https://doi.org/10.46813/2023-143-122

PLASMA PROFILES, SELF-ORGANIZATION AND ALFVEN EIGENMODES STUDIES USING THE HIBP DIAGNOSTIC IN THE TJ-II STELLARATOR

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This paper reports recent experiments in the TJ-II stellarator using a dual Heavy Ion Beam probe diagnostic. The studies were focused on characterizing plasma potential profiles, investigating self-organization mechanisms and Alfven Eigenmodes (AEs). Results showed plasma equipotential measurements consistent with vacuum magnetic surfaces and the presence of zonal flows in the plasma core region. The investigation of Alfven Eigen modes showed their radial localization and poloidal asymmetries in potential and density fluctuations driven by AEs.

PACS: 52.70.Nc, 52.55.Hc

INTRODUCTION

Turbulence and fast particles play important roles in transport in fusion plasmas. Turbulence can enhance transport of particles and heat across magnetic field lines. Fast particles, such as alpha particles, can also contribute to transport by transferring their kinetic energy to the background plasma through collisions. This can lead to heating of the plasma and also drive instabilities that can enhance and eventually control transport. Overall, understanding and controlling turbulence and fast particle transport is crucial for achieving the high temperatures and densities required for sustained fusion reactions.

Self-organization in plasmas refers to the emergence of large-scale coherent structures. Self-organization can be driven by turbulence via inversed energy cascades driven by Reynolds stresses. The presence of fast particles, such as those produced in fusion reactions, can also influence the self-organization mechanisms by providing a source of energy that can drive the formation of these structures.

Physics is an experimental science where models should be confronted with experimental measurements. The Heavy Ion Beam Probe (HIBP) diagnostic makes it possible to obtain simultaneously unique experimental data on potential and plasma density profiles and their fluctuations [1, 2].

The paper describes recent experimental data on plasma profiles and fluctuations in the TJ-II stellarator. The experimental set-up is described in the first section, followed by a description of the general properties of plasma potential profiles. The investigation of Alfven Eigen modes is then discussed, and finally, self-organization is reported.

EXPERIMENTAL SETUP

TJ-II is a flexible medium size heliac-type stellarator with a major radius of 1.5 m, an average minor radius of 0.2 m and a magnetic field of 1 T. It has two gyrotrons (ECRH1 and ECRH2) that can produce up to 300 kW at 53.2 GHz, and two neutral beam injection systems (NBI1 and NBI2) that can produce up to 500 kW, with an energy of 33 keV per port, for plasma heating. It is the second largest operational stellarator in Europe after W7-X (Fig. 1).

The results reported in the paper have been obtained using a dual Heavy Ion Beam Probe system [3]. The study used both HIBP1 and HIBP2 systems in scanning and fixed point mode to determine plasma profiles, as well as plasma potential and density fluctuations in a specific radial location (see Fig. 1). This set-up allows for the simultaneous investigation of the radial structure of fluctuations, ExB driven transport, and long-range correlated scales in the whole plasma poloidal cross-section in the TJ-II stellarator. The results show that plasma fluctuations are dominated by broadband turbulence in ECRH scenarios, while in NBI regimes, both broadband turbulence and Alfvénic instabilities are detected. Previous experiments have shown that heating, magnetic configuration, and plasma density scenarios can affect the dynamics of AEs.

PLASMA PROFILES STUDIES

The heavy ion beam diagnostic in the TJ-II stellarator has be used to perform the 2D characterization of plasma profiles [4]. This is achieved by using the ion beams to probe the plasma at multiple radial locations, and then analyzing the data to determine the density and potential profiles. This allows for the creation of 2D maps of the dominated by ECR heating, the core plasma potential is positive with values reaching 1 kV.

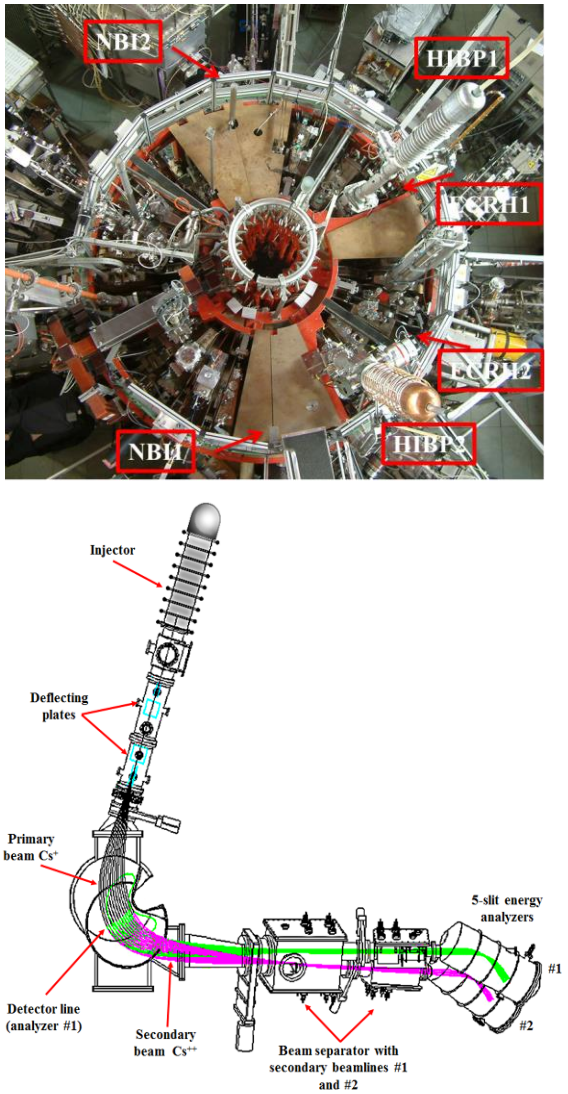

Fig. 1. Top view of the TJ-II stellarator (top) and schematic view of the HIBP2 (bottom)

On the other hand, in NBI dominated heating scenarios, the core plasma potential is negative with values reaching -0.5 kV. This difference in the sign of the plasma potential is due to the different heating mechanisms used in each scenario (Fig. 2).

Experiments using the heavy ion beam diagnostic in the TJ-II stellarator have shown that, within experimental uncertainties, the equipotential plasma potential surfaces are consistent with vacuum magnetic surfaces [5].

AE-MODES STUDIES

Alven Eigen modes are fluctuations in the plasma that are be driven by neutral beam heating. These modes can be characterized using heavy ion beam diagnostics, which measure the density and potential of the plasma [6, 7]. Fig. 2 shows the scenario of the experiment. Two phases of the scenario can be distinguished. In the first phase, plasma heating is sustained by two gyrotrons (ECRH1 and ECRH2) from the beginning of the plasma pulse to 1120 ms. In the second phase, plasma heating is combined by ECRH1 and NBI2. The second phase of the plasma pulse is the region of AE-modes generation.

Experimental results have shown that AEs in the TJ-II are radially localized, meaning they are confined to specific regions of the plasma (Figs. 3, 4). Additionally, there is evidence of poloidal asymmetries in the structure of density and potential fluctuations associated with AEs, indicating that these modes may have a distinct shape or pattern (Fig. 5). This unexpected results open a path for detailed model validation.

LONG RANGE CORRELATION STUDIES

The results in this section are based on the use of two Heavy Ion Beam Probe systems, HIBP1 and HIBP2, in a TJ-II stellarator [8]. The HIBP systems were used in both scanning and fixed point modes to study plasma profiles, potentials, and density fluctuations in a specific radial location. The dual system setup allowed for simultaneous investigation of fluctuations and long-range correlations in the whole plasma poloidal cross-section (Fig. 6).

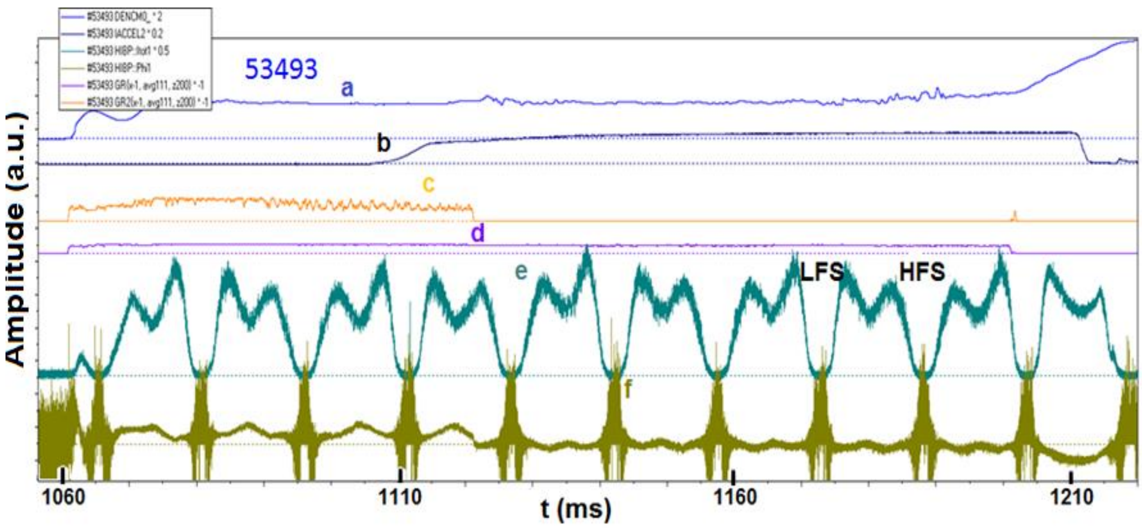

Fig. 2. Experiment scenario and signals of HIBP1 for plasma pulse № 53493: a – plasma density; b – NBI2; c – ECRH2; d – ECRH1; e – plasma density profile; f – plasma potential

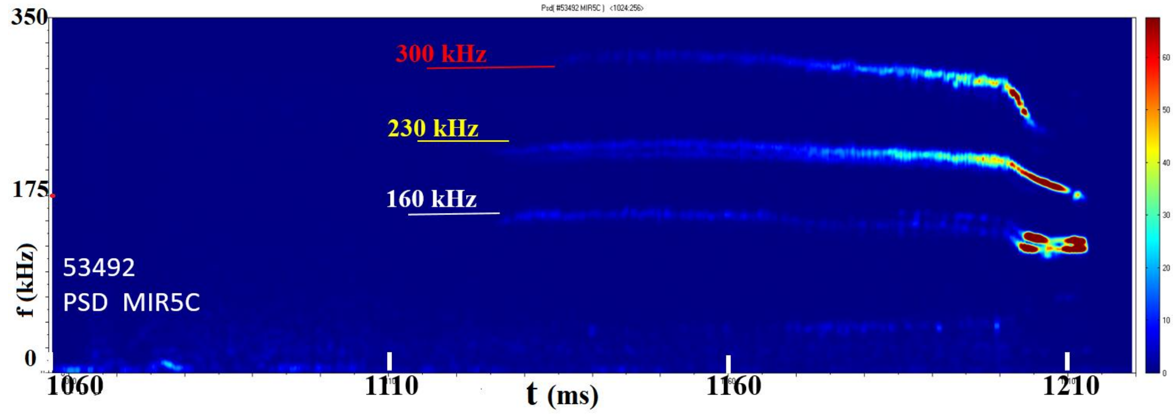

Fig. 3. PSD of the Mirnov probe signals in both phases of the scenario, plasma pulse № 53492

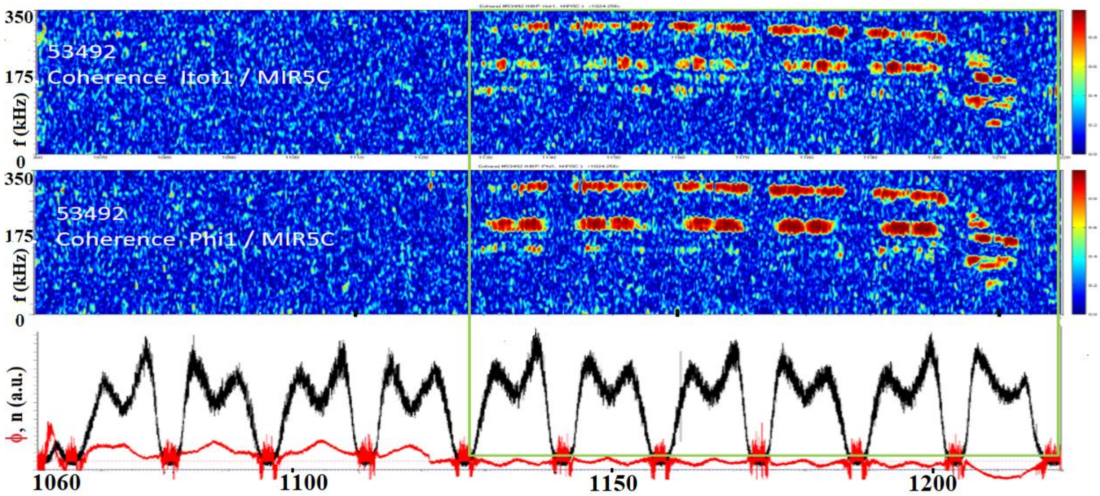

Fig. 4. Coherence of the HIB1signals with Mirnov probe signals, plasma pulse No.53492. The upper part of the figure shows the coherence of plasma density fluctuations with data from the Mirnov probe, the lower part shows the coherence of potential fluctuations with the Mirnov probe. Those results show evidence of AEs radial localization

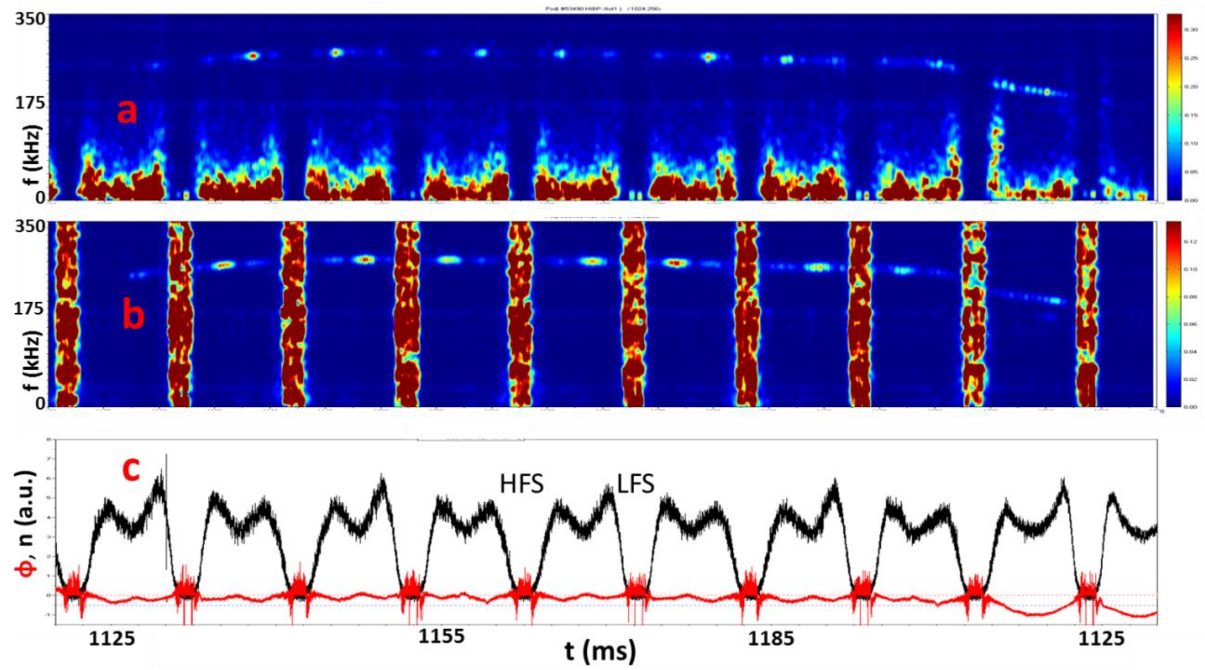

Fig. 5. PSD fluctuations of density and plasma potential of pulse # 53490: PSD of plasma density (a); PSD of plasma potential (b); plasma density profile (black color) (c); plasma potential (red color). Results show strong poloidal asymmetries in the level of density and potential fluctuations driven by AEs

In scenarios with combined ECR and NBI heating, LRC were detected at both Alfven Eigen modes frequencies and low frequencies (<10 kHz), with amplitude depending on the scenario.

The LRC were seen in potential fluctuations but not in density fluctuations, consistent with the presence of Zonal Flow structures. The origin of these Zonal Flows, whether directly driven by fast particle effects or a consequence of the plasma scenario, is currently under investigation.

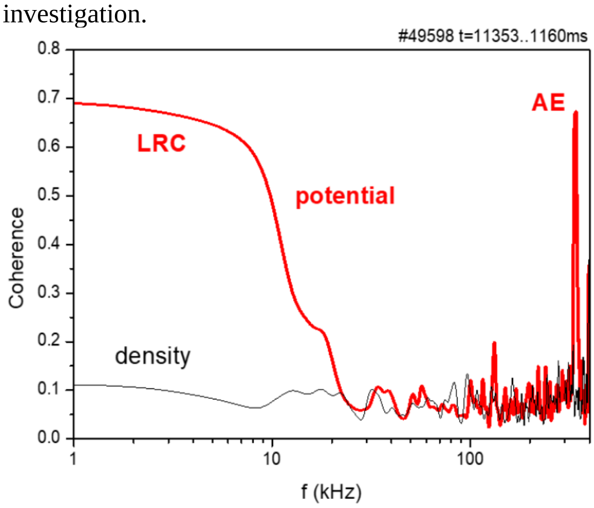

Fig. 6. Frequency resolved Long Range Correlation for density and potential fluctuations during the combined ECRH + NBI scenario

CONCLUSIONS

We have exploited the outstanding capabilities of the dual HIBP diagnostics of the TJ-II to address experimental results in some key fusion research areas. The obtained data are important for the scenarios calculations of W7X and, in perspective, the experimental fusion reactor ITER.

ACKNOWLEDGEMENTS

This work has been carried out with in the frame work of the EUROfusion Consortium and has received funding from the Euratom research and training program 2019-2020 and 2021-2022 under Grant agreement № 633053. O.O. Chmyga and O.S. Kozachok strongly appreciate the financial support of CIEMAT during their stay at LNF-CIEMAT during 2022 and 2023.

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Article received 03.02.2023

ДОСЛІДЖЕННЯ ПРОФІЛІВ ПЛАЗМИ, САМООРГАНІЗАЦІЇ ТА ВЛАСНИХ МОД АЛЬФВЕНА ЗА ДОПОМОГОЮ ДІАГНОСТИКИ ЗППВІ НА СТЕЛАРАТОРІ TJ-II

Л.І. Крупнік, J.M. Barcala, A. Cappa, О.О. Чмига, М.Б. Древаль, C. Hidalgo, С.М. Хребтов, О.Д. Комаров, О.С. Козачок, J. Martínez, A. Molinero, J.L. de Pablos та колектив стеларатора TJ-II

Повідомляється про нещодавні експерименти на стелараторі TJ-II з використанням подвійної діагностики на пучках важких іонів. Дослідження були зосереджені на характеристиках профілів потенціалу плазми. Досліджено механізми самоорганізації та власних мод Альфвена (AE). Результати показали, що вимірювання еквіпотенціалу плазми відповідають вакуумним магнітним поверхням і наявності зональних потоків в області плазмового ядра. Дослідження власних мод Альфвена показало їх радіальну локалізацію та полоїдальну асиметрію у коливаннях потенціалу та густини, викликаних AE.