Study on Differences of ECE and High-Resolution Thomson Scattering temperature measurements in DT (Deuterium-Tritium) plasmas on JET

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1.Introduction

In Deuterium Plasmas differences were detected in JET between electron temperature measurements (Te) made by Electron Cyclotron Emission - Te_ECE - and Thomson Scattering diagnostics systems (Te_TS) [1]. Similar behaviour was found in TFTR [2]. Plasmas heated by ECRH (Electron Cyclotron Heating) in Deuterium on FTU showed T_ECE < T_TS for 8 KeV ≤ Te ≤ 14 keV [3]. These differences can be due to the non-Maxwellian nature of the Electron velocity Distribution Function (EDF) [5,6]. The radiation temperature (Trad) measured by ECE is equal to the Te only for a Maxwellian plasma: being Trad dependent on the derivative of the EDF with respect to perpendicular velocity [5]. This paper describes differences of Te measured by ECE (ECE_MP, Martin-Puplett interferometer) and High-Resolution Thomson Scattering (HRTS) diagnostic. HRTS gives independent information on these differences, having shorter space resolution (2 cm), and faster repetition rate (20 Hz) on a different line of sight (16 cm from the magnetic centre): HRTS measurements confirm the trends observed using LIDAR TS [4,5]. Comparison between HRTS and ECE radiometer measurements is also reported (see sec.3). In addition, changes are detected on the ratio Te_ECE/Te_HRTS during the evolution of fast-ion linked MHD in DT, supporting the scheme of non-Maxwellian EDF. The paper is organized as follows: in sec.2 the main messages from this study are given; in sec.3 the comparison between HRTS and ECE_MP are shown for DTE2 discharges representatives of non-thermal tritium rich, and hybrid scenarios. The same comparison is reported for DD Neon seeded discharge adding the comparison of Te_HRTS with Te_ECE_Radiometer (Te_Radiometer). The time behaviour of (Te_HRTS/Te_ECE_MP)-1 is shown in presence of fishbone activity on hybrid scenario. Fishbones are MHD internal kink modes driven by spatial gradient of fast ion distribution function [7] and then to fast ion pressure; the behaviour of the (Te_HRTS/Te_ECE_MP) -1 versus MHD monitor is reported also for Neon seeded discharge; in sec.4 the conclusions are given.

2. Motivations and Main Messages

1. In this paper the difference between ECE Martin-Puplett interferometer (ECE_MP) and the HRTS plasma Temperature measurements are presented. The comparison of Te_HRTS with Te_Radiometer is presented as well. The reason is twofold: I) the need to detect the differences using another Thomson system completely different from LIDAR can contribute to the exclusion of systematic errors connected to the Thomson systems; ii) the possibility to compare the time behaviour of the ratio Te_ECE_MP/Te_HRTS with 20 Hz sampling frequency can make easier the correlation with physical effects related to MHD and fast ion physics. It's important to note that the calibration of ECE diagnostics was checked daily during the DTE2.
2. The ECE radiation Temperature depends on the absorption coefficient (or plasma thickness) which is proportional to the derivative of the EDF: the ECE is very sensitive to the distortions of EDF [5,6].
3. Thomson light spectrum is proportional to the electron velocity distribution function. The details of EDF distortion cannot be detected due to the limitation in signal to noise ratio of TS measurements.
4. The physical origin of the distortions of the EDF (which are causing the differences in the ECE and Thomson measurements) may be linked to effects of fast ions with energy higher than the critical energy interacting directly with EDF in thermal region (i.e. for velocities $v \approx 1 \div 2$ v_thermal) as demonstrated by a model calculation of the ECE radiation temperature [5].
5. In this paper examples of the ratio Te_TS(HRTS)/Te_ECE_MP behaviour during MHD activity linked to fast ions are shown in DT-Tritium-rich plasmas, in DT- Hybrid scenario, giving further evidence of link to distortions of EDF. In Deuterium Neon seeded discharges the same ratio follows the MHD monitor,
6. The comparison between Te_HRTS and Te_ECE is done using the equilibrium evaluation EFTP (equilibrium constrained by pressure profile): a sensitivity analysis using other types of equilibria (EFTF polarimetry constrained) has been done and the results are not changed (see also sec.3).

3. Comparison of temperature measurements by ECE and Thomson scattering

In this work we use the JET HRTS diagnostic, and for the comparison with ECE the use of equilibrium is necessary because HRTS and ECE Martin-Puplett interferometer have a different line of sight. The measured Te(R) radial profiles are projected on the equilibrium basis using the EFTP equilibrium (constrained by the pressure profile). The values of $Te(\psi)$ are evaluated and averaged in the interval ψ=0.07-0.12. The error bars are of the order of 5%.

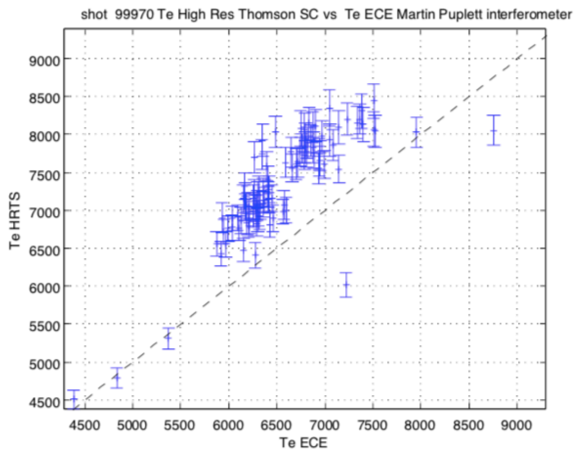

Fig.2: Te_HRTS vs Te_ECE_MP #99970

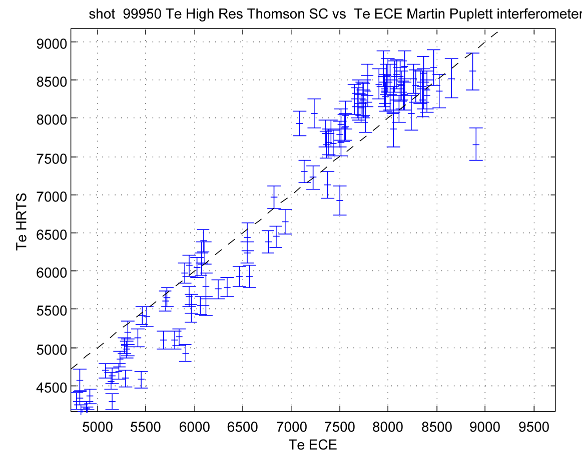

Fig.3: Te_HRTS vs Te_ECE_MP #99950

The figures 2 and 3 show the comparison of the Te_HRTS and Te_ECE_MP for a DTE2 discharge (#99970) tritium rich non-thermal plasma and #99950 hybrid: the ECE measurement is lower than HRTS at high Te.

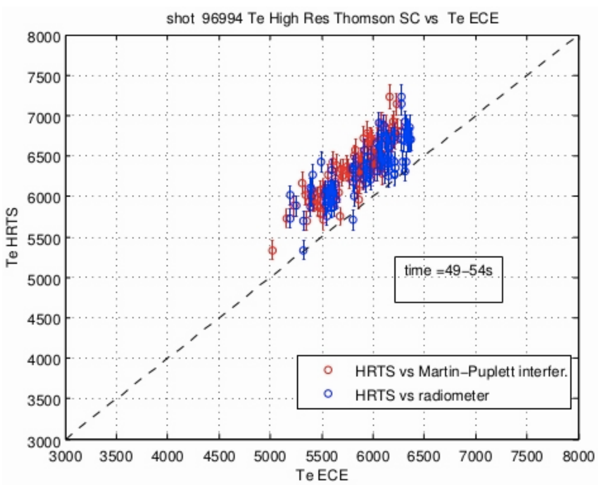

Fig.4: Te_HRTS vs Te_ECE_MP and Te_ECE_Rad. (See ref. 8)

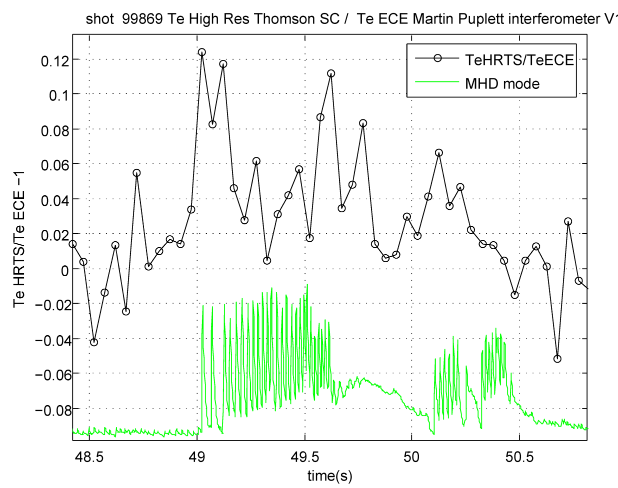

Fig.5: Time behaviour of Te_HRTS/Te_ECE_MP

The fig.4 shows the temperature comparison Te_HRTS vs both Te_ECE_MP and Te_ECE_Radiometer for the DD neon seeded pulse #96994 analysed in ref.8. The fig.5 shows the time behaviour of the (Te_HRTS/Te_ECE_MP)-1 (black trace) during the core n=1 MHD mode (green trace) fishbone activity in the Hybrid discharge #99869. The fishbones are MHD modes driven by the spatial gradient of the fast ion distribution function [7]: this correlation links the ratio Te_HRTS/Te_ECE_MP to the fast ion dynamics. The fig.6 shows the time behaviour of (Te_HRTS/Te_ECE_MP)-1 and MHD monitor for the DD neon seeded pulse #96994 (see ref.8).

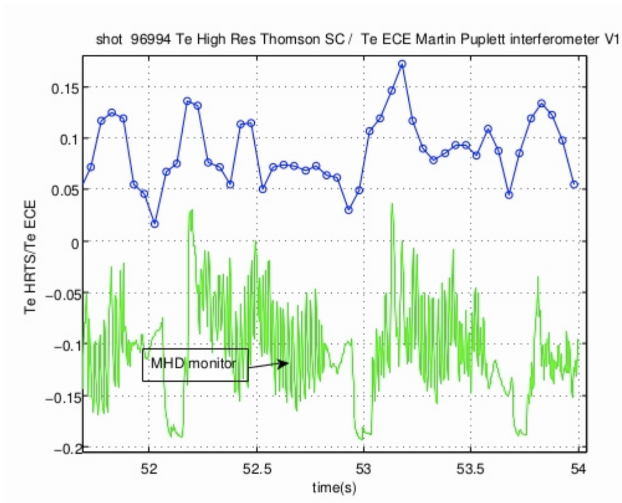

Fig.6: (Te_HRTS/Te_ECE_MP)-1 (blue line) and MHD n=1 monitor vs time for Ne-seeded pulse #96994.

4. Conclusions

Differences in the temperatures measured by High Resolution Thomson scattering and ECE Martin Puplett interferometer are detected in the DTE2 hybrid and non-thermal scenarios, and in DD neon seeded plasmas, definitely outside the error bars (see fig. 2,3,4). The difference is correlated to the appearance of a core n=1 MHD mode (fishbone) which is linked to the fast ion dynamics (see fig.5). In Ne-seeded discharge the ratio (Te_HRTS/Te_ECE_MP)-1 follows the behaviour of the MHD monitor.

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References

1.E. de la Luna et al. RSI 74(2003)1414

2.G. Taylor, R Harvey, Fus Sci Tech 55(2008)

3.G. Pucella et al, IAEA FTU OV, Nuc. Fus. 62(2022)042004

4.M. Fontana et al. Workshop EC-21 EPJ Web Conf 277(2023) 03006

5.G. Giruzzi et al. Workshop EC-21 EPJ Web Conf 277(2023) 03005

6.V. Krivenski, Fusion Engineering Design 53(2001) 23.

7.J. Wesson, Tokamaks 2nd edition, section 7.14, p.399.

8. S. Mazzi et al.,EPS 2023 Conference Poster#Fr_MCF36. The analysis of the pulse #96994 is presented.