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QSH in high current RFX-mod plasmas: thermal and topological features

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Introduction. The initial idea that the plasma core of a reversed field pinch (RFP) configuration is characterized exclusively by chaos has been overcome by experimental observation of conserved flux surfaces arising in the so-called Quasi Single Helicity (QSH) states. The QSH state is interesting because it brings about better plasma performances in terms of thermal content, heat transport and confinement time. In QSH, the $m=1$ magnetic mode spectrum is characterized by a dominant mode surrounded by a broad spectrum of secondary ones, with smaller amplitude. This state spontaneously appears in RFX-mod [1] plasmas [2]; the higher the plasma current, the more likely the QSH appears. In correspondence to the magnetic island associated to the QSH dominant mode, a localized thermal structure and a more emissive soft X ray (SXR) region have been observed [3]. Various experimental techniques have proven to induce this plasma state, among which the Oscillating Poloidal Current Drive (OPCD) is one of the more promising [4]. The good QSH reproducibility obtained with this technique allows for investigating the thermal structures associated to QSH in a controlled way, studying in detail the QSH plasma topology and its temporal evolution. Various diagnostics have been exploited: the Thomson Scattering (TS) [5] for electron temperature (Te) profiles resolved over 84 points; the soft x-ray (SXR) tomographic diagnostic [6] and the time resolved Te measurements as estimated by the SXR multichord camera [7].

Experimental results. Both in standard and in OPCD operation, QSH is characterized by the appearance of a hot structure in the core, which is spatially localized at lower Ip (<1.2-1.3MA) but is often radially larger at the highest currents ($Ip \approx$1.5MA), with more peaked temperature profiles and steeper gradients at the edge [8]. In this paper, we analyze QSH structures in 1.5MA plasmas. An example of the two types of QSH thermal structures observed is displayed in Fig. 1: in panel (a) a large hot central plateau in the Te profile, measured by TS, is illustrated; in (b) the corresponding Poincaré plot done with ORBIT (a Hamiltonian guiding center code [9]) at the TS toroidal measurement position for the $m=1,n=-7$ mode, shows a wide island, spreading beyond the vessel center. In (c) and (d), the Te profile and the corresponding Poincaré plot for a localized QSH thermal structure typical

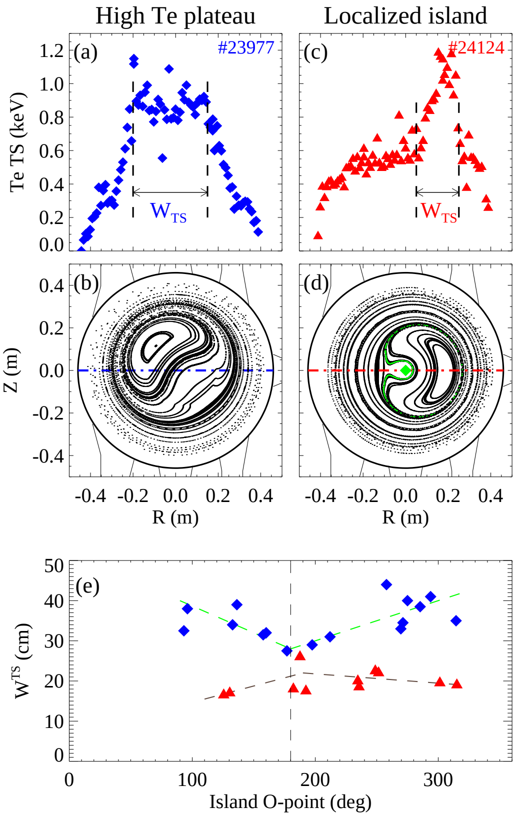

Fig. 1. *Te profiles from TS diagnostic for a high Te plateau case (a) and a localized Te structure (c), together with the corresponding Poincaré plots (b) and (d) for the dominant m=1,n=-7 magnetic mode; (e) Te structure width* w_{TS} *as a function of the island O-point.*

of lower *Ip* are shown: the radially localized hotter region corresponds to a less extended magnetic island, while the magnetic axis is still present in correspondence of the vessel axis (green diamond in (d); the green line in correspondence of the separatrix, absent in (b)). In both cases, the structure width w_{TS} can be estimated as displayed in Fig. 1(a) and (c): in the first case w_{TS} has been measured as the plateau width, while for a localized island it is the width at the structure foot. By means of a reference externally applied for *m=1,n=-7* mode, it is possible to set the magnetic island at different poloidal locations at the times of TS laser. In Fig. 1(e), w_{TS} as a function of the island O-point angle is shown: w_{TS} decreases at about 180° for high *Te* plateau structures (blue diamonds), as the thermal island is stretching beyond the vessel axis (TS laser path is at the mid-plane). For a localized island (red triangles), instead, which is narrower and covers a small part of the plasma column around the magnetic axis, w_{TS} is almost the same around 180°. This behavior is essentially due to the differences of the topology of the two *Te* structures, associated to the two different QSH configurations.

In Fig. 1(e) the TS profiles have been obtained all at the same OPCD phase in similar plasma discharges, and hence also with similar magnetic mode spectrum, for each type of QSH structures. Different *Te* profiles can be collected according to the poloidal angle of the island O-point, finally drawing a full 2D map of the electron temperature for both the QSH types. In Fig. 2, the *Te* contour plots (*Te* is normalized to 1) of a poloidal section for both islands are displayed: the localized island shows a hotter, bean-shaped structure, occupying only a small portion of the plasma core on one side of the vessel (red region); on the contrary, the high plateau is radially wider and extends beyond the vessel axis, thus covering a large part of the plasma core. In the case typical of lower *Ip* currents, the thermal island coexists with the

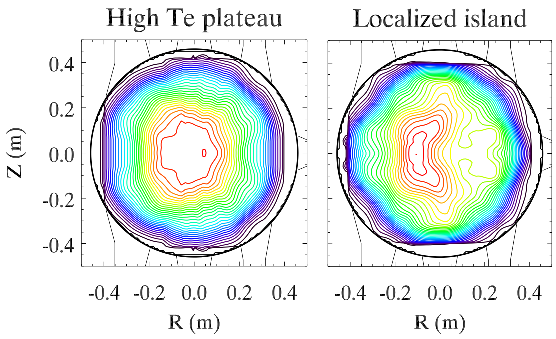

Fig. 2. *2D normalized Te contour plots (same color scale) for a high Te plateau and a localized structure, obtained by means of TS profiles of Fig. 1.*

magnetic axis near the core, while in the second case the island O-point is replacing the old magnetic axis. This corresponds to a new helical equilibrium established in the plasma [10], and characterized by this hotter and wider structure and lower particle and heat diffusion [9].

Analysis of the *m=1* spectrum shows a clear difference in the amplitudes of the modes for the two QSH types. As reported in [3], the amplitude of a QSH island can be associated to the ratio of the dominant $b_{1,-7}$ and the secondary $b_{1,n<-7}$ modes. The dependence is shown in Fig. 3: the width w_{TS} is higher for the plateau and correspondingly the ratios are higher (blue diamonds); at lower ratio values, the width is smaller and corresponds to a localized structure (red triangles).

The spatial characterization of the thermal islands has been extended to the whole QSH lifetime by means of the *Te* profile temporal evolution measured by the multichord SXR camera. In Fig. 4 the structure evolution as observed by the SXR multichord diagnostic and by the SXR tomography are displayed for two different cases of high *Te* plateaus. In frame (a), the high *Te* plateau has been observed during OPCD operation, with an external rotating reference applied to the $b_{1,-7}$ mode; in frame (b) the structure has been detected during a standard clean mode control plasma shot (for details, see [11]). In (a), the QSH evolution shows the appearance of a small localized hot island which is then replaced by the large plateau as the core is warmed up. The thermal island, both in the *Te* profile evolution and in the SXR emissivity reconstructions emerges as a small structure, and then evolves in a larger one as the $b_{1,-7}$ becomes high enough. In (b), instead, the high *Te* plateau in the core is achieved with no evidences of an initial seed represented by a small thermal island: since the beginning, a large hot structure emerges in the plasma column, then becoming hotter and more emissive. These two different evolutions could be ascribed to different operational regimes and plasma equilibrium: in (a) OPCD is sustaining the plasma dynamo, with a transient action together with a

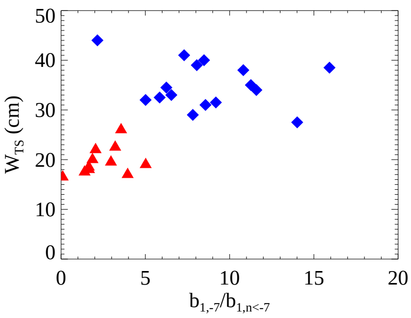

Fig. 3. *Thermal island width* w_{TS} *as a function of the ratio between the dominant magnetic mode* ($b_{1,-7}$) *and the secondary ones* ($b_{1,n<-7}$).

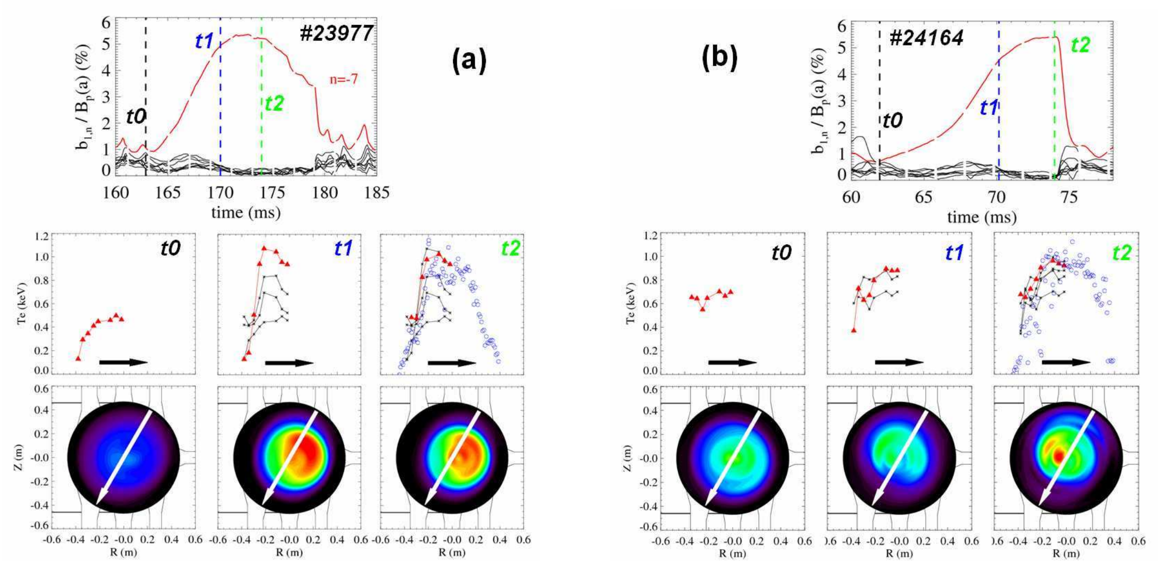

Fig. 4. *Two different temporal evolution of the high Te plateau structure: the magnetic m=1 spectrum is displayed, together with the Te profile evolution from SXR (red triangles) and from TS measurements (blue empty circles), and the 2D map of the reconstructed SXR plasma emissivity distribution.*

relative high amplitude externally driven rotation of the $b_{1,-7}$ mode at 40Hz. In (b), instead, a standard plasma shot, without any external rotating references, is shown: the QSH structure is mostly fixed at the same poloidal position during QSH. The fact that in (a) the island is externally driven by a mode rotation implies that the maximum *Te* value associated to the island O-point is rotating, intercepting different SXR chords at different times. This, together with the fact that the SXR is looking at one half of the poloidal section, could partially limit and affect the information on QSH thermal structure evolution (work is still in progress).

Conclusions. In this paper we have shown a 2D map of *Te* and magnetic topology of the thermal structures emerging in the core of 1.5MA plasma shots in RFX-mod. Different types of *Te* structures are observed in correspondence of different magnetic mode amplitudes: a hot large *Te* core plateau is seen at higher $b_{1,-7}/b_{1,n<-7}$ ratios, while a more localized one is present at lower ratios, which is typical for lower *Ip* operation. The time evolution of the plateau *Te* profile is work in progress to clarify: two different cases have been observed, related maybe to two different experimental conditions, which still need to be investigated.

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[1] P.Sonato et al., Fusion Engineering and Design 66, 161 (2003).
[2] P.Piovesan, this conference.
[3] F.Bonomo et al, 34th EPS Conference on Plasma Phys. Warsaw, 2-6 July 2007-ECA Vol.31F,P-2.051(2007).
[4] D.Terranova et al. Phys. Rev. Lett. 99, 95001 (2007).
[5] A.Alfier and R.Pasqualotto, Rev. Sci. Instrum. 78, 013505 (2007).
[6] P.Franz et al., Nucl. Fusion. 41, 695 (2001).
[7] F.Bonomo et al, Rev. Sci. Instrum. 77, 10F313 (2006).
[8] A.Alfier et al., Plasma Phys. Control. Fusion 50, 035013 (2008).
[9] M.Gobbin et al, this conference, P5.035.
[10] R.Lorenzini et. al., 'Single-helical-axis states in reversed-field-pinch plasmas', to be published in Phys. Rev. Lett.
[11] L.Marrelli, this conference.