PROGRESSES IN UNDERSTANDING THE EFFECTS OF ICRF/NBI FAST-IONS ON CORE TURBULENCE AND ALFVÉN ACTIVITY ON ASDEX UPGRADE


1) Max-Planck-Institut für Plasmaphysik, Boltzmannstr. 2, 85748 Garching, Germany
2) University of Seville, Avda. Reina Mercedes s/n 41012 Seville, Spain
3) Department of Mechanical Engineering and Manufacturing, University of Seville, Seville
4) School of Electrical Engineering, KTH, Stockholm, Sweden
5) LPP-ERM/KMS, TEC Partner, Brussels, Belgium
6) ICREA, 0810 Barcelona, Spain
7) Dept. of Atomic, Molecular and Nuclear Physics, University of Seville, Avda. Reina Mercedes, 41012 Seville, Spain
8) Department of Applied Physics, Aalto University, PO Box 14100, 00076 AALTO, Finland
9) See author list of U. Struth et al., Nucl. Fusion 62 042006 (2022)

Email: roberto.bilato@ipp.mpg.de

Active mitigation of the ion-temperature-gradient resilience to an increase of auxiliary heating is beneficial to enter more efficiently the burning-plasma phase in future fusion reactors. Fast-ions (FI) produced with neutral-beam-injection (NBI) and radio-frequency waves in the ion cyclotron range of frequency (ICRF) have recently shown their promising role in relaxing this resilience in the plasma core of present fusion devices [1] (and references therein). Advanced gyrokinetic simulations have clarified that FIs can influence microturbulence (main transport driver in the plasma core) both directly [2] and indirectly, e.g. via the excitation of magneto-hydrodynamic (MHD) instabilities [3]. However, the possible interaction with MHD FI-driven instabilities can impact the confinement of the FIs themselves, and thus their eventual thermalization with consequences for future reactors. Therefore, the impact of FIs on microturbulence and on MHD instability, and their mutual cross-talking, are strongly entangled with the confinement of FIs. This contribution presents the recent progresses on this topic, recently achieved on ASDEX Upgrade (AUG) [4], which offers flexible systems of NBI and ICRF heating and a comprehensive set of FI diagnostics. To operate at optimal plasma parameters for each investigated process, the experimental program has been split in the following three parts.

Firstly, a series of dedicated discharges characterized by ICRF minority-hydrogen (H) heating in deuterium (D) plasmas, with the confining magnetic field around ~2.5T and ICRF frequency of 36.5 MHz (this combination locates the fundamental IC resonance of H through the plasma core) were performed to document the sensitivity of transport in the presence of FIs to: i) different plasma parameters, such as H concentration, which impacts the ratio of the fast-H equivalent temperature to the electron temperature, \( T_e \), and its gradient, ii) the position of the ion-cyclotron resonance (changed by moderately varying the magnetic field), and iii) ratio of electron to ion heating (by varying the number of NBI sources and the power of heating with electron cyclotron range of frequencies (ECRF)) in order to impact the ratio, \( T_e/T_i \), and, thus, influence the growth rate of microinstabilities. In these discharges, the ratio of ECRF to total auxiliary heating power shows the largest influence on the FI impact on turbulence stabilization, Fig. 1. The concentration of ICRF-accelerated H plays also a role in stabilizing turbulence for a given auxiliary heating mixture. All this illustrates a
possible route to stabilize core ITG turbulence with FIs. Disentangling all the possible connections with MHD (e.g. fishbone instabilities) remains challenging, and both experiments and modelling are necessary to address their real quantitative relevance.

The core ion cyclotron emission (ICE), detected with arrays of B-dot probes located in the vessel shadow, is a core FI diagnostic particularly valuable for fusion reactors because of its non-invasive nature. The detected emission is typically caused by instabilities due to FIs. Often ICE is observed during the NBI start-up and attributed to the inversion-driven magnetoacoustics cyclotron instability (MCI) [5]. Here, however, we consider ICE due to the global Alfvén eigenmode (GAE) located near the magnetic axis, which persists for the whole NBI phase. GAE is sensitive to the anisotropy of the FI distribution function, and thus its ICE spectrogram varies when fast NBI-D is further (mainly) perpendicularly accelerated by ICRF at the 3rd harmonic (here, low confining magnetic field, ~1.6T, and low plasma current, ~0.4 MA) [6]. The flexibility available on AUG to vary the FI distribution function by operating different NBI sources, and/or by further ICRF-accelerating the NBI-D at the 3rd and/or 4th cyclotron resonance enables forward modeling (with codes, such as ASCOT-RFOF/TORIC) that can be used to extract from ICE spectrograms information on the FI distribution function. We show that indeed the predicted distribution function together with the expression of the GAE growth rate fit the instability spectra detected by ICE. Additionally, we discuss experiments done by varying the H content in a D plasma, Fig 2. The dependence of the AE frequency (ICE spectrogram) on the plasma ion composition might in principle be exploited to infer the tritium (T) fraction, and thus to real-time control the D-T mixture in a fusion reactor.

Finally, FIs can have beneficial effects on core transport, but they are also often the cause of an intense AE activity with a likely increase of FI losses. This can be not only a heating loss with negative consequences on fusion power, but can also locally overheat the plasma facing components, eventually compromising their integrity. It is therefore important to control FI losses, since in the presence of fusion alphas it is difficult to completely get rid of AE activity [7]. This has been addressed with dedicated AUG discharges characterized by up to 4 MW of ICRF on-axis heating. Additionally, the q-profile is kept elevated with on-axis counter-current drive by ECRF to help ICRF-accelerated H population to drive the toroidal AE (TAE) activity during the whole discharge, Fig.3. During the NBI phases, the losses detected by fast-ion-loss detector (FILD) are mitigated, although the AE activity stays almost unperturbed for the whole discharge. Supported by modelling, we discuss whether this is a local diagnostic effect or an actual global FI loss reduction, as well as understanding the physical mechanism behind it in view of its possible exploitation to actively control FI losses by calibrating the heating mixture.

REFERENCES