Diagnostic development as trigger of new physics: non-linear saturation mechanisms of plasma turbulence and dynamics of neutrals in fusion plasmas

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Measure what is measurable and make measurable what is not so
Galileo Galilei [1564 – 1642]

Physics is an experimental science where theories should be confronted with experimental results. This validation process requires the development of plasma diagnostics to show that a new model faithfully represent physics reality, including quantitative assessments of discrepancies between theoretical and experimental results.

From this perspective, the development of "dual" systems (i.e. diagnostics that allows to quantify simultaneously different physical quantities both with spatial and temporal resolution) has opened new perspectives for understanding the non-linear saturation mechanisms of plasma turbulence, impurity transport and the interplay between plasma turbulence and neutral dynamics in fusion plasmas.

<u>Experimental challenges to characterize the dynamics of Zonal Flows (ZFs).</u> The first experimental evidence of amplification in Long-Range-Correlations (LRC), as a proxy of ZFs, during the development of core transport barriers was reported in the CHS stellarator [1]. Those results were obtained using a unique experimental set-up employing two Heavy Ion Beam Probe (HIBP) systems. Later experiments performed in TJ-II, HSX and TJ-K stellarators, using dual edge probes as well as dual HIBP diagnostics, have shown that LRC in potential fluctuations are amplified either by externally imposed radial electric fields [2, 3] or when approaching the Low to High (L-H) confinement transition [4,5].

The unique capabilities of the dual HIBP system have allowed to expand the investigation of multi-scale mechanisms from the plasma edge [2] to the plasma core [6] in the TJ-II stellarator. In particular, experiments with combined Neutral Beam Injection (NBI) and Electron Cyclotron Resonance Heating (ECRH) have shown direct experimental evidence of the influence of ECRH on turbulent mechanisms, increasing both the level of fluctuation and the amplitude of LRC for potential fluctuations but not for density and poloidal magnetic fluctuations as well as affecting neoclassical radial electric fields.

Furthermore, the amplification of ZFs by neoclassical or / and biasing induced radial electric fields has enabled to measure plasma potential variations in the same magnetic flux surfaces [7].

From the perspective of plasma physics, synergies between stellarators and the main-line tokamak seem particularly meaningful to address fundamental open questions like: Are there different paths to reach the L-H transition and what is the role of ZFs [8]?.

Experimental challenges to characterize neutral dynamics. The electron density of coherent turbulent structures (blobs) has been measured using the helium line ratio technique at the plasma edge of the TJ-II stellarator [9]. Turbulent plasma density structures have been compared with the raw helium emission structures related to both density and neutral fluctuations. The impact of neutral fluctuations on the observed turbulent structures, an almost fully unexplored area of research, has been investigated [10] with indications that thermal neutrals could react to low frequency plasma fluctuations in agreement with recent simulations [11]

Those findings illustrate how unique dual diagnostic capabilities implemented in medium size plasma devices [Fig. 1] make them ideal plasma physics experiments for deeper understanding of ZFs dynamics, impurity transport, advanced control of turbulent transport and neutral dynamics [12].

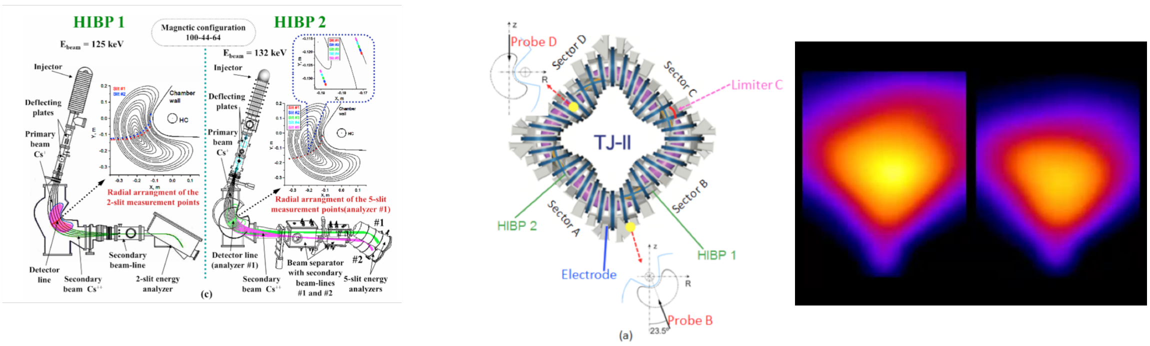

Fig. 1 Dual Heavy Ion Beam Probes [6] (left), dual Langmuir probes [2] (center) and dual fiber bundle [10] (right) to characterize ZFs and the dynamics of neutrals in the TJ-II stellarator.

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