

Probing the edge ion temperature by passive Doppler spectroscopy in the TJ-II stellarator

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INTRODUCTION. Edge parameters have a strong influence in the core of magnetic confined plasmas and in the design of plasma facing components. The edge ion temperature, T_i , is relevant in the plasma-surface interaction models and for predictions of the power fraction transported by convection and conduction to the walls.

Charge eXchange Recombination Spectroscopy (CXRS) is the usual technique used to determine T_i at the core [1, 2], but only a specialized system can reach the plasma edge [3]. Passive spectroscopy is an alternative technique for edge diagnostic; and although local spatial resolution requires inversion of line-integrated data, this is not necessary if the ion species emission is spatially well localized.

In the last years, the spectral line shape and T_i fluctuations at the edge have been modeled [4], but no experimental data have been found in the literature using passive spectroscopy. In contrast, retarding field analyzers have been used to monitor the edge ion temperature (see Ref. [5] for a set of references). In this work, measurements of T_i in the edge of the TJ-II plasma through passive spectroscopy are reported. Some limitations in the experimental procedure as well as in the data analysis are discussed. Spectral lines belonging to low ionization stages of different impurities (C, He and Li) have been used for this purpose.

EXPERIMENTAL. The spectral line shapes of intrinsically edge ions have been recorded in TJ-II plasmas by means of high spectral resolution spectrometers viewing the plasma perpendicular to the main magnetic field by means of fiber guides. One of them has spatial resolution capabilities, 9 equal-spaced channels, while the other one monitors the impurity emission lines, with time resolution, along a fixed chord collinear to any of the nine channels. The experimental systems and data analysis methods are described in [6] and [7]. The information provided by them is complementary in order to understand the data obtained in a complicated geometry such as that of TJ-II plasmas. The experimental systems have been focused in the measurement of the edge ion temperature in discharges

heated by only ECRH (up to 600 kW at the second harmonic) and with additional heating of two neutral beam injectors: NBI_1 and NBI_2 parallel and anti-parallel to the magnetic field (up to 400 kW from each injector).

The main assumptions implicit in Doppler broadening of ion temperature are: impurity ions are thermalized with protons and the Zeeman effect is negligible or can be corrected. The thermalization time between protons and other ions (C and Li) has been estimated assuming solely Coulomb collisions [8]. For typical edge densities of $1 \times 10^{18} \text{ m}^{-3}$ and a temperature of 50 eV, the thermalization time with C is about 50 μs and 100 μs for Li. On the other hand, ionization rate by electronic collisions is strongly influenced by the electronic density. If we assumed an electronic density of $1 \times 10^{18} \text{ m}^{-3}$, and an electronic temperature of 50 eV, the ionization time of C^+ and C^{2+} are comparable with thermalization time between C and protons. Ionization time for $\text{Li}^+ \approx 1000 \mu\text{s}$ and therefore this is the most probable ion, among those herein chosen, to reach thermal equilibrium with protons. These estimations are shown in the figure 1.

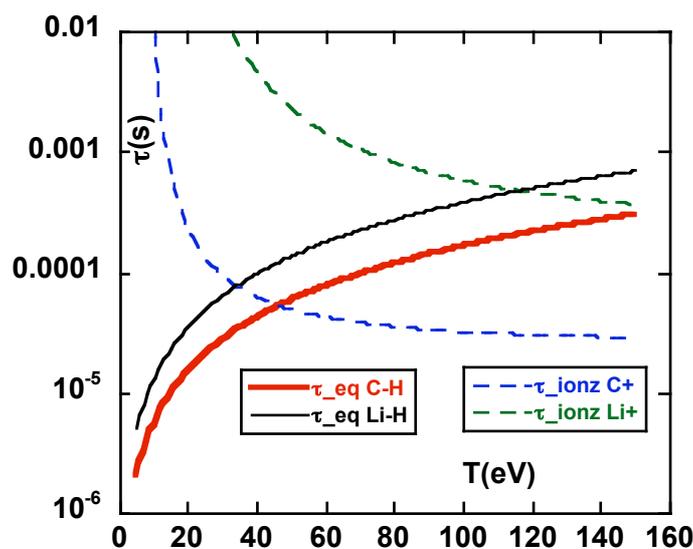


Fig. 1. Equilibration time, by Coulomb collisions, between protons with C and Li at an edge density of 10^{18} m^{-3} (solid lines); and ionization times by electronic collisions at similar density (dashed lines).

RESULTS AND DISCUSSION. In order to illustrate the results provided by this method we have selected a TJ-II discharge heated by solely ECRH in which one of the gyrotrons was modulated at a low frequency (30 Hz). The ion temperature evolution of Li^+ is shown in Fig. 2 (left), while its line intensity is shown in Fig. 2 (right), respectively. The modulation timing provided by one central ECE trace is also displayed in both plots (blue line). As can be seen, the modulation is echoed in the line intensity evolution (red trace in right plot), with a slow rising with respect to ECE. The effect in the ion temperature is more

delayed and less evident. These data suggest the existence of a mechanism coupling the ECRH power to the ions at the plasma edge.

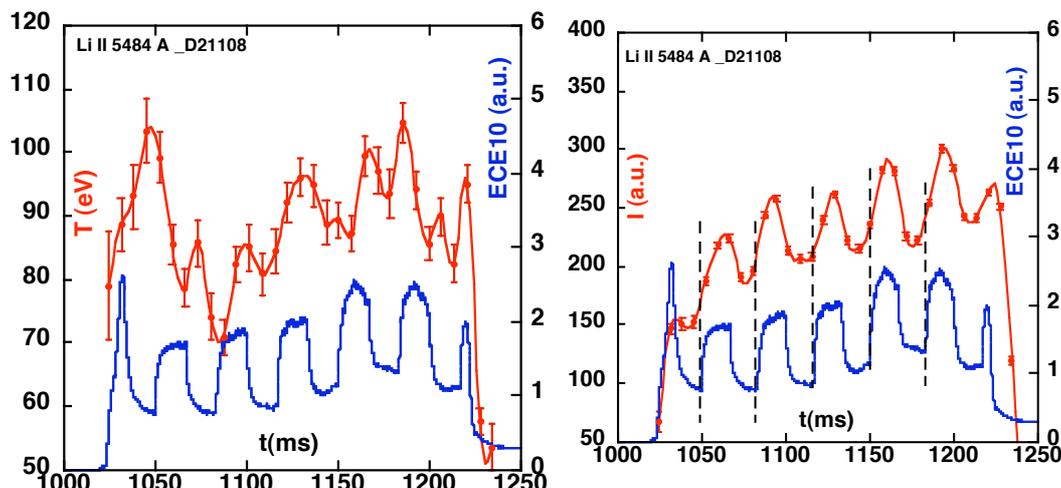


Fig. 2. Li^+ peripheral ion temperature time evolution in a modulated ECRH discharge (on the left) and similar comparison for the Li line intensity.

In Fig. 3, the ion temperature evolution for C^{2+} (464.7 nm) is presented. In the left plot, the results for a long ECRH (490 kW) discharge are shown. The right plot displays the results for an ECRH discharge where one NBI_1 pulse (420 kW) and parallel to the magnetic field was injected. A reduction of C^{2+} temperature is observed from the beginning of the NBI injection during the duration of the hot discharge.

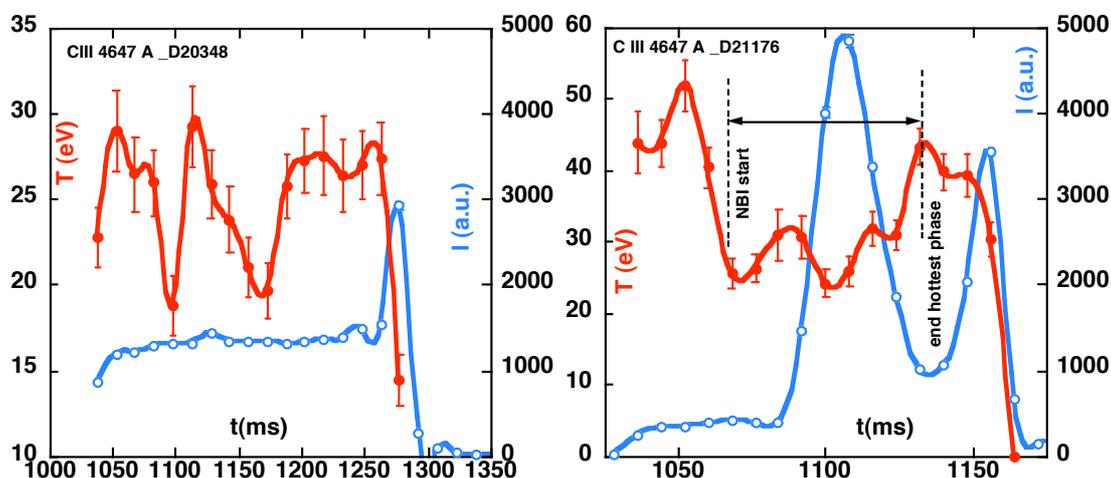


Fig. 3. Time behaviour of C^{2+} ion temperature in an ECRH TJ-II discharge (left) and in an NBI (co-beam only) discharge (right).

In Fig. 4 (left) the evolution of the ion temperature with time is presented for three different ion species: Li^+ , He^+ and C^{2+} . Although they do not correspond to the same discharge, they are very appropriate to illustrate the main conclusion of this work: the ion temperature of Li^+ is systematically higher than that of other edge ions, and the temperature of C^{3+} and C^+

(not shown) exhibit the most significant temperature fluctuations. In Fig. 4 (right), we show the ion temperature evolution of C^{2+} along with several traces of the discharge (line-averaged electron density and total radiation).

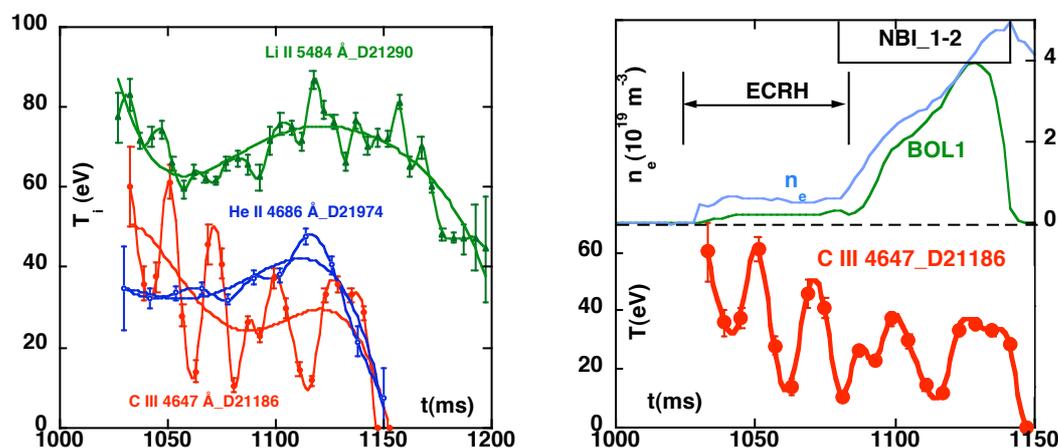


Fig. 4. Comparison of the time evolution of edge ion temperatures deduced from different species in TJ-II discharges (left). C^{2+} temperature evolution along with density and radiation traces (right).

In conclusion, typical T_i obtained with the 548.4 nm Li^+ spectral line is in the range of 60–90 eV. Those estimated by the 464.7 nm C^{2+} and 468.6 nm He^+ spectral lines are significantly lower. We believe that the origin of this discrepancy might result from either the lack of thermalization for these species, or, due to its different spatial extension, different parts of the spatial profile are being mixed. A dedicated system monitoring the plasma edge with spatial resolution of a few millimetres would help to understand better these results.

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