# Thermal characterization of small scale structures in a RFP plasma

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## 1) Background

The evidence of thermal structures in RFX-mod RFP plasmas are associated to large magnetic island related to the growth of the inner resonant m=1,n=-7 tearing mode (QSH states) [1]. The purpose of this work is to present a systematic analysis of small thermal structures in RFX-mod temperature profiles, performed thanks to the high spatial resolution of the two Thomson Scattering (TS) diagnostics [2] operating on the RFX-mod experiment .

## 2) Analysis

The analysis is based on the main TS diagnostic data. The edge TS diagnostic (6 points sampled every 25 ms) results too limited in radial extension to discriminate the structures shape; when available, it has been used as a constraint for the electron temperature ($T_e$) value in the intersection region of the two diagnostics.

Thomson profiles (78 points sampled every 10 ms) have been selected, obtaining a database of about 60 discharges. After a smoothing of the $T_e$ profile, the position and extension of the regions with downward curvature have been identified (Fig 1). The corresponding safety factor $q$ profile and the resonant m=1 modes eigenfunctions have been reconstructed, in order to identify the mode resonance radii, where their amplitudes and phases have been calculated.

The database is composed mainly of QSH, and by a significant subset of Multiple Helicity discharges (MH, with no dominant mode) .

## 3) Results

The relation between the resonant radii and the small peaks position, firstly described in [3], has been confirmed in the considered database: the correlation among the peak position and the mode phase (and hence on the expected poloidal angle of the islands O-point) is verified in about the 75 % of the database (i.e. 25 % of the identified structures cannot be identified as magnetic island, Fig 2).

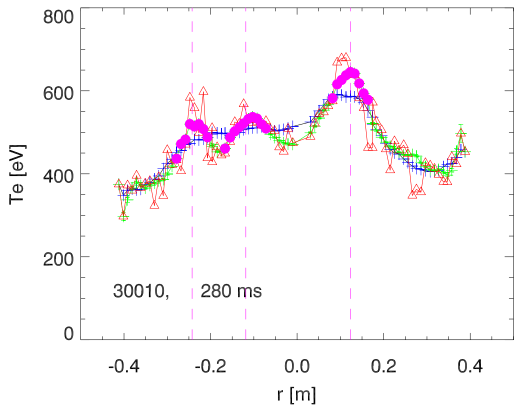


*Fig 1: Example of Thomson scattering profile showing multiple peaks. The raw profile (red) has been filtered (green) and the regions with downward curvature (magenta) identified*

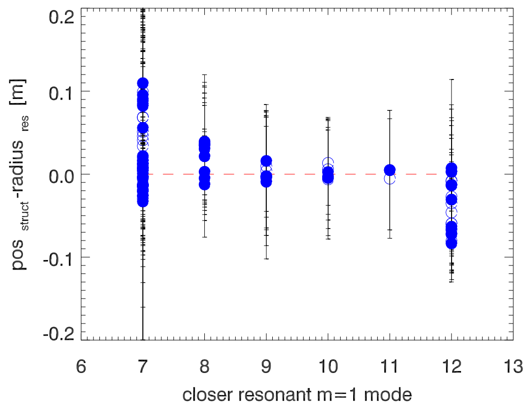


*Fig 2:Difference between the thermal structures position and the closer resonant radius: full dots indicate phase agreement, empty dots the other cases*

Fig 2 draws also a systematic dependence of structures radial deviation with the radius, which can be related to uncertainties in the equilibrium reconstruction.

The occurrence probability of the peaks in the $T_e$ profiles results low and small islands tend to develop immediately before a crash of the dominant mode amplitude; this is consistent with the typical growth of secondary modes at the crash (Fig 3).

As can be seen in Fig4, in the resonance proximity, i.e. for thermal island width smaller than ~6 cm, the island extension agrees with the semi-empirical relation [4]:

$$W_i \approx 4\sqrt{\frac{b_r R_{res}}{nB_p \left. \frac{dq}{dr} \right|_{res}}}$$

Where $b_r$ is the n-harmonic amplitude at the resonance, $R_{res}$ is the resonance radius, $B_p$ the poloidal field at the resonance and $dq/dr$ is the $q$ derivative.

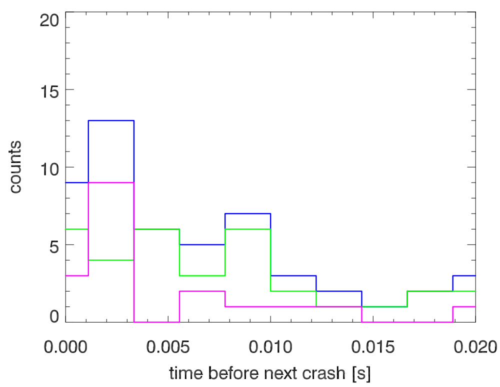


*Fig 3: Distribution of multiple peaks profiles as a function of time before a magnetic crash: the peak below 3 ms is peculiar to the QSH population (magenta line); green line refers to the MH samples*

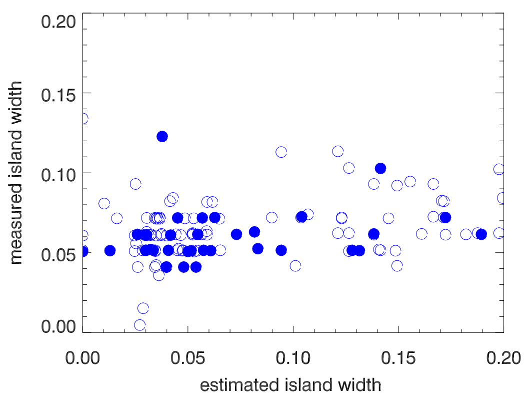


*Fig 4: Measured island dimension as a function of their calculated width, showing a a saturation in the island dimensions at about 0.1 m. Full dots refer to MH profiles*

For greater widths, i.e. above ~10 cm , the semi-empirical calculation is not valid and the island extension results overestimated. The agreement found for low width values is a confirmation that the Te peaks identify magnetic islands: their position and extension are qualitatively in good agreement with tomographic SXR inversions (Fig 5), within the uncertainties of the inversion procedure.

On the other hand, the Poincarè plots (obtained with the Orbit code [5]) of considered cases do not show conserved structures in correspondence of the identified thermal peaks. This discrepancy can be ascribed to errors in $q$ profiles and/or mode eigenfuctions reconstructions.

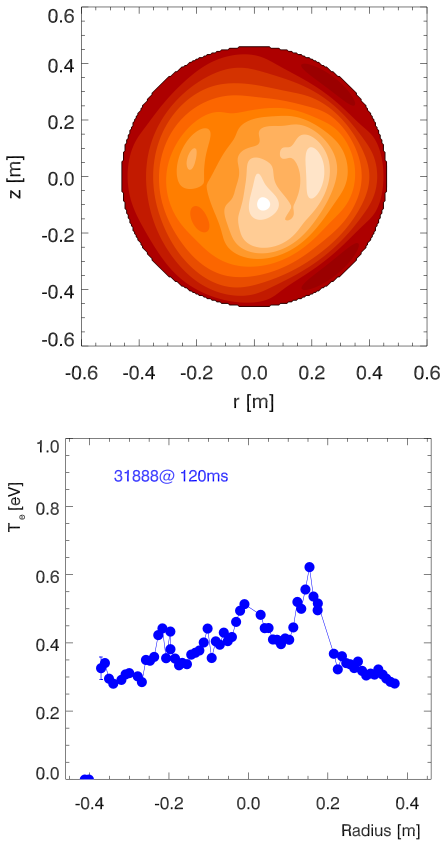


*Fig 5: Multiple structures in SXR inversion (up) and related TS profile (down). Different toroidal positions do not allow a direct comparison, except for the radial positions of the "hot spots"*

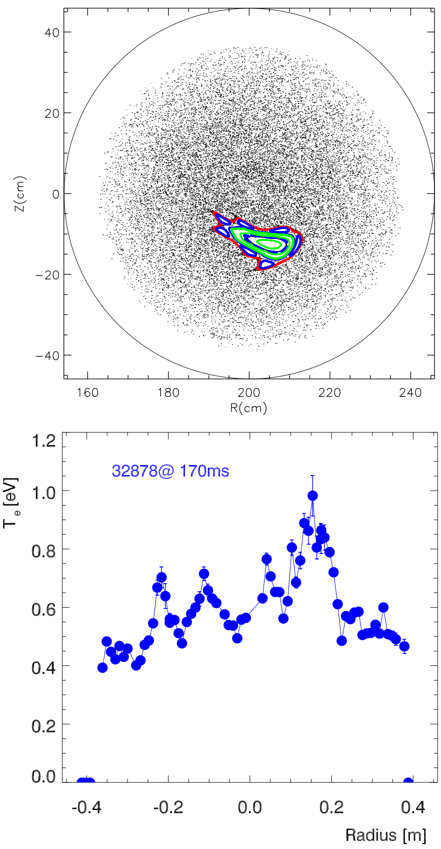


*Fig 6:Conserved structures in ORBIT code Poincarè plot and related TS profile. The Poincarè plot does not highlight conserved structures*

As far as high frequency magnetic activity is concerned, the database has been analyzed to identify micro-tearing activity at about 100 kHz [6], which are thought to be related to the temperature gradients in the QSH thermal structures. Actually, to discriminate the contribution of dominant mode islands, the database should be restricted to the MH discharges. Fig 7 shows average n-modes spectra considering the MH phases with and without $T_e$ peaks, and the QSH ones. Also if the 2 MH classes have nearly the same behaviour with respect to the frequency, the maximum at about 120 kHz (related to n<0 and reminiscent of micro-tearing activity) is absent in the cases without $T_e$ peaks. This is consistent with expectations since, in the MH cases with $T_e$ peaks, the $T_e$ gradients represent the source of free energy for the micro-tearing instabilities. The maximum at 120 kHz is not very pronounced, consistently with the low values of $\nabla T_e$ in the database (typically 2 KeV/m , in comparison with 3-10 KeV/m reached in the cleaner RFX QSH - see Fig 8).

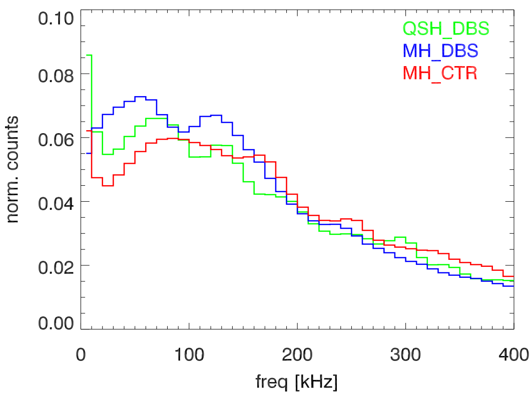


*Fig 7: Average spectrum of QSH and MH populations in the database.*

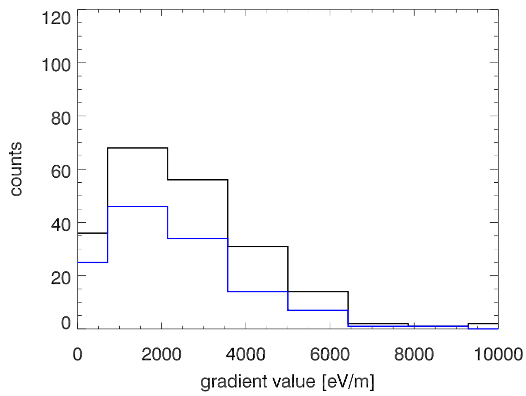


*Fig 8: Distribution of Te gradient values for the whole sample (black line) and for MH discharges (blue).*

**4) Conclusions**

Summarizing, multiple, small scale temperature structures in Thomson scattering $T_e$ profiles are definitely related to n≠-7 modes. Multiple structures have a low occurrence but happens with preference at the instants immediately before a magnetic crash of the dominant mode. Position and size of secondary islands agree with calculated values, and in some cases can be recognized with SXR tomography. There is no clear signature of high frequency magnetic activity related to the development of these structures; in this respect a wider database with better probes coverage will improve the understanding level.

**References:**

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