows of 10 ms with FFT data length of 512 points and 50% of overlap sampling. The significance level $\gamma_0 = 0.16$, defined by the number of spectral averages and window length, in this case 10 ms and $N_{av} = 39$. The minimum and maximum poloidal separation (d_{sep}) at the density cutoff position are estimated to be 25 cm and 32 cm, respectively.

Figure 5 shows the temporal evolution of the poloidal velocity of the edge modes. In order to calculate the poloidal velocity, the rate of cross phase change $\frac{d\phi}{df}$ is needed. For this study, the points in the frequency window where the coherence value is greater than 0.4 were taken and then a linear regression was used. The error bars in $\frac{d\phi}{df}$ corresponds to the standard deviation obtained with the linear regression. A good determination of $\frac{d\phi}{df}$ is deduced if the number of points is sufficiently high and the coherence is good. The poloidal velocity is calculated as $v_{pol} = (2\pi * d_{sep})/(\frac{d\phi}{df})$. The values calculated with this method are similar to the perpendicular velocity (close to the $E \times B$ velocity plus the phase velocity) using the Doppler reflectometer [4].

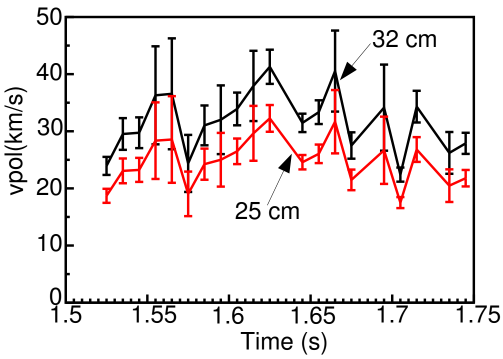

Figure 5: Temporal evolution of the poloidal velocity for two different density cutoff separation (25 cm and 32 cm) for shot #21131.

7. Discussion and conclusions

Some properties of the edge modes in H-mode discharges are identified and it seems that the pressure gradient plays a role in the existence of these modes. The radial structure at the edge is determined using the 1D Geometric Optics model and it is consistent with the results of the mode number analysis. Preliminary results of the poloidal velocity of these edge modes in the laboratory frame were obtained using the poloidal correlation technique.

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[1] Perez C P *et al.* 2004 *Plasma Phys. Control. Fusion* **46** 61, [2] Snipes J A *et al.* 2001 *Plasma Phys. Control. Fusion* **43** L23, [3] L.Cupido *et al*, Rev. Sci. Instrum.**77**, 10E925 (2006), [1] Conway G D *et al.* 2004 *Plasma Phys. Control. Fusion* **46** 951,