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An Investigation of the Role of Topological Structures on Confinement in the TJ-II Stellarator

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Introduction

In this paper we address the problem of how to detect and quantify small spatial structures, such as those caused by chains of magnetic islands, that could be superimposed on signals obtained by a linear VUV/X-ray camera specifically developed for this purpose [1], and we address their possible correlation with plasma confinement.

Extracting low-level signals is already an enduring problem in many areas of science and technology [2,3]. In our case, small features, flats and humps, associated with high order magnetic islands are supposedly superimposed on a large-amplitude slowly varying continuum signal, *i.e.* the broadband radiation profile. In the past we developed a procedure for tackling a similar problem [4]. However, in this work we must take into account the long time window employed for integrating radiation, which also smooths out plasma fluctuations. In addition, this system also filters out low energy radiation, thereby eliminating problems associated with chord-integrated signals. Finally, this system also facilitates the locating of the magnetic axis.

The small features defined above have been detected previously in impurity-ion line-emission and bremsstrahlung profiles of hot plasmas [4 and references therein] using fast-spectroscopic scanning systems with high spatial resolution capabilities. Due to the good conduction along field lines, islands may be expected to show up in temperature and pressure profiles, and consequently in impurity ion radiation profiles. It has been postulated that such features arise as a result of perturbations in electron temperature and ion density profiles caused by chains of magnetic islands. Their role in confinement is the ultimate research goal of this work. In this article, which is a continuation of our previous work [4,5], we describe a dedicated procedure that automatically searches for such features in TJ-II radiation profiles acquired with the linear VUV/X-ray camera.

Experimental

The measurements reported here were made on the TJ-II stellarator [6]. These studies were carried out with the 1024-channel linear x-ray camera furnished with a new set of x-ray filters (5, 10 and 25 µm of Be) optimised for the boronized discharges of TJ-II [1]. The camera detects the incident extreme ultraviolet (EUV) and x-ray radiation that has been converted to visible light by a luminescent screen working in reflection mode. An old spectroscopic format, 1024 pixel (25 µm × 25 mm), intensified photodiode array is used to collect this light. In order to maximise both the spatial resolution and sensitivity, each rectangular pixel collects plasma radiation, after it has passed through a filter, coming from a defined volume, which is narrow in the poloidal direction and extended in the toroidal direction. The array can integrate photons along a time window upwards of 17 ms, typically 30-50 ms, that is a compromise between signal and time resolution.

The method followed to extract information on topological structures from the profiles obtained is as follows. A smoothed version of the raw profile is subtracted from the raw profile in order that small fine structures (high frequency information) emerge from the continuum radiation profile (low frequency information). Here the flats and humps appear as positive and negative peaks respectively. This method is not unfounded, as a similar technique called *straightening through smoothing* has been used in the past for extracting signals from strong background [3].

From the information we can either quantify individually the frequency of appearance of structures in a set of selected profiles (up to 30), or just average and process the subtracted signals. Also, we can largely suppress the electronic noise and the photon-statistics fluctuation effects, by varying the smoothing parameters and establishing an appropriate threshold for eliminating non-significant features. In an ideal situation, this threshold should be fixed exclusively by the error data bar, but in practice, when the source strength cannot be increased at will, and the spatial resolution is finite and fixed by the need to obtain sufficient signal, these conditions must be more relaxed. The first condition imposed by the method is spatial reproducibility. We can apply it to a sequence of profiles from either a single discharge or from a selected set of similar discharges having the same magnetic configuration and similar plasma currents. However, in both cases, as the number of profiles used for averaging is increased two challenges for extracting physically relevant information are faced. First, how precise is the basis used to locate the experimental centre, *i.e.* the magnetic axis, and second, what criteria should be used for defining *similar discharges*. The first, if incorrect, could create some jitter in the averaged and statistically treated features, while the second, if *unsimilar*, could cause real features to be smeared out or to disappear, if such features were to vary somehow between

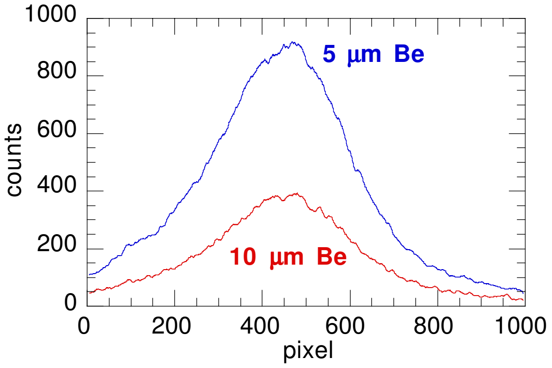

FIGURE 1. Standard x-ray profiles revealing small features (two different filters were used).

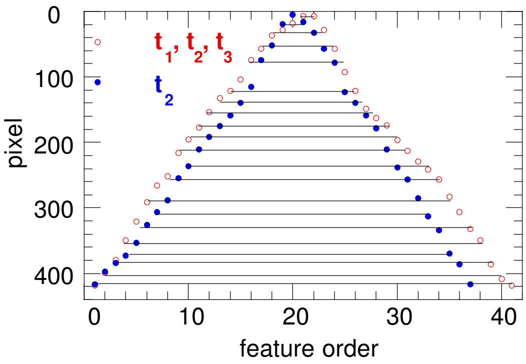

FIGURE 2. A comparison of detected features for two different set of profiles.

discharges. Thus, the method of averaging several profiles cannot be applied to a large number of profiles, since their combined jitter could destroy the information. Hence, the most restrictive condition is to force these to be symmetric in order to be consistent with the hypothesis that they are due to chains of magnetic islands associated with high-order resonances. The study of these features under different plasma conditions should clarify, not only on the numerical procedure validity, but also on their role on plasma confinement.

As a cross-check we have created profiles with superimposed un-correlated noise and we have processed them using the same procedure employed for handling the experimental data. In this way, we can check if noise features which are larger than the various thresholds fixed in the algorithm, even if their appearance is similar to real features, can or cannot reproduce the positional stability of real features that can occur in experimental profiles. Furthermore, such noise events should not display the systematic symmetry that should occur with real features.

Results

We have selected a set with 4 discharges belonging to the same TJ-II configuration, in which the only parameter that varies is the electron density (by modifying the level of gas injection). For each set, three x-ray profiles, with an integration time of 30 ms, were recorded along the flat-top of each discharge (with the 10 µm Be filter). In Fig. 1 we have plotted two chord-integrated profiles that are representative of those used in the analysis procedure for two different filters. The pixel locations of the features detected by the algorithm are plotted along the vertical axis of Fig. 2, where the zero detector pixel in the vertical axis is the profile centre. In the same plot, the order numbers assigned to the features are plotted along the horizontal axis. Here the numeration begins on the left-hand

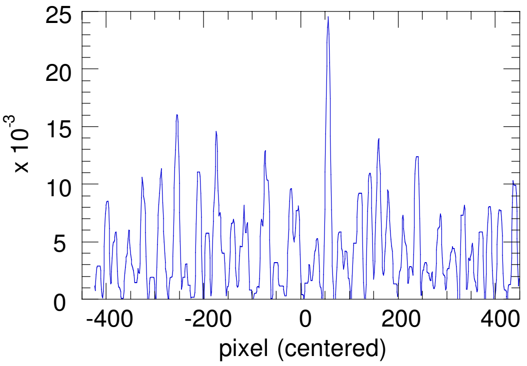

FIGURE 3. A plot of the features obtained after averaging several samples.

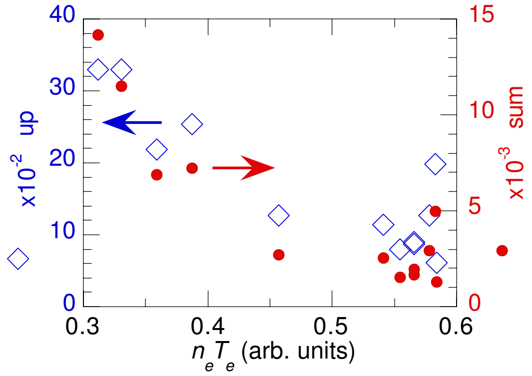

FIGURE 4. A plot of the feature quantifiers (*sum* ● and *up* ◊) as a function of $n_e T_e$.

side of the profiles. The full points correspond to the analysis where only profiles features corresponding to time t_2 (4 profiles) are displayed whereas the open circles correspond to the analysis using all 12 profiles. This strategy has been chosen to compared a situation where profile centres and plasma current present minimum variations, since they were taken at the same time with a situation which mixed slight variations on these parameters, although variations in the centres are conveniently handled by the numerical method. In general, in Fig. 2, good symmetry is observed in both the sequence and the positioning of features. This finding verifies that the algorithm centring procedure works satisfactorily and that features do not process with time along the selected discharges as otherwise the features would be smeared out. Indeed, these features are very weak as can be seen in Fig. 3 where the result of averaging several profiles is displayed. As this analysis was performed with intensity-normalised radiation profiles, the vertical axis shows the magnitude of these structures.

In order to determine if there exists any systematic correlation between the features found and the properties of the plasma, we have selected the product of the line-averaged density and the ECE measured central temperature ($n_e T_e$) as a simple measure of confinement. In Fig. 4, we compare the $n_e T_e$ measured for the selected discharges with the parameters *sum* and *up*. Here *sum* is the total area under the curves of the identified features and *up* is their fractional occupancy of the profile. It can be seen from the Fig. 4 that both parameters are related to $n_e T_e$.

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