SOME FEATURES OF THE DISRUPTION INSTABILITY IN REVERSED SHEAR TFTR PLASMAS

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Abstract

The behaviour of MHD perturbations before and during disruptions in TFTR reversed-shear plasmas with $q_{min} \approx 2$ was analysed. In the q_{min} region tearing modes, wave-like modes, and mixed tearing plus wave-like modes are followed by disruption. Sometimes a helical “snake” (helix) appears at the X-point of the q_{min} island. The local outward electron energy transport near the X-point can be explained by the development of “positive” magnetic islands. It is proposed that the disruption is initiated when the X-point of the islands coincides in one toroidal position near the torus equator.

Introduction

There is now considerable interest in reversed-shear (RS) plasmas because the experiments show promising improvements in the plasma confinement. However, this is unfortunately accompanied by an increased rate of disruptions. This stimulates the study of the instabilities in RS plasmas in the hope of finding ways for disruption suppression. This paper presents some of the most interesting features of the MHD perturbations accompanying disruption in RS plasmas.

Diagnostics

In TFTR, arrays of Mirnov coils allow identification of external perturbations with poloidal/toroidal mode numbers up to m=6-7/n=2-3. ECE emission in two cross sections (labelled GPC1 and GPC2) separated by 126^{o} in the toroidal direction was used to measure internal MHD perturbations. These two main diagnostics have a time resolution of 2 μs. Motional Stark Effect (MSE) measurements and the TRANSP analysis code were used to find the q-profile. Soft X-Ray (SXR) channels were used to monitor cut-off of the ECE signals. The ECE data are analyzed using a visualisation method [1] which can also produce 3D stereoscopic images of complicated phenomena.

Comparison of the RS and Supershot Disruptions

Analysis shows that the disruption instabilities in RS plasmas and in TFTR supershots (SS) with positive shear have the same sequence of events - minor disruption (first fast thermal quench), slow thermal quench, second fast electron and ion thermal quenches, positive current spike, and current quench [2, 3]. For the two types of discharge, time scales are similar for the fast electron thermal quenches, 50 – 200 μs, and the the current quenches, 4 – 5 ms. The slow thermal quench is shorter in RS plasmas. The main difference, however, is in the size of the positive current spike. In RS disruptions, $\delta I_p \sim 4 - 5\%$, about a factor two smaller than in SS disruptions where $\delta I_p \sim 6 - 8\%$. Probably the reason for this difference is the relatively small magnetic energy inside the plasma column ($l_i I^2/2$) and resulting shorter l_i/R timescale for current density flattening. As in the SS plasmas [2], the probable J(r) flattening in RS plasmas decreases the MHD-stability of ideal modes and the major disruption could be the result of such an ideal instability. The key events of the RS minor disruption are a relaxation-like phenomenon and the resonance between q_{min} and q(a) modes.

Mode dynamics in RS disruptions

Strong wave-like, mono-tearing, double-tearing and mixed modes are observed in the q_{min} region.

A. In high power NBI shots wave-like perturbations develop as separate fishbone-like bursts in a frequency range of 10 - 70 kHz (m=even(4)/n=2 or m=even(2)/n=1) and in some cases produce enormously strong deformation of the electron temperature profile without visible tearing structure. As the perturbation increases, the initial wave-like structure can transform into a mixed structure with a single tearing mode in the normal shear and a wave-like perturbation in the reversed shear region.

Fig. 1a shows evolution of the electron temperature profile in two toroidal cross-sections separated by 126°. Figs. 1b, c show isometric images of the electron temperature profile. A clearly visible hot island (double-tearing mode) has formed only ~1 ms before the minor disruption. In the mixed case the X-point has increased size (t_2, t_4) and the perturbation pushes to the outside through the X-point. It resembles a deformed version of Waelbroeck's ribbon-like X-point which was discussed in [4].

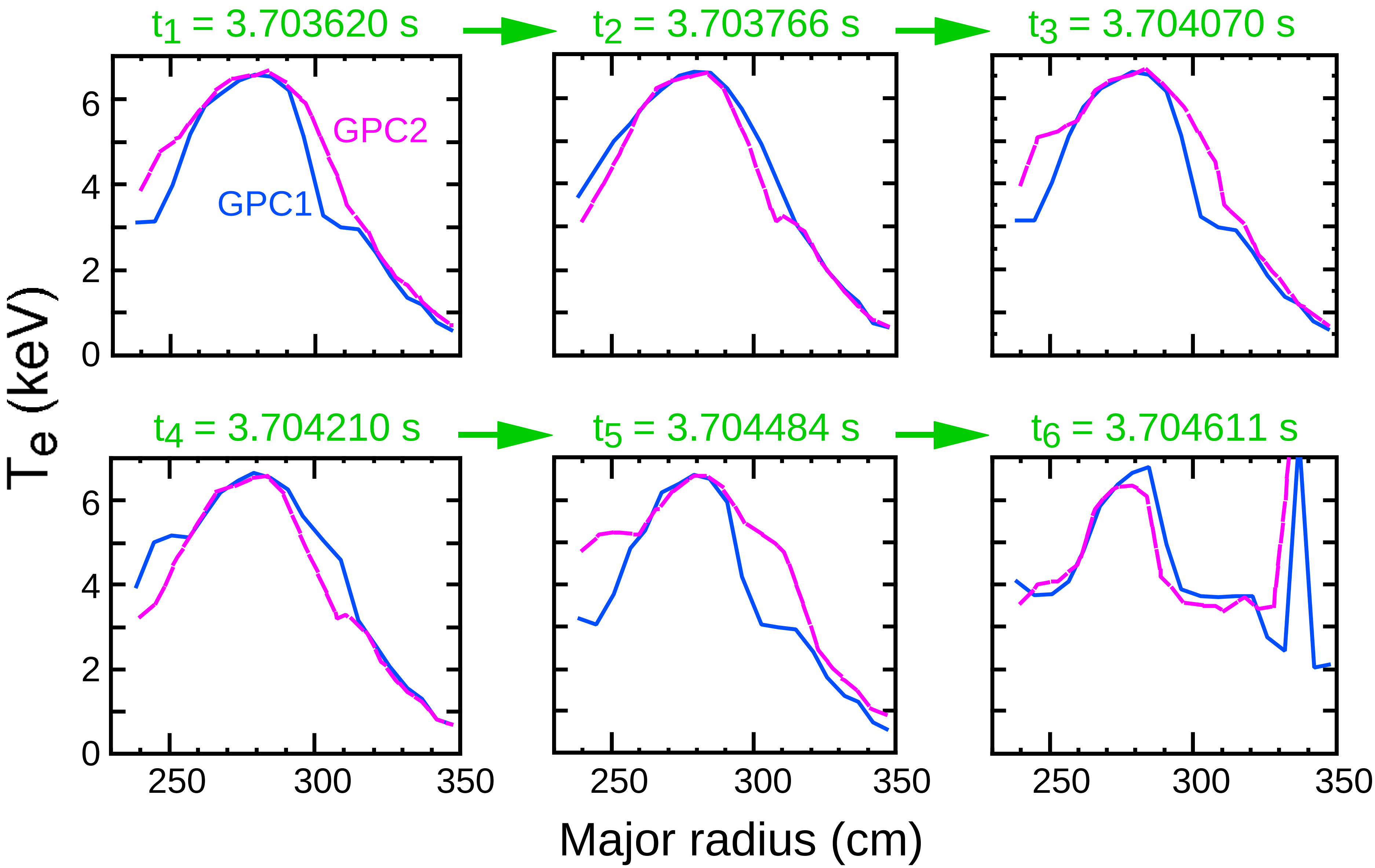

Fig. 1a Sequence of temperature profiles during a disruption in a RS plasma. Toroidal locations separated by 126°.

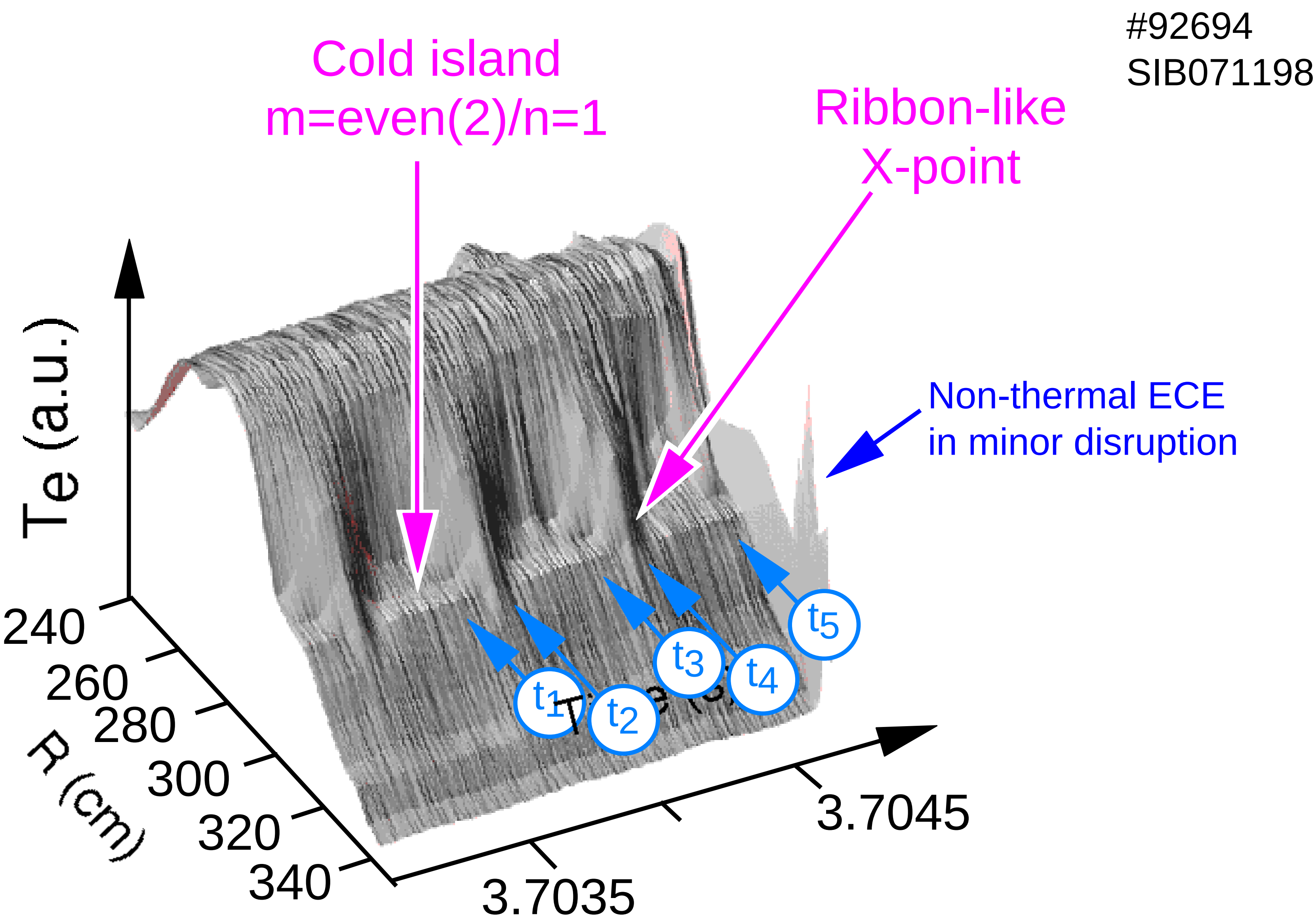

Fig. 1b   Low field side view (GPC1)

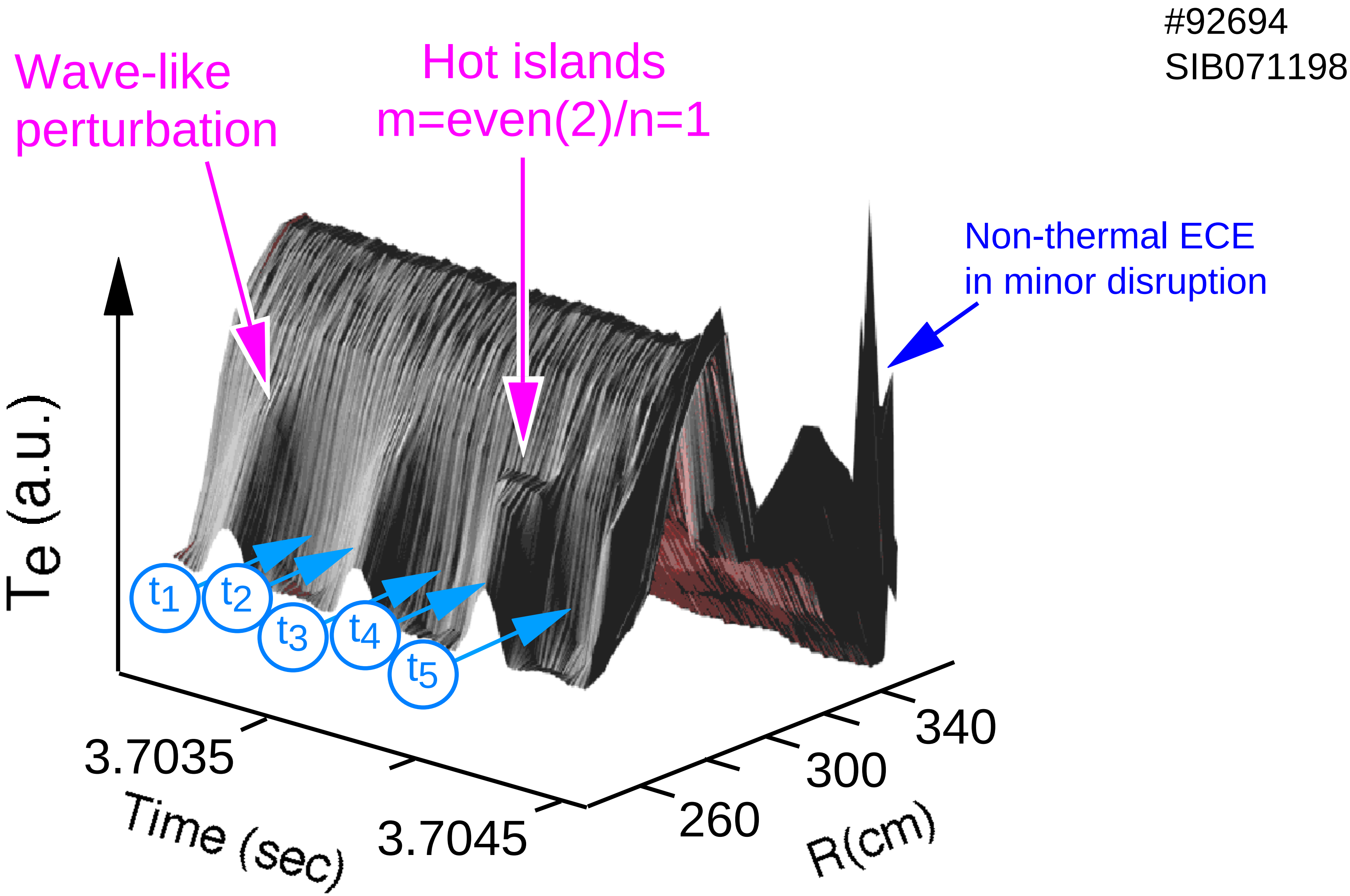

Fig. 1c High field side view (GPC1)

B. Fig. 2 shows relaxation-type MHD activity which is typical for the negative shear region near q_{min}. The development of this perturbation causes a fast (~ 100 μs) changes in the electron temperature profile in a narrow region adjacent to the negative shear region. It looks like a sawtooth relaxation (fragment (a) of Fig. 2), but the nature of the precursor is not clear because the precursor is not visible in the frequency range $f < 250 - 500$ kHz and in the space range $\delta r > 3 - 5$ cm. (The size of the relaxation region is 2 - 3 cm, estimated according to [5]). This activity precedes the disruption and probably plays the trigger role of the disruption (t3 in Fig. 2)

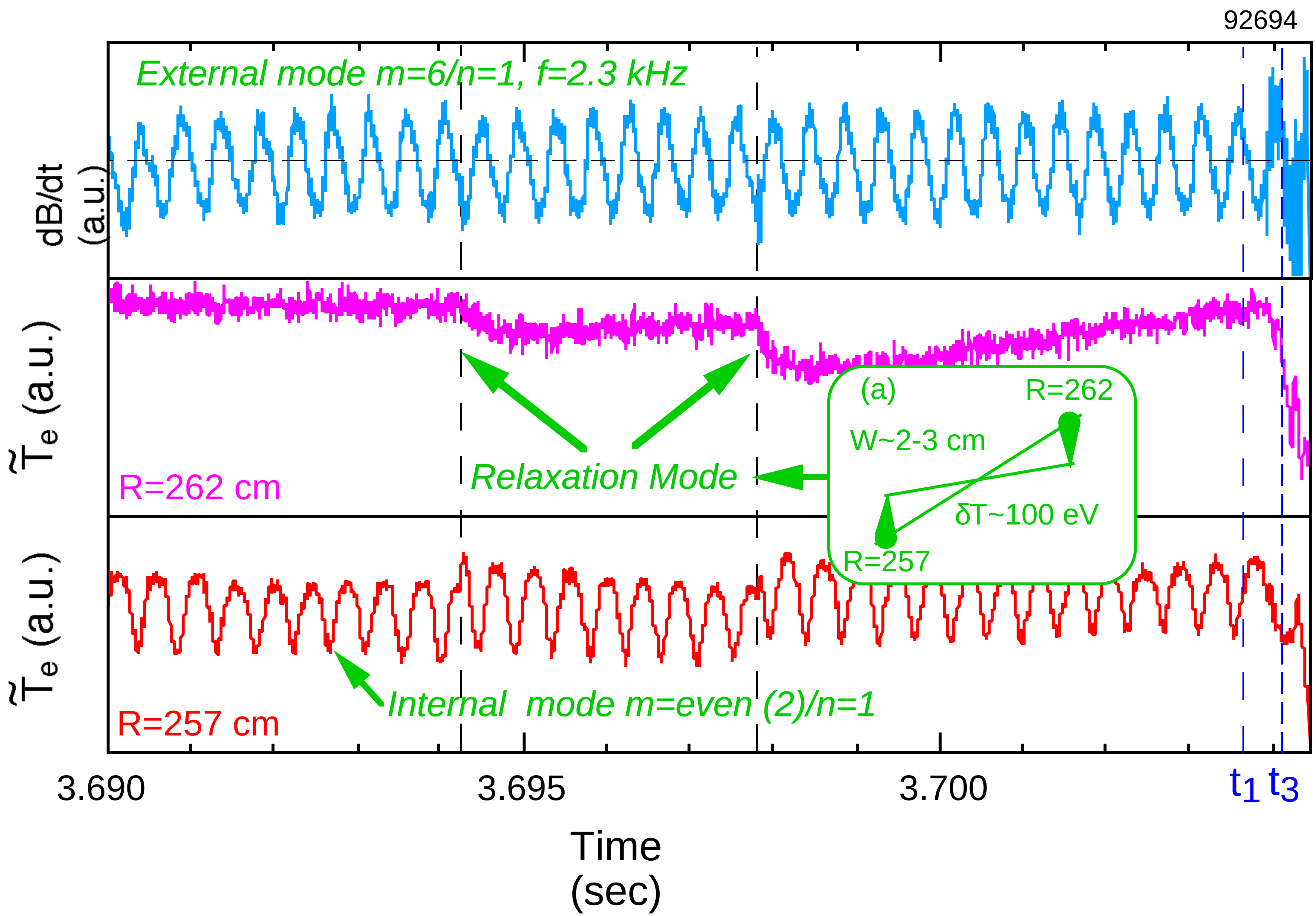

Fig. 2 Relaxation phenomena in the border between negative shear region and q_{min} prior to disruption

C. Helical "snake" perturbations could be observed in the RS shots before and during disruption. Fig. 3a shows the evolution of the ECE perturbations in the q_{min} region, which leads to the minor disruption. The TRANSP q(R) profile is shown in Fig. 3c. A sawtooth-like phenomenon (discussed above) at the time $t \approx 3.482$ s preceded by fishbone-like perturbations, develops in the q_{min} region (R = 310 - 314 cm). A magnetic island suddenly appears 3 ms later at t = 3.485 s, probably as a result of some relaxation processes. The analysis of ECE signals shows that this perturbation is an even(2)/1 single-island tearing mode. The helix has appeared at the X-point of this island 0.5 ms before the disruption and propagated through the external magnetic surfaces leading to the minor disruption. A ballooning-like mode at the edge of the helical bulge sometimes can accompany this type of MHD activity. Fig. 3b shows the 3D top view image of the electron temperature profile for the time interval ~ 2 ms.

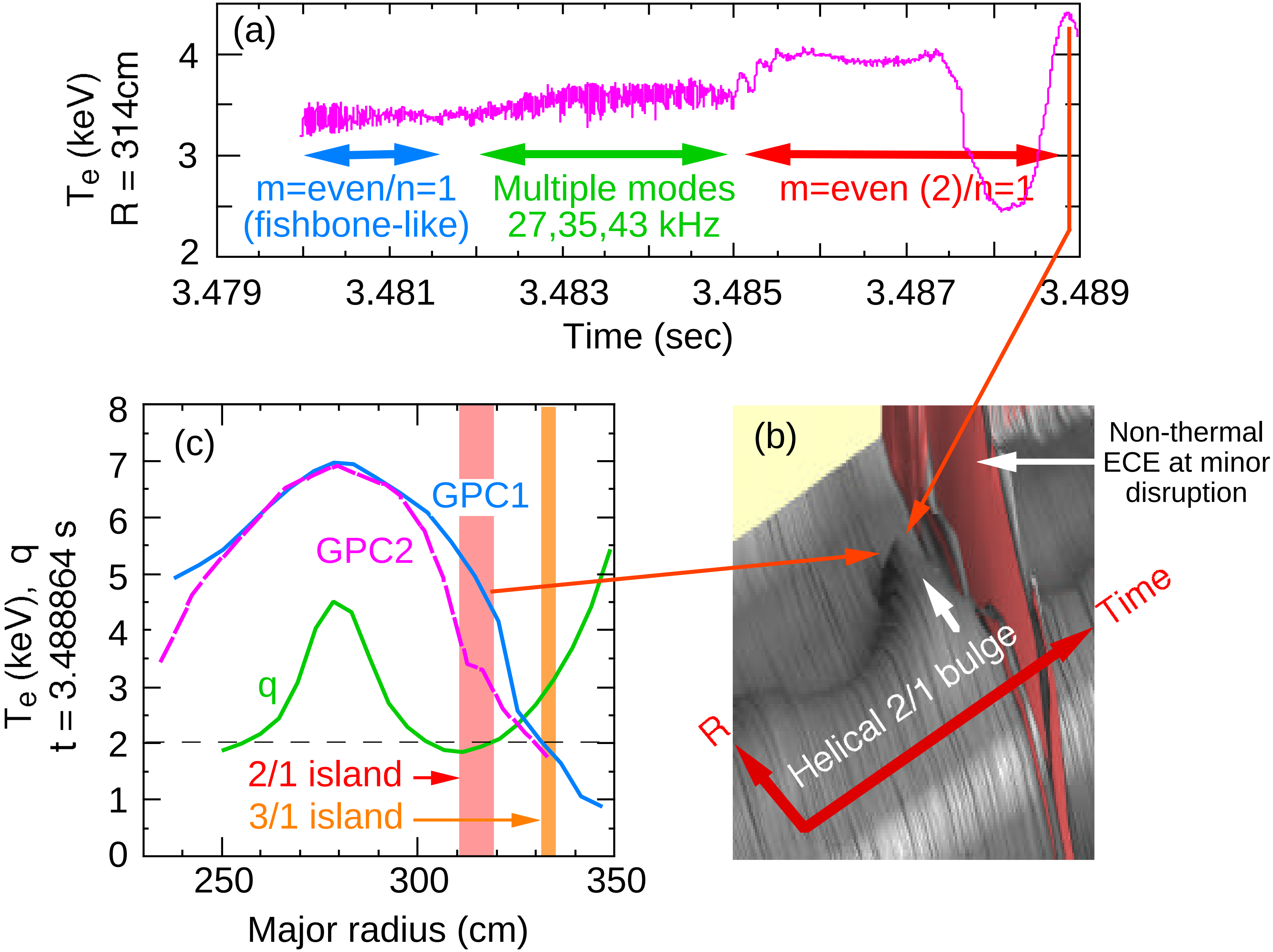

Fig. 3 Helical snake in the island X-point near q_{min} before minor disruption. q-profile from TRANSP

Sometimes a fast helical "bridge" between hot and cold regions of the plasma can be observed during a minor disruption in the q_{min} region. Fig. 4 shows the development of the bridge in a discharge with q_{min} = 2. In this discharge, the tearing mode starts at t = 3.068628 s. 16 μs later the hot bridge at the X-point of the (even(2)/1) island reaches the external(3)/1 mode region. At this moment the first non-thermal ECE appears at the position of 3/1 island. 14 μs later we can see the flattening of the electron temperature in the toroidal position of GPC1 between q = 3 (int) and q = 3 (ext) (the q(r) profile is from TRANSP). Only 18 μsec later the temperature across the torus becomes equal and the plasma shifts inwards (~ 9 cm) indicating a drop of plasma energy. This moment coincides with the beginning of the turbulent edge magnetic activity. During the next 300 μs the central temperature drops slowly from 4 keV to 2 keV (slow thermal quench) and in 50 μs it disappears during the second fast thermal quench. The plasma current spike, an indicator of global magnetic reconnection, starts at that time. One of the possible explanations of this phenomenon can be the development of the bulge-type perturbations [6], another one is the development of the "positive" magnetic islands in the X-point of the initial magnetic island in low shear region near q_{min} [7].

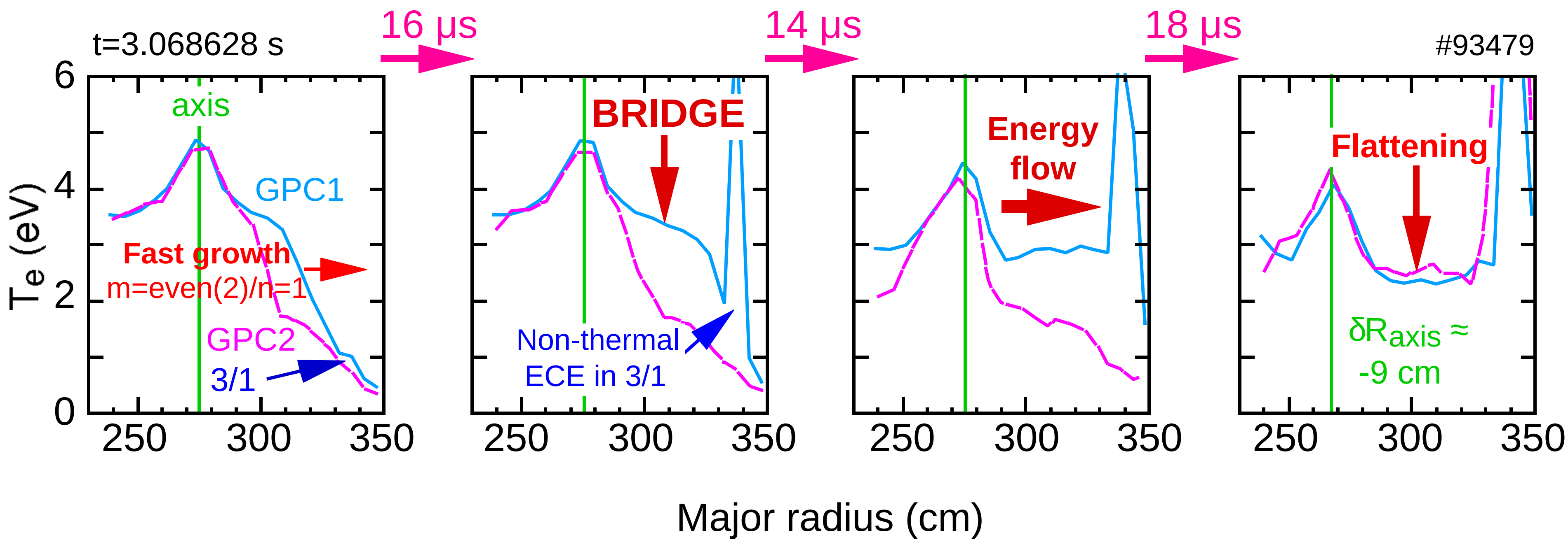

Fig. 4 Development of localized "bridge" between core and edge causes rapid cooling of center and inward shift of axis

Conclusions

The RS disruption observed in TFTR discharges is the result of the non-linear development of the m/n = q_{min} perturbation. The scheme of the development is similar to the sawtooth development near $q(r_S) = 1$ in SS discharges. A peculiarity is the development of the islands near q_{min} and subsequent appearance of the helical “bridge” from the hot plasma region to the periphery. This behaviour could be understood if we take into account that in low shear region there is a possibility for the development of an additional “positive magnetic island” in the region of positive current perturbation [7]. Such positive islands have radial orientation and as the perturbation increases it penetrates the magnetic surfaces connecting the hot and cold regions. The development of the “bridge” in RS discharges is the analog of the “Hot spot” in a positive-shear sawtooth but with m/n = q_{min}. A possibility for avoidance of the disruption in this case could be the distortion of q_{min} and q(a) resonance, for example by rotational shear or local ECD in the q_{min} region.

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