On the effect of Neon injection on density peaking in FTU plasmas

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Introduction

Impurity seeding has been demonstrated to have a beneficial effect in particle confinement [1]. FTU is a metallic machine operating with a TZM toroidal limiter (98% molybdenum) and a stainless steel AISI 304 vacuum chamber. This configuration together with its characteristics (compact high magnetic field device: R = 0.93 m, a = 0.3m, Bt up to 8 T, Ip up to 1.6 MA) make this machine suited to develop advanced scenarios at fields and densities relevant to ITER operation as well as its supporting physics [2].

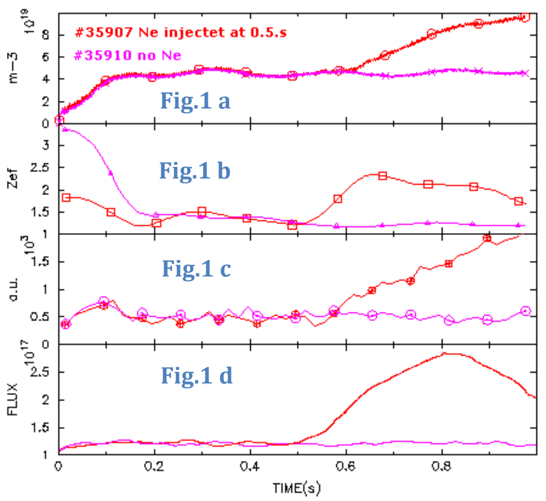

Figure 1: time traces for the discharges: 35907 (Bt 5.2T, I 360 kA), Ne injection at 0.5s red traces, and 35910 (pink traces, reference discharge no Ne puffing, same parameters). Starting from the highest: a) line density, b) Z effective, c) Neon brightness, and d) Soft X peripheral signal at 14 cm from the center.

For this reason an analysis on the recent campaign with Ne-gas puffing in different L-mode plasma (I=350-370 kA, B=5-6.5 T, ne0=0.2-1. 1020 m-3, Te0=1-4 keV) is important in order to understand the mechanism that leads to spontaneous density peaking. In fact compared to unseeded discharges, an increase of the average electron density for the same level of total gas puffing and an evident peaking of the radial profile is observed in all Ne seeded plasmas (typically 30% increase of the peaking factor).

[1] *See the appendix of P. Buratti et al., Proceedings of the 24th IAEA Fusion Energy Conf., San Diego, USA, 2012

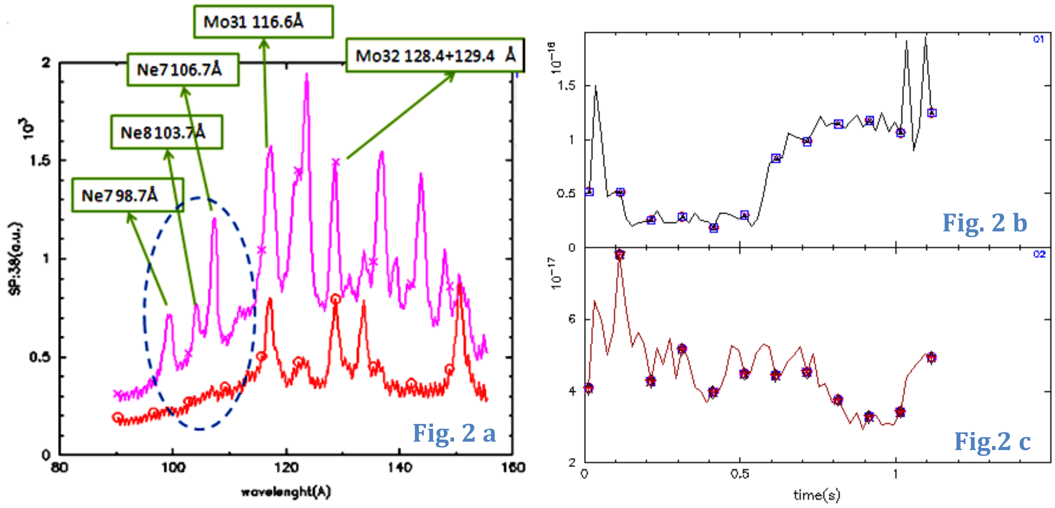

Figure 2: a) Spectroscopy for the discharge 35907, pink line at 0.75s (250 msec after Ne puffing), red line before (0.5s). Different spectral lines are present, the Neon impurity is dominant together with the Molybdenum. b) The line trace of the Ne brightness normalized on the peripheral chord of the density shows an increasing for the signal, c) at low: a decreasing for the Mo brightness normalized on the central chord points that the heavy impurities do not contribute at the peaking.

Observation of the density peaking

In figure 1 the evolution of some relevant quantities in a discharge with Ne injection (#35907) is contrasted with a reference case without injection (#35910). The Ne gas puff happens at t = 0.5 s (please note that no D2 pumping is present in this phase). The presence of the impurity is clearly indicated by various diagnostic systems, in fact all the red traces (fig.1: Density, Z effective, spectroscopic, soft X) are different in respect of discharge without Ne presence (pink traces). The fig.1a shows that an increase of line-average density (associated with increased profile peaking) starts about 100 msec after Ne injection. However the Z effective signal (fig.1b) highlights the fact that the discharges are both contaminated by presence of impurities in the machine before puffing. In fact the figure 2a shows the UV spectra before and after the Ne injection, more impurities are present, in particular Molybdenum. If the line trace of the brightness normalized on the peripheral chord of the density is considered for the Ne doped shot #35907, an increasing for the Ne signal is evident (fig.2b), as far as decreasing for the Mo signal (fig. 2c).

In order to understand if the electron-density peaking arises from a convective flow and cannot be attributed to the contribution of the Ne electrons, alone an estimate is conducted thanks to the interpretation of the spectroscopic data. The Z effective shows an increase by about one in correspondence of the Ne injection (fig.1 b). So a rough estimate of the Neon density can be done: $\frac{Z^2_{\mathrm{Neon}} \cdot n_{Neon}}{N_e} \simeq 1$

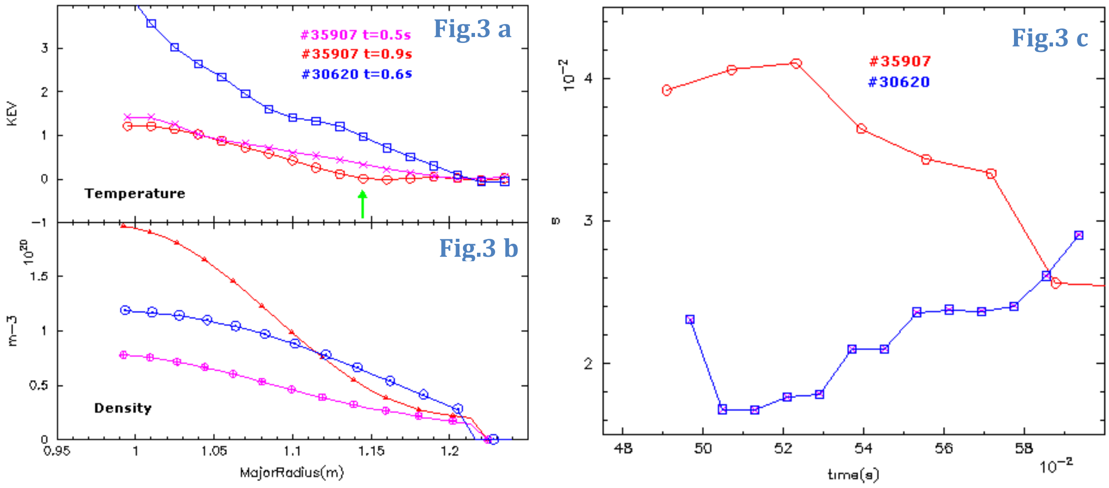

Figure 3: a) The edge temperatures of the Ne doped discharge #35907 shows a cooling at the edge (green arrow) when the density is peaked (fig.3 b) in respect of the Lithium discharge #30620.
Figure 3 c: the energy confinement time of the Lithium discharge increase, opposite to the discharge with the Ne puffing (red trace).

so $\frac{n_{Ne}}{N_e} \cong 1\%$ where $N_e \cong 6 \cdot 10^{19} m^{-3}$ for t=0.8sec. It's reasonable to conclude that around a 10% of electrons coming from Neon can contribute to the density peaking, in fact: $\frac{Z \cdot n_{Neon}}{N_e} \cong 10\%$. As the central density increasing is ≈100% it results that the observed peaking cannot be attributed simply to the electrons stripped from the puffed Ne. A particle transport-related mechanism should be invoked in order to explain the higher electron density peaking. Analogous peaking of the electron density was observed in FTU in Liquid Lithium Limiter (LLL) discharges [3] as well as in similar experiments on other machines [4]. Turbulence analysis of Lithium doped FTU plasmas [5,6] has shown that the presence of the light impurity modifies the phase between fluctuating fields responsible to transport and leads to an inward deuterium pinch and outward impurity flux. Under the same density peaking, the transport mechanisms between the discharges doped with Neon in respect of those with Lithium seem to be different. In fact the temperature at the edge for the Ne doped discharge is sensibly low (fig.3a), this fact can trigger the virtuous pinch effect that lasts also when the presence of the gas at edge is disappeared [1]. Opposite to the Li discharges, the Ne doped shot shows a decreasing of the confinement time (fig.3).

Transport analysis and summary

Analogous to what was done in presence of Li [7] that leads to assess the flux of electrons, an estimate of the particle diffusion coefficient and pinch velocity, using a simple model for the particle flux [8] can be done for Ne doped discharges. The particle flux, neglecting particle source, can be obtained by

$$\Gamma(r) = -\frac{1}{r}\int_0^r \rho \frac{\partial n_e}{\partial t} d\rho \quad \text{that leads to} \quad \Gamma(r) = Un_e - D\frac{\partial n_e}{\partial r}$$

assuming a velocity pinch U and a diffusion coefficient D. In particular, thanks to a two colors scanning interferometer that provides high spatial resolution (40 chords, 1 cm) and time resolution of 62 μs [7], it's possible to reconstruct a detailed evolution of the density profiles useful for the determination of the particle flux [8]. In figure 4 the D and U coefficients of the transport equation are shown for a set of Ne doped discharges and a Lithium case. Where the process described is more reliable, that is inside half radius of the plasma, the D and U coefficients for both cases Ne and Li doped discharges, estimate the inward pinch. Nevertheless the Lithium case show higher values of the D coefficients. The statistic is poor to determine if the Neon doped discharges have lower diffusivity in respect of the ones with Lithium.

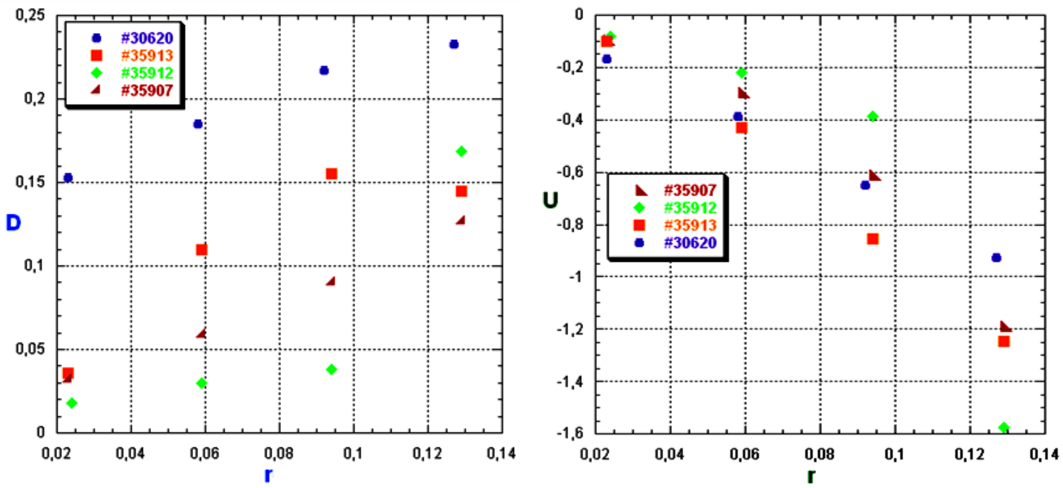

Figure 4: D (at left) and U (at right) coefficients vs radius in the inner region. The Lithium case (#30620) shows higher D values in respect of Ne doped discharges (#35907, #35912, #35913).

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