A study of ion heating by means of spectroscopic techniques in the TJ-II stellarator

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Introduction. Ion temperatures have been measured in the TJ-II stellarator in parallel and perpendicular direction through passive emission spectroscopy. The main problem in determining the proton temperature arises when it is deduced by spectroscopic means [1], due to the difficulty in the interpretation of the H_α - D_α line wings, and for being an intrinsically cord-averaged method. Absolute ion temperature values, and its behavior in TJ-II ECRH modulation experiments are studied by using a simple zero-dimensional code, which keeps the essential physics responsible of the heating and cooling of ions immersed in a high temperature plasma. Since non-negligible tails in the H_α line-shape have been observed, a high energy proton population has been included as an additional source of collisional heating in the ion power balance.

High energy tails in the ion distribution function have been observed in several fusion devices, either tokamaks or stellarators, with neutral particle analyzers (NPA): TCA [2], FT-1 tokamak [3], W7-A [4], Heliotron J [5], when they are heated by ECRH. Ion tails could be also understood like a manifestation of non-Maxwellian distribution functions, but in this work we approximate that high energy proton component by a Maxwellian distribution. The first experimental evidence for this effect when using high resolution spectroscopy is herein presented.

Experimental. The light collected was analysed in tangential (T) and perpendicular (P) directions using 1 m Czerny-Turner spectrometers. Their focal planes were equipped with an intensified silicon photodiode array (T) which permits 15 -30 ms temporal resolution, and with a CCD (P) which supplies spatial resolution [6]. A second order filter was employed to clean the H_α zone from parasite lines which can disturb the spectral line emission.

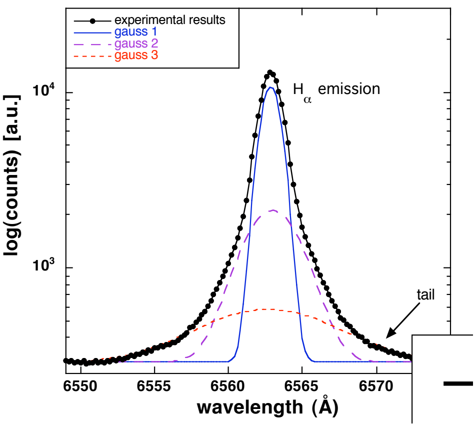

Fig. 1. Three component Gaussian fitting for H_α emission. The tails in the spectral line suggest a high energy population of protons.

The analysis procedure employs a least-square fit routine which uses as model function Gaussians [6]. In Fig. 1, a H_α spectrum for an ECRH TJ-II discharge is presented. The first component, G1, corresponds to the emission of hydrogen atoms from the plasma boundary, while since the second component, G2, provides the same temperature as that deduced from the NPA data [7], it has been associated to the thermal temperature T_i. The necessity of including a third Gaussian, G3 component (red line), is clear in order to obtain the optimal fitting to the experimental data. Therefore, the third component corresponds to a more energetic proton population and it will be called 'suprathermal population'.

Results and modeling. The equivalent ion temperature of the hottest component which results from the H_α spectral analysis in the (T)-direction is typically five times higher than that of the T_i, Fig 2(a). In the (P)-direction, the observed suprathermal temperature is ten times the T_i, Fig. 2(b). The suprathermals density is of about 20 – 30 % the thermal one.

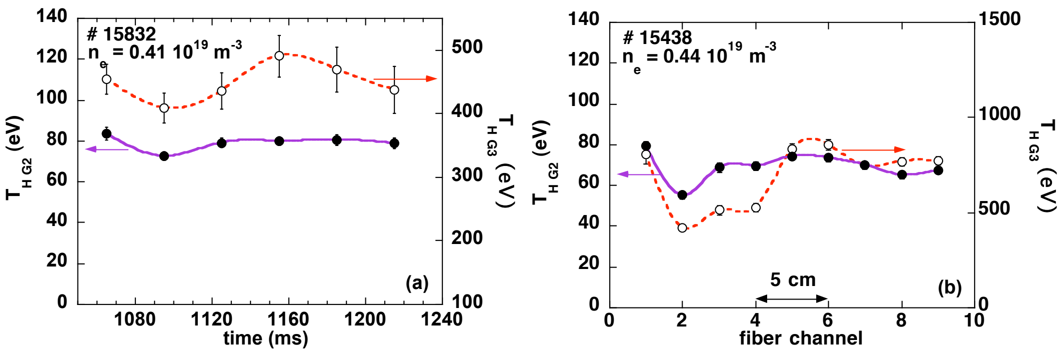

Fig. 2. (a) Temporal evolution of the temperature for G2 (solid circles) & G3 (open circles) measured in the parallel direction.(b) Spatial distribution of the temperature for G2 (solid circles) & G3 (open circles) measured in the perpendicular direction.

A zero-dimensional ion heat transport model previously developed [8] has been upgraded and extended by including the energy transfer terms between the fast ion component and thermal ions. The plasma is assumed to be composed of electrons with density and temperature (n_e, T_e), protons (n_p, T_p), neutrals (n_o, T_o), one single type of impurity ions (n_z, T_z) and a population of fast ions (n_{sp}, T_{sp}). All data are deduced, as far as possible, from the experimental data. The time evolutions of proton and impurity temperatures are:

$$\left.\begin{aligned} \frac{3}{2}\frac{d(n_pT_p)}{dt} &= n_eQ_{ep} + n_zQ_{zp} + n_{sp}Q_{sp-p} - n_pQ_{cx} - Q^p_{conv} - \frac{3}{2}\frac{n_pT_p}{\tau_{Ei}} \\ \frac{3}{2}\frac{d(n_zT_z)}{dt} &= n_eQ_{ez} + n_{sp}Q_{sp-z} - n_zQ_{zp} - Q^z_{conv} - \frac{3}{2}\frac{n_zT_z}{\tau_{Ez}} \end{aligned}\right\} \qquad (1)$$

(the meaning of each term is explained in Ref. 8). A source term related to the heat transfer via collisions with the high energy population was included as

$$Q_{sp-p} = \frac{3}{2}\frac{\left(T_{sp} - T_{p}\right)}{\tau_{sp-p}} \qquad Q_{sp-pz} = \frac{3}{2}\frac{\left(T_{sp} - T_{pz}\right)}{\tau_{sp-z}} \qquad (2)$$

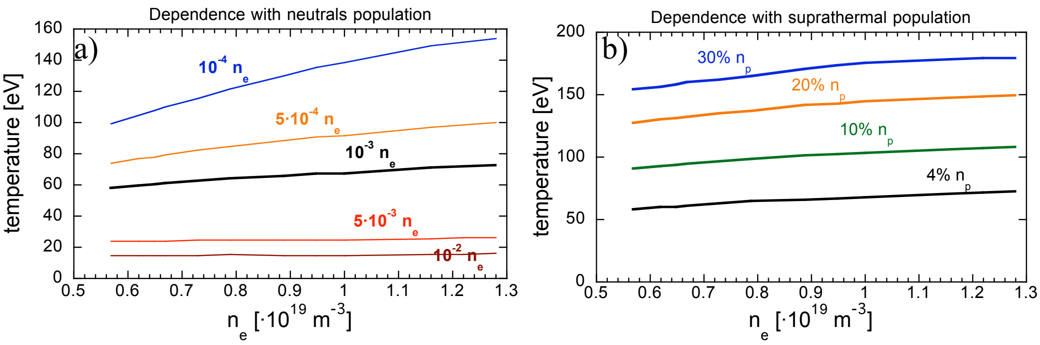

Fig. 3. Model results showing the influence on the temperature of: (a) neutral density and (b) the suprathermal populati o n .

In Fig. 3 model results are presented. The two most critical parameters: (a) neutral density, (b) suprathermal population; have been varied keeping the rest constant. As expected, an increase in the neutrals density implies an increment in the charge-exchange energy losses, and therefore in a diminution of the calculated temperatures. On the other hand, the higher the proportion between suprathermal and bulk populations the higher the plasma bulk temperature.

An experiment that varies the injected power into the plasma, and whose results are presented in Fig. 4, showed that the higher the power injection the higher the suprathermals temperature, and consequently with Eq. 1, the higher T_i. This effect cannot be explained without including the fast proton population, which in turn depends on the P_{inj}. Raw data presented in Fig. 4 are cord-integrated, therefore a model which reconstructs local information was employed to deduce the central ones [6], plotted in Fig. 5. For model calculations, the main free parameter to be chosen is the central neutrals density. Right axis in Fig. 5

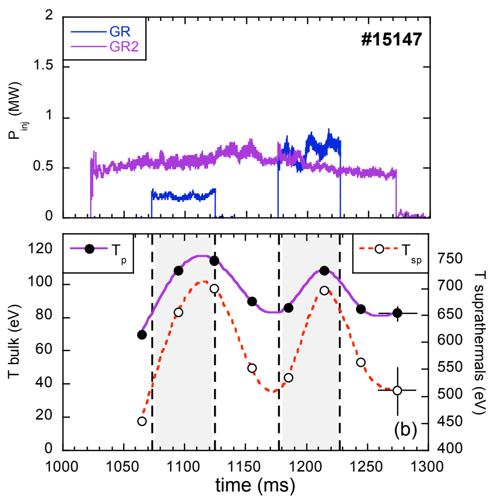

Fig. 4. (a) Power injected to the plasma with two gyrotrons: one fixed, the other alternating pulses. (b) Spectroscopy results obtained from H_α line.

shows the neutrals density (solid circles) which is necessary to reproduce the experimental results (open diamonds). This density is found to be consistent with experimental data from other devices of similar size. Note that at the beginning and the end of the discharge the neutral density is higher, which reflects the typical behavior of this parameter in a hot plasma when it was measured [9].

The necessity of including the observed fast proton population is supported by the model, since if the terms in Eq. 2 are removed, the obtained central temperature (solid diamonds in Fig. 5) does not account for the experimental data. Any change in other free parameters cannot explain the experimental results at these low densities.

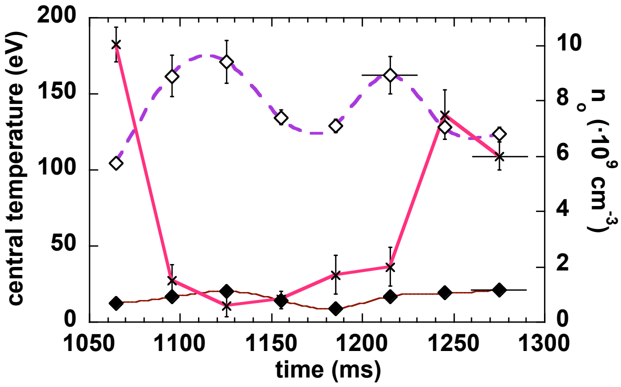

Fig. 5. Left axis: central temperatures deduced with (open diamonds) and without (solid diamonds) suprathermal population. Right axis: neutrals density (crosses) necessary to explain the experimental results.

In conclusion, we have suggested, supported by a zero-dimensional ion heating model, that the fast ion population observed in the TJ-II is related to ECRH, playing a significant role in the ion thermal heating of the plasma.

References.

[1] M. Larionov, *Sov. J. Plas. Phys.* **16**, 696 (1990).

[2] Pietrzyk Z A *et al* 1993 *Nucl. Fusion* **33** 197

[3] Bulyginsky D G *et al* 1983 *Controlled Fusion and Plasma Physics (Proc. 11th Eur. Conf., Aachen)*, vol. **7D** Part I 457

[4] Erckmann V *et al* 1984 *Plasma Physics and Controlled Nuclear Fusion Research (Proc. X lnter. Conf., London)* vol. **2** P-419

[5] Kaneko M *et al* 2003 *Proc. 30th EPS Conf. Control. Fusion and Plasma Physics (St. Petersburg)* vol. **27A** P-3.28

[6] Baciero A *et al* 2001 *Rev. Sci. Instrum.* **72** 971

[7] Fontdecaba J M *et al* 2004 *Fusion Science and Technology* **46** 271

[8] Zurro B *et al* 1990 *Plasma Phys. Control. Fusion* **32** 565

[9] Razdobarin G T *et al* 1979 *Nuclear Fusion* **19** 1439