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Peculiarities of space and time evolution of iron impurity injected in the FTU tokamak plasmas

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Introduction

The spatial structure and the time evolution of the iron impurity injected by means of laser blow off (lbo) have been studied to investigate previously observed discrepancy concerning the charge state distribution of iron. A fine radial scanning (about 2 cm of resolution) of the lines of sight of the spectrometers in a set of reproducible discharges, with plasma current Ip = 500 kA , magnetic field B = 6 T , central electron temperature Te(0) = 1.8 keV and electron density Ne(0) = 8Æ10^{19} m^{-3} . Several charge states of Fe have been monitored, ranging from peripheral ones (Ar- I , Na-I , Mg-I) measured by two VUV spectrometers, to intermediate and central ones (Li-I , Be-I in VUV and Be-I , Li-I, He-I with a soft X-ray bent crystal spectrometer). These measurements revealed two unexpected results:

1) time histories of the peripheral lines of sight of the external charge states (Ar-I, Na-I , Mg-I) have a typical ionization peak at 5 ms and a second one 40 ms later.
2) The ionization degree of the intrinsic iron in the core is lower than expected at those temperatures and it is lower than in the case of the injected one.

Time history

Iron injection produces perturbations both in the SOL than in the confined plasma. In the unperturbed SOL, at the LCMS an average electron density Ne(LCMS) = 0.7Æ10^{19} m^{-3} and temperature Te(LCMS) = 25 eV are measured, with strong poloidal asymmetries. After the injections, a decrease of Ne and Te lasting approximately 40-80 ms is found. The decrease is stronger at the poloidal position corresponding to the poloidal limiter, where Ne(LCMS) = 0.3Æ10^{19} m^{-3} and Te(LCMS) 10 eV are measured. The decrease of Ne and Te in the SOL is evident at all the radial positions.

Inside the LCMS the temperature reduces a bit and the small drop in the range $0.7 < r/a > 1$ is the cause of the second bump observed in the time histories of low ionized states along peripheral line of sight (fig 1).

This time behaviour can be simulated only performing time dependent impurity transport simulations, taking into account the changes of the temperature profiles induced by the injection. Radial profiles of a few brightnesses are simulated with the anomalous transport coefficients typical for FTU D=0.8 m^2/s , V= 3 m/s. The atomic physics giving the best agreement with the measurements is Arnaud and Rothenflug (1992).

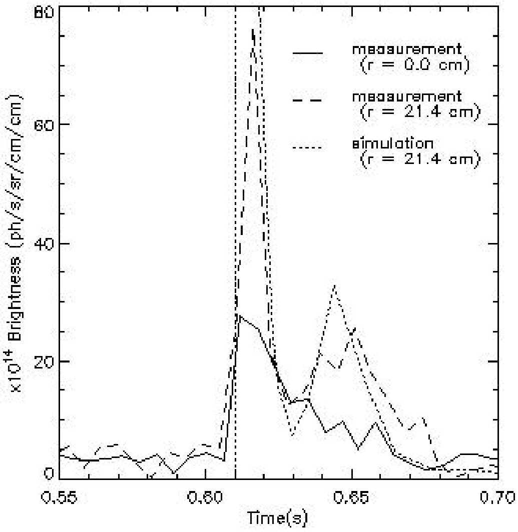

Fig.1 Time history of line emission of Fe^{8+} along a central l.o.s. (continous line), along a peripheral (impact parameter 21.4 cm) l.o.s. (dashed) and simulation (dotted)

Intrinsic and injected iron

The K_α spectrum of iron was studied by a high resolution (λ / $\Delta\lambda$ > 10000)bent crystal spectrometer (CRX). A typical X-ray spectrum of intrinsic iron is shown in fig. 2. The observed wavelength region extends between the $1s^2\ {}^1S_0$ - $1s2p\ {}^1P_1$ resonance transition (λ=0.18500 nm) of the He-like ion and the $1s^2 2s^2\ {}^1S_0$ - $1s2s^2 2p\ {}^1P_1$ transition (λ=0.18702 nm) of the Be-I like ion. The spectrum was obtained during the current plateau phase of the shot 15381 far from the LBO injection (integration time: 0.92-1.32 s). The Voigt function fit of the resonance including the 19 most prominent unresolved dielectronic satellites (thick line) and the gaussian fit of the most prominent resolved satellites (thin line) are also shown (the atomic data of [1] are used). The same spectrum observed after the injection (integration time: 0.6 - 0.76 s) is shown in fig 3 .When iron is injected, the intensity ratio of the satellites produced through inner-shell excitation (q and β) to the resonance line (w) decrease.

The q/w and β/w ratios, once the contribution from dielectronic recombination is subtracted, depend on the $n_{Li\text{-}I\ like}$ / $n_{He\text{-}I\ like}$ and $n_{Be\text{-}I\ like}$ / $n_{He\text{-}I\ like}$ ratios. The measured $n_{Li\text{-}I\ like}$ / $n_{He\text{-}I\ like}$ ratio changes from 1.4 to 0.9 after the injection, while $n_{Be\text{-}I\ like}$ / $n_{He\text{-}I\ like}$ changes from 2 to 0.9 (fig. 4). The different ionization degree of the higher charge states, for intrinsic and injected iron, is not observed in the VUV range. A grazing incident spectrometer (GRITS) in fact observes the Δn=0 2p-2s transition of FeIX to FeXXIV. In particular the measured ratio of $n_{Li\text{-}I\ like}$ / $n_{Be\text{-}I\ like}$ is about 0.6, independent on the impact parameter of the spectrometer and on the origin of iron (intrinsic or injected).

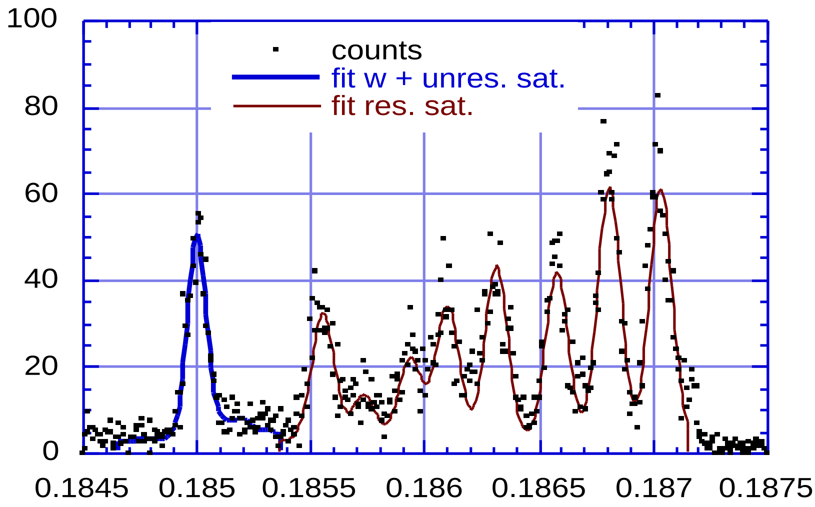

Fig. 2 He-like and satellites spectrum for intrinsic iron

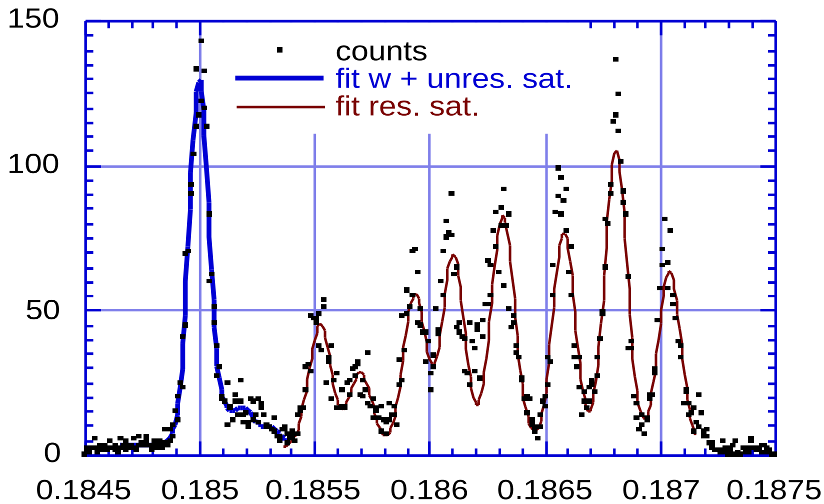

Fig. 3 He-like and satellites spectrum for injected iron

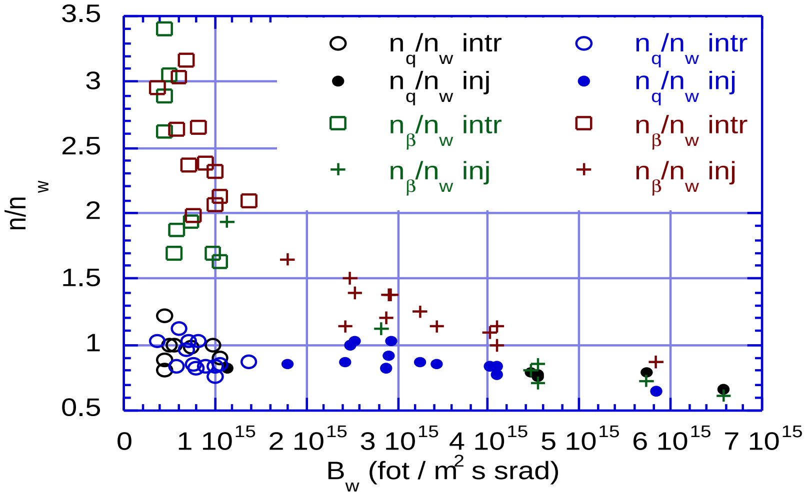

Fig. 4 q / w and β / w ratios of intrinsic and injected iron (q ➡ Li-I , β ➡ Be-I , w ➡ He-I)

Discussion

The different ionization of iron is observed only in the centre ($0 < r/a < 0.2$) by means of X-ray, while VUV emissions, extending up to $r/a = 0.7$, do not show such an effect. This phenomenon could be related to the different mechanisms of iron production. In the case of injection, since neutral ions are produced at low energy (a few eV) and ionized in the plasma periphery, they reach the centre with an ionization degree in equilibrium with the local electron temperature. Intrinsic iron can be produced by both physical sputtering of deuterium and impurities (including self sputtering). FTU has a stainless steel chamber and a molybdenum inner limiter. SOL is dominated by medium-high Z metallic impurities and it has a relatively high temperature. Consequently a non negligible amount of non thermal incident particles could be expected, producing high energy sputtered iron neutrals. They could penetrate deep into the plasma, arriving to the centre in a lower ionization states. However a theoretical analysis is necessary to confirm this possible interpretation.

References

[1]P. Beiersdorfer, M. Schneider, M. Bitter, S. von Goeler, Rev. Sci. Instrum. **63**, 5029 (1992)
[2]M. Leigheb et al, 14th PSI Rosenheim, Germany, May 22-26, 2000