Convective Transport Suppression in the Scrape-Off Layer
Using Ion Cyclotron Resonance Heating
on the ASDEX Upgrade Tokamak

G. Antar[1] S. Assas[2], V. Bobkov[2], J.-M. Noterdaeme[2,3], E. Wolfrum[2],
A. Herrmann[2], V. Rohde[2], and ASDEX Upgrade Team

[1] *American University of Beirut, Riad El-Solh, Beirut 1107 2020, Lebanon*
[2] *Max-Planck Institut für Plasmaphysik, Boltzmannstr. 7, 85748 Garching, Germany*
[3] *University of Gent, EESA Department, B-9000 Gent, Belgium*

Abstract. Turbulence properties in the scrape off layer (SOL) in the presence of ion cyclotron frequency heating (ICRH) are compared to instance where it is absent. The discharges are all in a high confinement mode (H-mode) discharge maintained by 5 MW of neutral beam injection. In consequence of the ICRH, the probability distribution function is recorded to be closer to a Gaussian and a net decrease in the low-frequency density fluctuations is reflected in the power spectra. Consequently, the level of turbulent fluctuations decreases significantly. Turbulence suppression is also reported during edge localized modes (ELMs) where both the ELMs induced transport and duration are strongly affected. We deduce that ICRH may be used as an effective tool to suppress convective transport and to reduce ELMs amplitude.

Introduction. The effects of the ion cyclotron resonance heating (ICRH) on the scrape off layer (SOL) has been an outstanding issue for several decades emphasized by the search for efficient coupling of additional heating to the plasma without generating impurities. The first study of turbulence behavior in the presence of ICRH was done on the compact helical system where a decrease in the level of fluctuations was observed as the ICRH power exceeded 300 kW [1]. On the other hand, intermittency in the SOL was shown to be caused by convective large-scale structures that are called avaloids [2] or blobs [3]. This transport has a universal character with similar properties of turbulence detected on various devices [4, 5].

Experimental setup. H-mode in discharges 21408 and 21409 is achieved using 5 MW of NBI leading to type I ELMs. The magnetic field is -2.3 T, the plasma current is 1 MA and the plasma is in the lower-single null magnetic configuration with a major and minor radii respectively equal to 1.72 and 0.44 m. The four antennas are used with approximately 1 MW on each leading to 2.7 MW of coupled power.

The ion saturation current. Fig. 1(a) shows the I_{sat} signals for the shot 21408 before and during ICRH. The contribution of ELMs was removed from the data, causing empty lapses in (a). The intermittent bursts clearly present without ICRH are absent with ICRH. This is made even clearer in Fig. 1(b) where the empty time lapses are removed and almost all the spikes which caused SOL intermittency have disappeared.
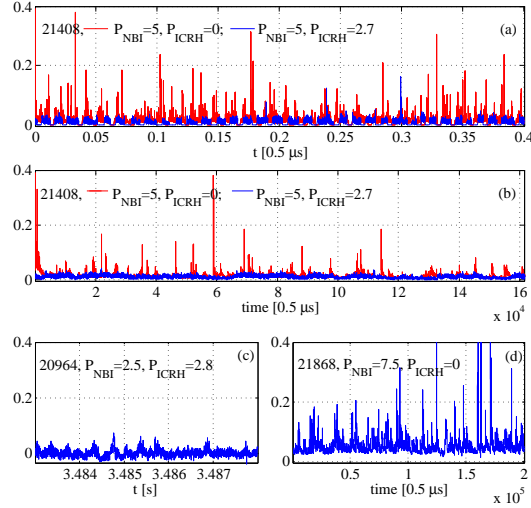
1

Figure 1: In (a), we plot I_{sat} [A] of the mid-plane filament probe with (blue) and without (red) ICRH; The initial times for the two plots are respectively $t_0 \sim 2$ and 6.1 s. The empty time lapses are mainly caused by ELMs and negative biasing to avoid sparks that we have removed. In (b), we removed the empty time lapses in order to clearly show the radical changes occurring to I_{sat} when ICRH is switched on. In (c), we inserted I_{sat} from shot 20964 where $P_{Tot} = 5.3$ MW coming from 2.5 of NBI and 2.8 of ICRH; The fluctuations can thus be compared to 21408 at $t \sim 2$ s with the same P_{Tot} coming from NBI alone. In (d), the I_{sat} taken from discharge 21868 with $P_{Tot} = P_{NBI} = 7.5$ MW is plotted. Another comparison is thus possible between the fluctuations shown in (d) and those in 21408 around $t \sim 6.1$ s with about the same total power.

Statistical analysis. We have shown that in the SOL neither the diffusive nor the convective component are modified when NBI is switched on and that the power distribution of the turbulent fluctuations is unmodified. When ICRH is on the situation is dramatically different. Below we insert the values of the first order moments of the ion saturation fluctuations where the a net difference is reported with respect to plasmas without ICRH.

P_{ICRH} [MW]	$\langle I_{sat} \rangle$ [mA]	δI_{sat} [mA]	$\delta I_{sat}/\langle I_{sat} \rangle$	Skewness	Flatness
(21408) $0 \rightarrow 2.7$	$15 \rightarrow 17$	$10.5 \rightarrow 6$	$70\% \rightarrow 35\%$	$7.6 \rightarrow 0.8$	$65 \rightarrow 5.6$
(21409) $0 \rightarrow 2.7$	$15 \rightarrow 22$	$10 \rightarrow 7$	$67\% \rightarrow 32\%$	$12 \rightarrow 1$	$52 \rightarrow 7$

In Fig. 2(a) the probability distribution functions (PDF's) of I in-between ELMs is illustrated for plasma with NBI and NBI-ICRH heating. Negative fluctuations are Gaussian as it is reflected in the parabolic shape of the PDF [8] and this part remains unmodified when ICRH is added. We deduce that the 'diffu-

2

sive' component of turbulence in the SOL by incoherent eddies is unaltered. The positive values of I were shown to be dominated by the convective component of turbulence caused by large-scale and large radial velocity structures [2, 4]. This component of the radial transport suffers a dramatic reduction where most of the bursts disappear during ICRH.
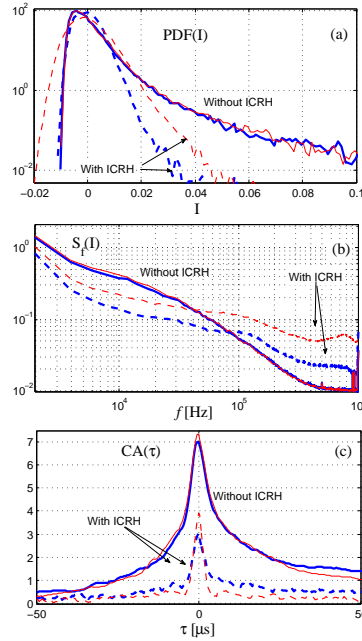
Figure 2: In (a), the PDF of I is plotted in a semilogarithmic frame with dashed and solid lines for data with and without ICRH respectively. In (b) and (c), we illustrate the power spectrum of I as a function of the frequency f, and the auto-conditional average CA as a function of time τ with the same legend for the type of lines as in (a).

The frequency spectra of I are determined and plotted in Fig. 2(b) where a net decrease in the low-frequency range is reported, whereas the high-frequency part increases slightly. Moreover, we calculated the auto-conditional average of the intermittent spikes with and without ICRH heating and plotted the result in Fig 2(c). The dramatic decrease of the highest amplitude spikes in the signal clearly reflects the fact that less plasma is transported across the SOL by the high intensity events. One can also show that the number of large bursts decreases significantly in agreement with the PDF behavior.

Edge localized modes. ELMs-induced transport, is profoundly affected by ICRH and this is clearly seen on the I_{sat} plotted in Fig. 3(a) for an arbitrarily chosen ELM with and without ICRH. A net decrease in the signals amplitude and the duration of the ELM-induced transport is observed. The auto-

conditional function is determined for ELMs (CA$_{ELM}$) and plotted in Fig. 3(b) where the above result is verified statistically, that is, the ELM-induced amplitude decreases by about a factor of 3. Comparing 21409 to 21408, we deduce that this decrease is not significantly modified by mid-plane gas puffing. Accordingly, ICRH suppresses the ELM-induced convective transport similarly to in-between ELMs.
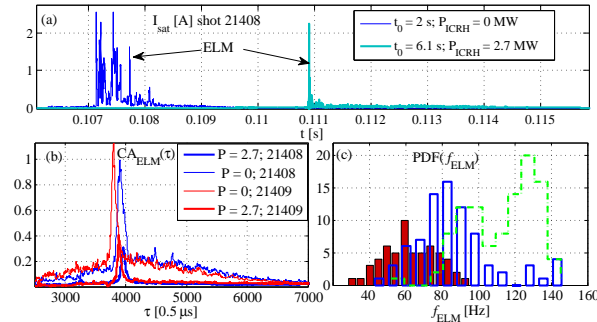

Figure 3: In (a), we plot I_{sat} during 21408 where two ELMs are visible one with an initial time $t_0 = 2$ s (no ICRH) and the other at $t_0 = 6.1$ s with ICRH. In (b) the auto-conditional average of ELMs is illustrated for 21408 and 21409 and with and without ICRH. In (c) the two bar charts reflect the PDF of the ELMs frequency f_{ELM} for 21408 with (filled) and without (empty) ICRH power; The stairs plot shows the same for 21049 with the presence of ICRH.

Conclusion. We conclude that ICRH leads to (1) turbulence decrease in the SOL *via* the suppression of large-scale convective structures; this leads to distribution functions close to Gaussian. (2), the ELM-induced transport also is shown to be strongly affected by the ICRH where a decrease by a factor of 1/3 is recorded.

References

[1] T Morisaki, *et al. Plasma Phys. Control. Fusion*, 37:787, 1995.
[2] G. Y. Antar, *et al. Phys. Rev. Lett.*, 87:065001, 2001.
[3] S. I. Krasheninnikov. On the scrape off layer plasma transport. *Phys. Lett. A*, 283:368, 2001.
[4] G. Antar, G. Counsell, Y. Yu, B. LaBombard, and P. Devynck. *Phys. Plasmas*, 10:419, 2003.
[5] B. Ph. van Milligen, *et al. Physics of Plasmas*, 12(5):052507, 2005.
[6] G Y Antar, *et al. Plasma Phys. Control. Fusion*, 50:095012, 2008.
[7] O. Gruber, *et al. Nuclear Fusion*, 41(10):1369–1389, 2001.
[8] G. Antar, P. Devynck, X. Garbet, and S. C. Luckhardt. *Phys. Plasmas*, 8:1612, 2001.
[9] J M Noterdaeme, *et al.* In *17th IAEA Conf. on Fusion Energy*, pages F1–CN–69, Yokohama, Japan, 1998. IAEA CDP/11.