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Small scale structures in the RTP T_e profiles

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Introduction

Measured electron temperature profiles of tokamak plasmas are often smooth. This may be due to a low diagnostic resolution. Some high resolution diagnostics do measure structures on the profiles. Steep gradient regions associated with transport barriers have been observed in e.g. RTP [1], JET [2] and TUMAN-3M [3]. Flat regions associated with large magnetic islands have been observed in e.g. RTP [4], JET [5], TEXT-U [6]. In the Rijnhuizen Tokamak Project (RTP, $R = 0.72$ m, $a = 0.164$ m, $I_p < 150$ kA, $B_t < 2.4$ T) even smaller structures are observed. A double pulse Thomson scattering (TS) diagnostic enables the measurement of the electron temperature (T_e) and density (n_e) with a spatial resolution of 3 mm full width at half maximum (FWHM), i.e. 2 % of the minor radius [7, 8]. Peaked structures named 'filaments' have been observed in RTP [9, 10] during electron cyclotron heating (ECH), see Figure 1. Quasi-periodic structures of typically 10 mm are observed in Ohmic plasmas (OH), see Figure 2. This paper presents some observations made on filaments. This is a small part of the comprehensive study on filaments presented in [9]. The significance and parameter dependence of structures in OH discharges are also presented.

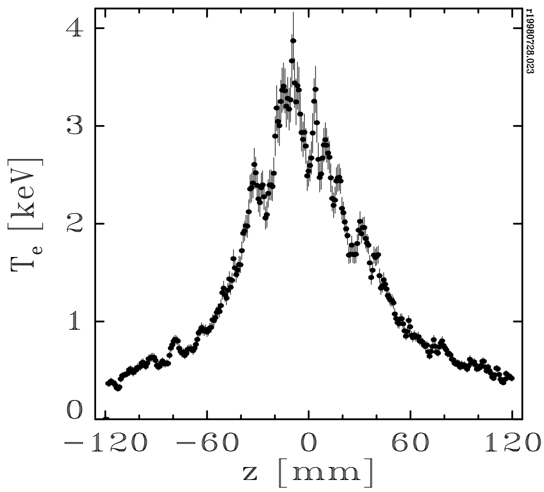

Figure 1
Filaments appear on the T_e *profile of an ECH discharge.*

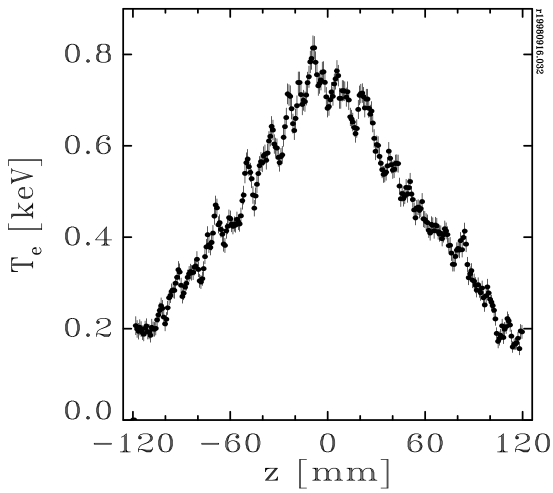

Figure 2
Quasi-periodic structures appear on the T_e *profile of OH discharge.*

Filaments during ECH

Filaments are not observed during the OH phase, but appear 4 - 5 ms after the ECH onset, about 3 ms after the central T_e rise is established. This indicates that a filament is not a pre-existing structure that is heated along with the bulk by ECH. Some time is needed to establish the required conditions for filament creation. After ECH is switched off the filaments persist for a few hundred microseconds.

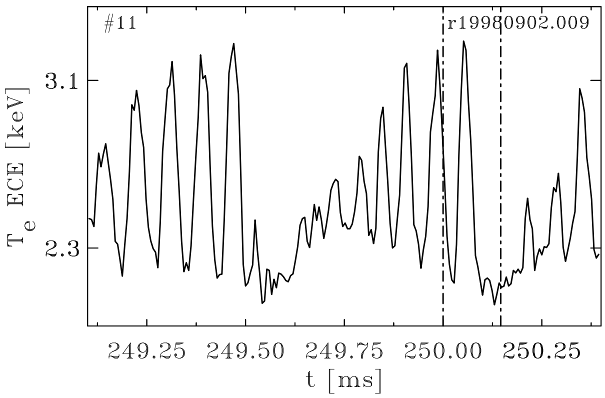

Figure 3
Central ECE time trace showing the sawtooth crash and precursor, and moments of TS measurements.

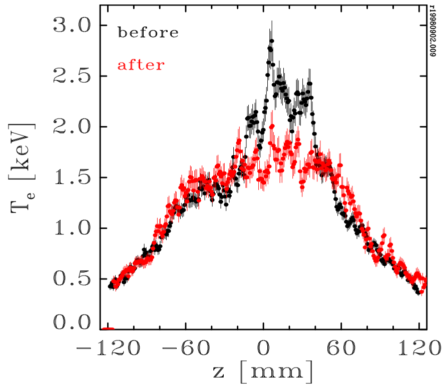

Figure 4
T_e *profile before (black) and after (red) a sawtooth crash of the discharge of Figure 3.*

Figure 3 shows a time trace of the central ECE channel measuring T_e of an ECH discharge (I_p = 120 kA, $\bar{n}_e$ = 1.9·10^{19} m^{-3}, q_a = 3.1). A sawtooth crash and precursor are observed. The double pulse TS is triggered just before and just after (vertical lines) the sawtooth crash. Figure 4 shows the two T_e profiles. The post-crash profile is much flatter than the pre-crash profile. The filaments are destroyed at the sawtooth crash. Similar double pulse TS measurements show that the filaments reappear within 0.2 ms after the sawtooth crash. This period is an order of magnitude lower than the time scale of initial filament creation after the ECH onset. Hence the conditions for filament creation are not destroyed at sawtooth crashes.

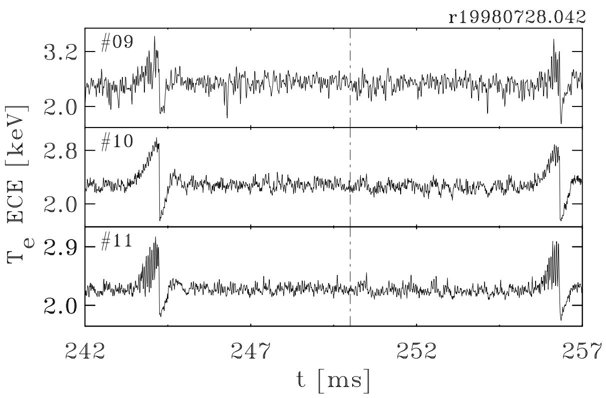

Figure 5
Central ECE time traces without large MHD activity at the time of TS measurement (vertical line).

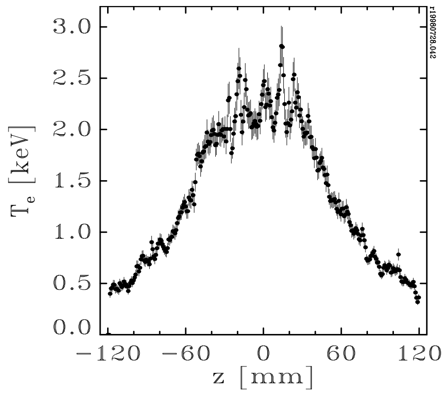

Figure 6
T_e *profile with filaments of the ECH discharge of Figure 5.*

Figure 5 shows the time traces of three central ECE channels of an ECH discharge (I_p = 80 kA, $\bar{n}_e$ = 1.5·10^{19} m^{-3}, q_a = 4.6). Sawtooth activity is present, but not at the time of the TS measurement (vertical line). The profile still contains filaments, see Figure 6. Extensive measurements show that the filament amplitude is independent of the amplitude of the m = 1 precursor [9].

Quasi-periodic structures during OH

The dimensions of the quasi-periodic structures on T_e profiles of OH discharges are close to the resolution and therefore the significance is tested. An extensive error analysis has been performed to determine the error (δT_e) on the TS measurement [11]. The structure profile ($\tilde{T}_e$) is defined as the difference between T_e and a smooth profile through T_e, see Figure 7. The average power spectrum of the relative structure profile ($\tilde{T}_e/T_e$) of a series of 24 OH discharges (I_p = 80 kA, $\bar{n}_e$ = 3.5·10^{19} m^{-3}, q_a = 5.0 ± 0.1) is shown in Figure 8 (black line). The decay near 1/λ = 0.2 mm^{-1} is due to the instrument function of the TS diagnostic [11]. The Fourier spectrum of the instrument function is also in Figure 8 (red line). The spectrum of the structures is a factor 2 – 2.5 above this spectrum for 1/λ < 0.10 mm^{-1}. Structures wider than λ/2 = 5 mm are therefore significant. This is almost twice the resolution of the TS system. The spectrum of artificial noise is also shown (dashed red line) to illustrate the size of the spectral fluctuations that can arise from statistics only.

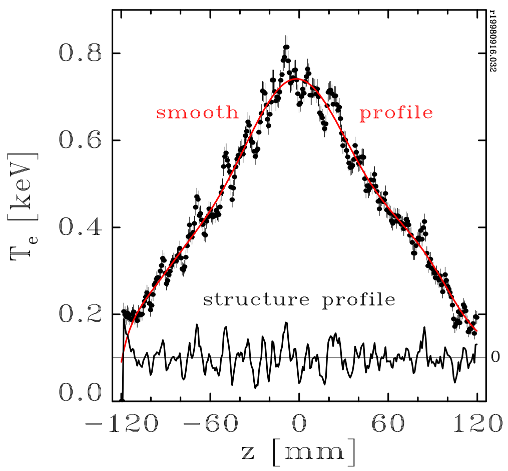

Figure 7
Temperature profile (T_e)*, smooth profile (red) and structure profile* ($\tilde{T}_e$) *of an OH discharge.*

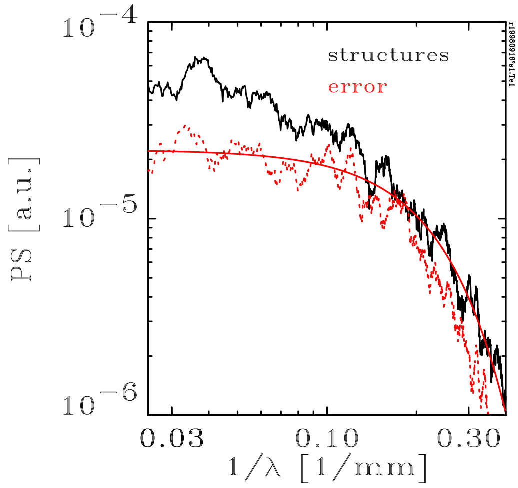

Figure 8
Power spectrum of the relative structure profile of 24 OH discharges.

Parameter studies have been performed on the relative height ($\tilde{T}_e / T_e$) and the width of the structures, defined as the distance between two local minima in the profile, for a data set of >150 OH discharges. The width of the structures does not depend on the radial position, but there is a weak inverse dependence on q_a. The structures appear at random positions along the z-axis. The relative height shows a positive correlation with q_a. Increasing T_e and n_e decreases the relative height, but these parameters have no effect on the width.

Discussion

The fact that the filament creation time after ECH onset is longer than the core energy confinement time suggests that current diffusion, i.e. modification of the q profile might play a role in filament creation. The filaments are found inside the sawtooth inversion radius where q is close to 1. There is a limited set of observations of filaments in T_e profiles with a pronounced off-axes maximum, obtained by application of off-axis ECH. In those cases, the value of q is well above unity. These observations suggest that ECH in a region of low shear at a simple rational value of q is the condition that is favourable for filament creation.

The quasi-periodic structures during OH are genuine temperature fluctuations and not due to a diagnostic artefact. The nature of the structures is still unclear.

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