Fast particle mode studies with NBI heating on ASDEX Upgrade using reflectometry

S.da Graça[1], G.D.Conway[2], P.Lauber[2], V.Igochine[2], A.Gude[2], D.Curran[3], I.Classen[4], D.Borba[1], M.Garcia-Muñoz[2], M.Maraschek[2], A.Silva[1], F.Serra[1], M.E.Manso[1], M. Van Zeeland[5], N.C.Luhmann Jr.[6], H.K.Park[7] and the ASDEX Upgrade Team[2]

[1] *Associação EURATOM / IST, Instituto de Plasmas e Fusão Nuclear- Laboratório Associado, Instituto Superior Técnico/Universidade Técnica de Lisboa, P1049-001,Lisboa, Portugal*

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

[3] *Physics Department, University College Cork, Cork, Ireland*

[4] *FOM Institute for Plasma Physics Rijnhuizen, 3430 BE Nieuwegein, The Netherlands*

[5] *General Atomics, San Diego, California 92186-5608, USA*

[6] *University of California at Davies, Davies, CA 95616, USA*

[7] *POSTECH, Pohang, Gyeongbuk, 790-784, Korea*

1. Introduction

In ITER, the D-T reactions will produce α particles at 3.5 MeV which will sustain the thermonuclear burn. The transport and confinement of the α particles will affect both the efficiency of the plasma self-heating and the lifetime of plasma facing components due to fast ion losses damage [1]. On ASDEX Upgrade a multi-channel broadband FM-CW reflectometer (which can be operated in either fixed or swept frequency mode) covering the density range $0.3 - 6.64 \times 10^{19}$ m^{-3} [2] is used to study density fluctuations on the tokamak High-Field-Side (HFS) and Low-Field-Side (LFS). In this paper, the Alfvén Cascades (ACs) behaviour for different NBI deuterium injection energies (60 and 93 keV) as well as the radial structure of ACs with 93 keV NBI during the temporal q_{min} evolution will be presented.

2. Technique

ACs have been widely used as MHD spectroscopy to infer the temporal evolution of $q_{min}(t)$ as the AC frequency ramp is described by $df_{AC}(t)/dt \simeq (mv_a)/(2\pi R)(dq_{min}(t)^{-1})/dt)$ [3] where f_{AC} is the AC frequency, v_a the Alfvén velocity and R the major radius. Consequently, the AC slope depends on the evolution of q_{min}. Moreover, a Grand Cascade (GC) occurs when all toroidal mode numbers are present and $q_{min}(t)$ passes an integer value. In ASDEX Upgrade, experiments of NBI-driven ACs by introducing on-axis NBI during the current ramp up phase at $Bt = 2.5T$ in low density plasmas have been performed. Three similar discharges (with slight changes on the line integrated core density) with different heating scheme: #25525 (93 keV NBI), #25527 (60 keV NBI) and #25528 (60 keV + ECRH) have been compared.

The radial structure of AC modes has been obtained by correlating reflectometry with Electron Cyclotron Emission Imaging (ECEI), Soft-Xray and magnetic signals. The ECEI diagnostic consists in a 2D measurement of the electron temperature in a 2D array of 8 (horizontal) by 16 (vertical) positions in the poloidal plane, covering an area of 10 by 40 cm. Here, only the ECEI channels at the midplane are used and so only the 1D structure of ACs is presented. The Soft-Xray is composed of various cameras, in particular, the I-camera located at the midplane on the LFS, the M-camera placed below the midplane on the HFS and the G-camera mounted inside the divertor with line of sights from LFS to HFS. The Soft-Xray signal is measured along a line of sight, it is considered that the emissivity is strongest at the flux surface where the chord is tangent to [5].

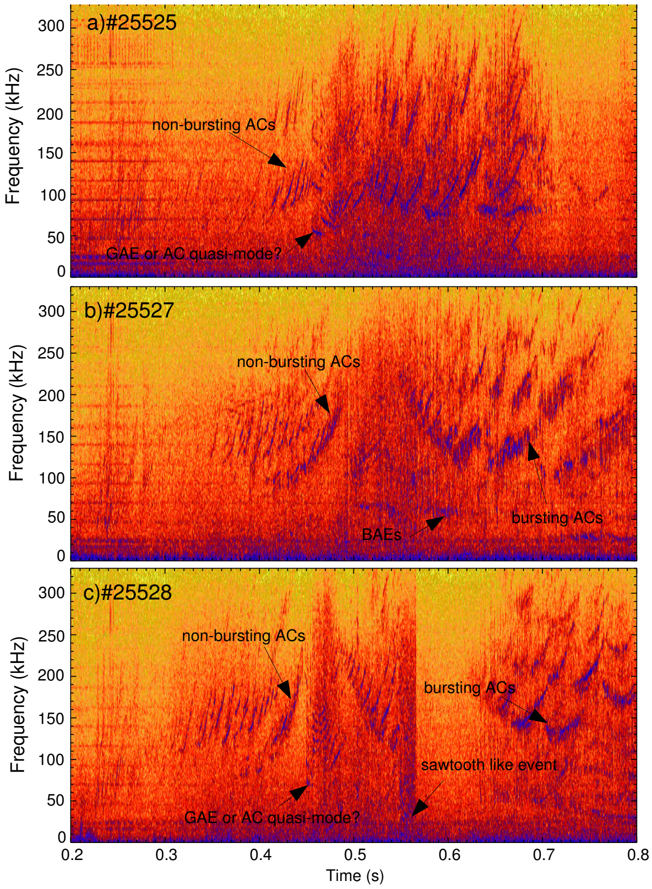

Figure 1: Time-frequency spectrograms of Q band HFS signal at 48 GHz for shots: (a) #25525, (b) #25527 and (c) #25528.

3. Experimental results

In ASDEX Upgrade, HFS/LFS asymmetries on reflectometer signals have been detected during ACs experiments [6]. On the LFS, the REF signal seems to be affected by turbulence and small changes on ∇n_e. Consequently, figure 2 shows only the spectrograms of Q band HFS signal with a probing frequency at 48 GHz corresponding to $n_e = 2.86 \times 10^{19}$ m^{-3}for the three discharges described in section 2. In all cases, a GC is observed at $t \simeq 0.48s$ corresponding to $q_{min} = 2$. During the GC, downward as well as upward frequency sweeping modes are observed but the nature of the downward frequency sweeping modes is not well understood, so two possible candidates can be considered: AC quasi-mode or Global Alfvén Eigenmodes (GAEs). In figure 2(b), an high frequency bursting mode with a frequency of around 60 kHz appears at $q_{min} = 2$ and has been identified as Beta Alfvén Eigenmode (BAE) [7]. In discharge #25527, after $q_{min} = 2$, ACs with a bursting behaviour have been observed. Also, in figure 2(c), a sawtooth like event at around $t \simeq 0.55$ s ejects approximately 50% of the fast-ion population from the plasma center and redistributes the fast ions toward the plasma edge [8]. However, just after at $t \simeq 0.64$ s, ACs with a busting behaviour are observed.

For the discharge, #25525, a coherence analysis technique using ECEI, magnetic, Soft-Xray and reflectometer signals is applied to determine the radial structure of ACs for different time windows. Here, the reference signal is either REF or magnetic signals while the Soft-Xray and ECEI signals provide the profile information. The significance level of the coherence is $\gamma_0 = 0.23$, defined by the number of spectral averages and window lengths, in this case 5 ms and $N_{av} = 18$. Small time windows are employed for coherence analysis as the AC frequency and radial structure are changing in time. Figure 3 shows the radial coherence profiles for (a) $n = 2$ AC at $t \simeq 0.251 - 0.256$ s near $q_{min} \simeq 3.3$, (b) $n = 3$ AC at $t \simeq 0.438 - 0.443$ s near $q_{min} \simeq 2.2$, (c) $n = 1$ downward sweeping mode (AC quasi-mode or GAE) at $t \simeq 0.457 - 0.462$ s corresponding to $q_{min} \simeq 2$ and (d) $n = 2$ AC at $t \simeq 0.666 - 0.671$ s near $q_{min} \simeq 1.5$. Here, r/a coordinate is used where $2r$ is the diameter of flux surface at the height of magnetic axis. The maximum value of the AC radial coherence profile moves inward when q_{min} is decreasing which is explained by the expected inward evolution of the radius of q_{min}. The radial coherence profiles in figure 3(a) and (c) present some minima and maxima on the radial coherence profiles when Soft-Xray with magnetic or reflectometer signals correlation is used. A helical mode with a single poloidal mode number m has a Soft-Xray fluctuation profile with m minima and $m+1$ maxima. This feature is due to a line integration effect but at least the radial position of the AC peak as well as its radial width can be determined [4]. Figure 4 shows the radial coherence profile from HFS (negative r/a) to LFS (positive r/a) using the correlation between Soft-Xray by using I,G and M cameras and magnetic or reflectometer signals during the AC to TAE transition at $t \simeq 0.271 - 0.276$ s. The TAE radial structure is broad and expends towards the edge near $q_{min} \simeq 3$. Moreover, an HFS/LFS asymmetry is seen at the edge, in fact the radial coherence profile decreases at the edge on LFS but not on HFS. This characteristic is confirmed by reflectometer data as this mode is observed on HFS but not on LFS at $r/a \simeq 0.8$.

5. Conclusions

A large variety of modes have been observed during ACs dedicated experiments: bursting and non-bursting ACs, downward sweeping modes that can be identified as AC quasi-mode or GAE as well as BAEs. The radial structures of ACs during the decrease of q_{min} have been obtained as well as the HFS/LFS radial coherence profile at the AC to TAE transition near $q_{min} \simeq 3$. Comparison between experimental data and LIGKA simulations is foreseen.

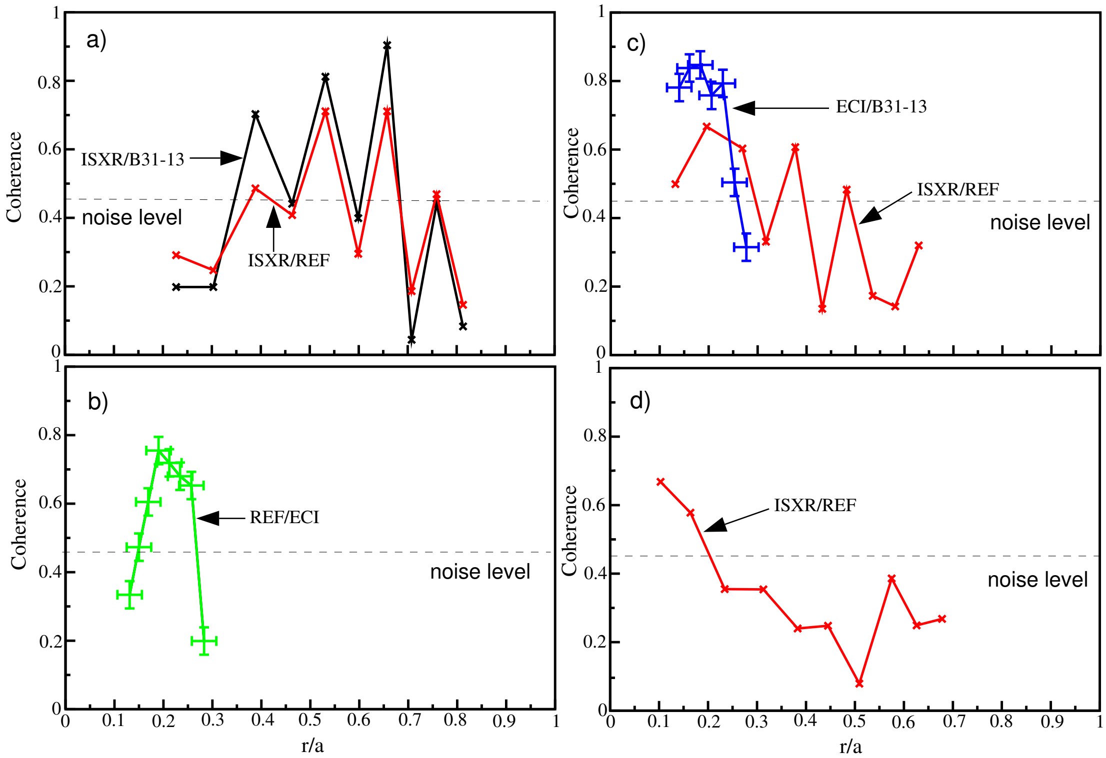

Figure 2: Radial coherence profiles for 4 time windows: (a) $t \simeq 0.251 - 0.256$ s (b) $t \simeq 0.438 - 0.443$ s, (c) $t \simeq 0.457 - 0.462$ s and (d) $t \simeq 0.666 - 0.671$ s using ECI, reflectometer, magnetic and Soft-Xray signals for shot #25525.

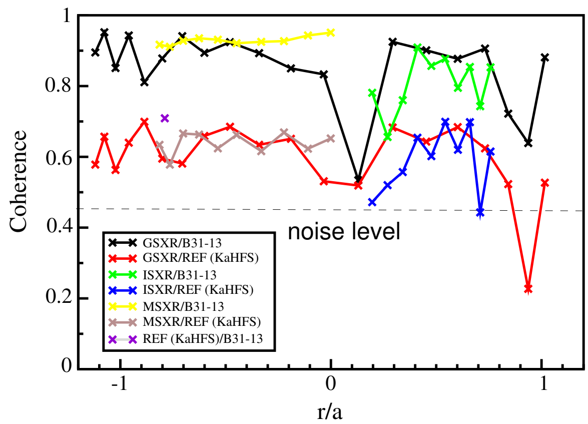

Figure 3: Radial coherence profiles from HFS (negative r/a) to LFS (positive r/a) using Soft-Xray (from various cameras: I, G and M), magnetic and reflectometer signals at $t \simeq 0.271 - 0.276$ s for shot #25525.

[1] ITER Physics Basis, Chapter 5, 2010 *Nucl. Fusion* **47** S264,

[2] Silva A *et al.* 1999 *Rev. Sci. Instrum.* **70** 1072,

[3] Sharapov S *et al.* 2006 *Nucl. Fusion* **46** S868,

[4] Classen I *et al.* 2010 *Rev. Sci. Instrum.* **81** 10D929,

[5] Piovesan P *et al.* 2008 *Nucl. Fusion* **48** 065001,

[6] da Graça S *et al.* 2010, EPS conference, Dublin, Ireland, P4.118

[7] Classen I *et al.* presented at this conference,

[8] B. Geiger *et al.* 2011 *Plasma Phys. Control. Fusion* **53** 065010,

Acknowledgements: This work has been carried out in the frame of the Contract of Association between the European Community and IST and has received financial support from Fundação para a Ciência e a Tecnologia (FCT). The content of publication is the sole responsibility of the authors and it does not necessarily the views of the Commission of the European Union or FCT or their services.