Investigation of Turbulent Transport of Heavy Impurities in FTU Electron Heated Plasmas

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Effects of radio frequency (RF) heating on the confinement of heavy impurities have been observed on various Tokamaks (JET AUG, C-mod [1,2,3]); in particular the impurity inward pinch velocity is found to decrease along with the increase of centrally deposited RF power (impurity pump-out). In this paper we present a study of the transport of Mo ions in electron heated FTU high density, high field plasmas with the aim of searching for an RF related turbulent pinch. Traces of Mo have been injected using the laser blow off technique in full LH (1 MW) current driven FTU plasmas at B_T=5.3 T, I_p=360 kA varying the power of centrally deposited ECRH up to 1.2 MW (the total available ECRH power on FTU amounts to 1.5 MW). The dynamics of Mo is studied in the XUV range (central line brightness of Mo XXXI 116Å and Mo XXXII 128Å) and in the SXR region (two-camera system, one horizontal and one vertical) with a 50μm thick beryllium filter and the electron temperature is provided by Thomson Scattering. Transport analysis is carried out with JETTO [4] and with an impurity transport code that solves the transport equation for each ionization stage [5]. Previous investigation of electron transport on FTU LHCD discharges has led to the detection of a turbulent pinch sustaining peaked electron density profiles for several confinement-times during the CD phase [6].

Experiment

As a reference discharge (no ECRH heating) we have selected the pulse #27737 in which Mo was injected at t=0.82 s during the LHCD phase, Fig. 1(a). This discharge develops a strong e-ITB, T_{e0}=4 keV, at t=0.53 s, r=7 cm after the switching on of the LH power. The SXR tomography shows the presence of an m=1, n=1 island rotating at 17 kHz which is first detected at t=0.67 s, well before the Mo injection, Fig. 1(b).

The SXR emissivity profiles appear to be hollow until the end of the LH phase and the peak of the emission been located at r=5cm. The difference between the central channel and the channel at r=5 cm increases at t=0.75 s, Fig 1(a). Since T_e and n_e are not hollow and in FTU the dominant contribution to the SXR comes from line emission of intrinsic Mo, we conclude that the hollowness of the SXR profiles is due to Mo trapped in the rotating island.

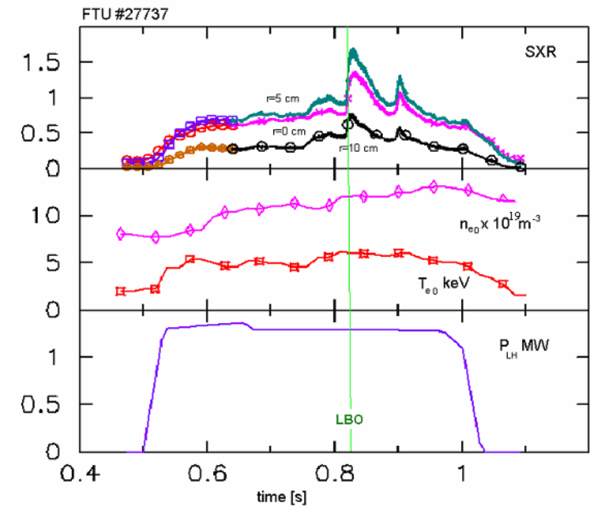

Fig. 1 (a) top: line integrated SXR channels, middle: central electron density and temperature; bottom: heating power

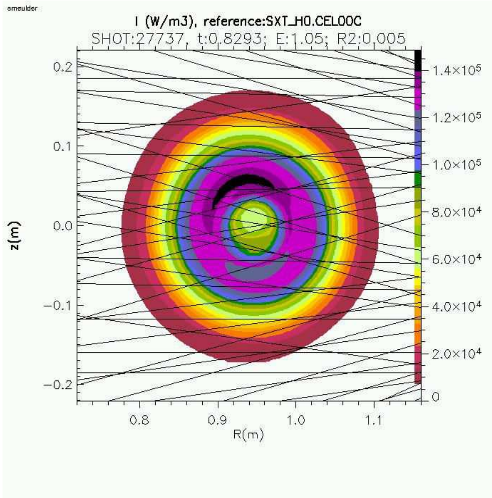

Fig. 1 (b) Tomographic reconstruction of SXR emission

The injected Mo reaches the island in 20 ms and outflows on a time scale of 50 ms, comparable to the energy confinement time, τ_E=40 ms. Transport analysis of the transient after the blow off allows the discrimination between the diffusion coefficient D and the pinch velocity V_r, Fig. 2(b) . The outward pinch inside r=10 cm is related to the pre-existing transport barrier and rotating island. The values of the transport coefficients just outside the barrier (r=11 cm) are D=1.1 m^2s^{-1} and V_r=4 ms^{-1}.

Shot #27448, Fig 2(a), is heated with 400 kW of ECRH power (in addition to 1.2 MW of LH) its deposition profile peaking around r=3 cm. Mo has been injected at t=0.75 s. We find here that the Mo reaches the center of the discharge in about 20 ms and outflows in 50 ms. No relevant MHD activity is found in this shot.

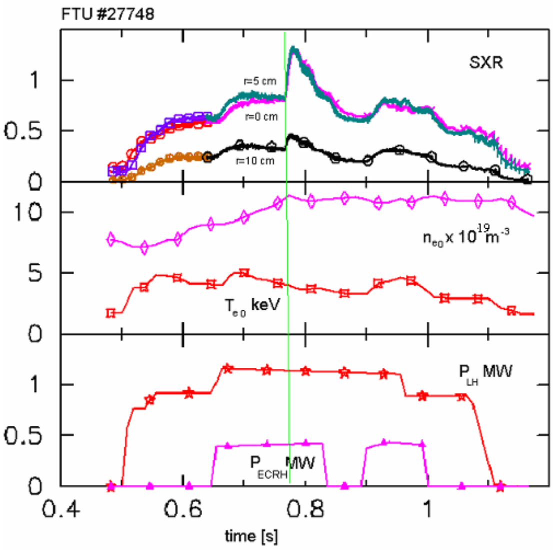

Fig. 2 (a) top: line integrated SXR channels, middle : central electron density and temperature; bottom: heating power

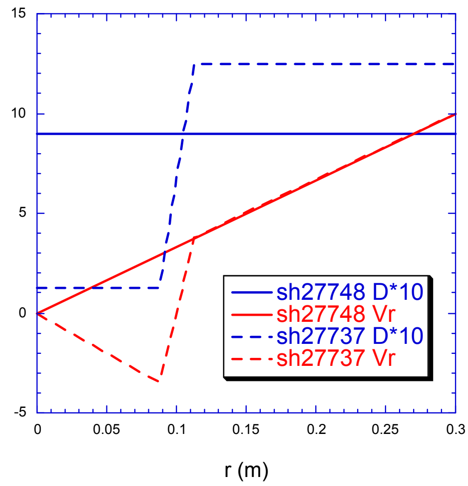

Fig. 2 (b) Mo transport coefficients, MKS units. Full lines refer to shot 27748, D (blue) and -Vr (red). Dotted lines refer to shot 27737.

From transport analysis, the values for D and V_r at r=10 cm are respectively 0.9 m^2s^{-1} and 3.7 ms^{-1} Fig 2(b). The peaking factor ratio $S=V_r/D$ at r=10 cm is 4.1 m^{-1}, comparable to the reference shot (3.7 m^{-1}). The effect of the ECRH on the impurity transport at this power level is negligible. By further increasing the ECRH power up to 800 kW (shot #27749, Fig 3(a)) the outer SXR channels (r=5 cm and r=10 cm) start decreasing during the ECRH heating phase.

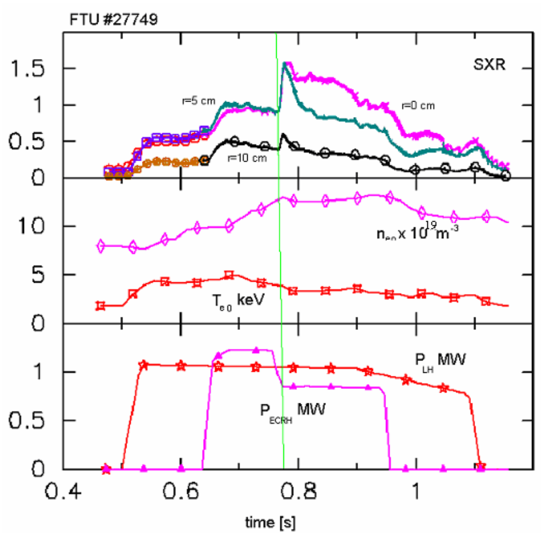

Fig. 3 (a) top: line integrated SXR channels, middle : central electron density and temperature; bottom: heating power

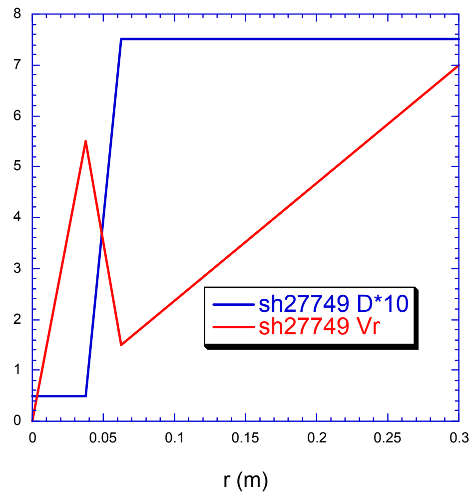

Fig. 3 (b) Mo transport coefficients, MKS units, , D (blue) and -Vr (red).

Accumulation of the injected Mo is observed in the central line of the SXR, in spite of no clear signature of a transport barrier (ρ^*_{ITB}<0.014 around r=5 cm). The pinch velocity inside r=5 cm doubles as compared to shot #27748. Outside r=10 cm, SXR data can be simulated with a pinch velocity decreased by a factor two and a diffusion coefficient lower than that found in the reference case, Fig 3(b). The peaking factor V_r/D found at r=10 cm is equal to 2.5 m^{-1}, 35 % lower than in the reference case. In shot #27749 the molybdenum reaches the core and is confined for several confinement times (central SXR channel, Fig 3(a)). The effective charge (Z_{eff}=3) is identical in all discharges and the ECRH power deposition profiles do coincide, while the LH deposition profiles differs (due to the different densities): in particular pulse #27748 has a centrally peaked LH power deposition and the q profile is monotonic, while in pulse #27749 the LH power is deposited slightly off axis and the safety factor profile is reversed. Microstability analysis carried out with Kinezero [6] shows that all discharges are in the high collisionality regime ($\nu_{eff} = \nu_{ei}/n\omega_{de}$ above 2 for $k_\theta\rho_i$=1 where ω_{de} is the vertical drift frequency and ν_{ei} is the electron-ion collision frequency). The fastest growing modes in the gradient region (r>10 cm) are the dissipative trapped electron modes (TEM ($k_\theta\rho_i$ about 1) which appear to dominate the spectrum up to half the plasma minor radius.

Summary

We have investigated experimentally the effect of ECRH heating on impurity transport by injecting Mo in full LHCD FTU plasmas. The experiments show that there is no accumulation of the Mo for $P_{ECRH} \leq 400$ kW, where the injected impurity outflows on a time scale of the order of the energy confinement-time. By increasing the coupled ECRH power up to 800 kW we find that a strong inward pinch develops in the central region (r≤5 cm) which brings to the accumulation of the Mo as seen by the central SXR line of sight, while the inward pinch in the region outside the peak of the ECRH power-deposition-profile (r=10 cm) is reduced.

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