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On the influence of the magnetic topology on transport and radial electric fields in the TJ-II stellarator

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1.- Introduction.

We have investigated the influence of the magnetic topology on confinement and electric fields in ECH plasmas in the stellarator TJ-II, taking advantage of the flexibility of this almost shearless device. A wide range of rotational transform values can be attained ($\iota/2\pi$=0.9 to 2.1) and the rotational transform profile can be tailored by inducing currents using both ECCD and two sets of OH coils. In this way it is possible to introduce rational surfaces inside the plasma and to modify the magnetic shear to examine their effect on confinement and related magnitudes.

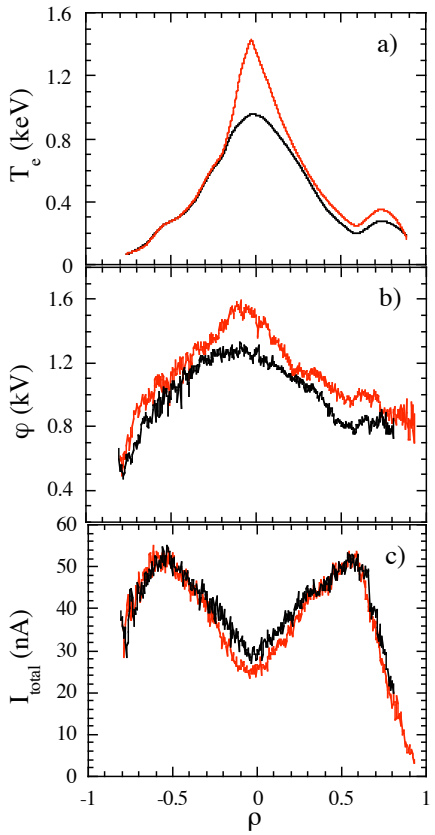

Figure 1. Temperature, potential and beam intensity profiles, with (red) and without (black) e-ITB, measured by HIBP.

2.- Low order rationals effect.

We have positioned low order rationals close to the plasma core both by a magnetic configuration scan and by inducing current in order to modify the rotational transform profile. The formation of electron internal heat transport barriers (e-ITBs) [1], characterized by an increase in the core electron temperature and plasma potential, has been reported. e-ITBs are triggered by positioning a low order rational surface close to the plasma core region (for effective radius $\rho \approx 0.2$-0.3), while they disappear when the rational surface is positioned at outer positions [2]. For the available power, there are no indications of barrier formation in plasmas whose magnetic configurations do not contain low order rationals. The measured radial electric field E_r in

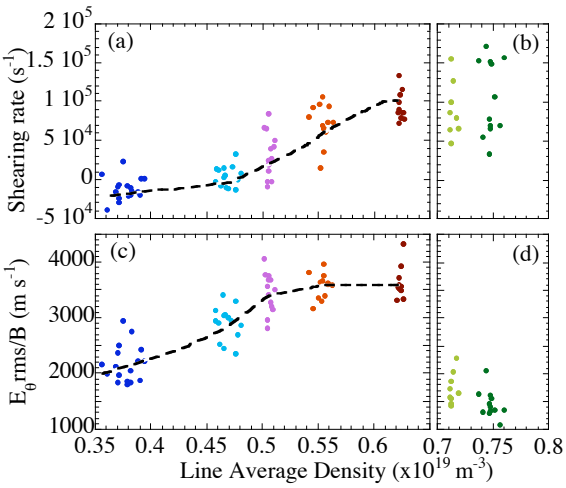

Figure 2. Shearing rate vs. line density without (a) and with (b) polarised electrode and their corresponding turbulence levels (c,d).

plasmas that present e-ITB is in the range of 10-15 kV/m, three times that of plasmas without barriers, which is in the range of 4-5 kV/m. The rotation velocity in the plasma core is three times faster in the case with e-ITB, in agreement with the ion-momentum balance equation. The estimated E_rxB shearing rates in the discharges with low order rationals (10^5-10^6 s^{-1}) are consistent with the interpretation that positioning a rational surface close to the ECH deposition profile can enhance the outward electron flux creating an ambipolar E_r able to reduce heat transport as will be explained in Section 3. The formation of the ITB has been observed with positive and negative magnetic shears. We are showing in Fig. 1: a) the temperature profiles in plasmas with and without barrier; b) the potential profile measured by HIBP for the same cases as before, demonstrating that a stronger positive radial electric field appears in the core; and c) the total beam intensity measured by HIBP, which is proportional to plasma density, showing that the density is lower in the case with barrier in this discharge.

We have also obtained the first experimental evidence of coupling between the development of sheared flows and the structure of turbulence close to the plasma LCFS [3]. The resulting shearing rate is comparable to the one required to trigger a transition to improved confinement regimes with reduction of edge turbulence, suggesting that spontaneous sheared flows and fluctuations keep themselves near marginal stability (see Fig. 2). While these results support the importance of turbulence to understand the observed interplay between magnetic topology and transport in the edge, the time scales of the perturbation in density and plasma potential (50-300 ms) measured by HIBP [1] and its localization within the ECH deposition profile, support the idea of the

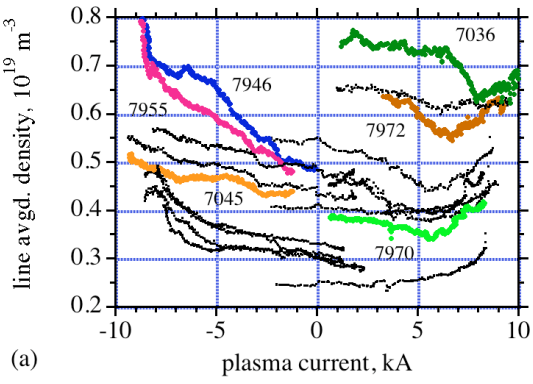

Figure 3: Effect of plasma current on line density.

dominant role of ECH convective fluxes in the formation of e-ITBs in the plasma core of TJ-II.

Finally, OH-coils [4] have been used to induce positive and negative currents up to $|I_p|<$ 10 kA. It is shown that the negative shear (provoked by negative current) correlates with improved confinement, causing that the profiles become wider in a long time scale, while a non-monotonic behaviour of plasma confinement versus shear is observed for positive currents, as can be seen in Fig. 3. As plasma current evolves, the rotational transform profile crosses several low order resonances whose signature can be seen in the line density evolution as well as in other thermal signals.

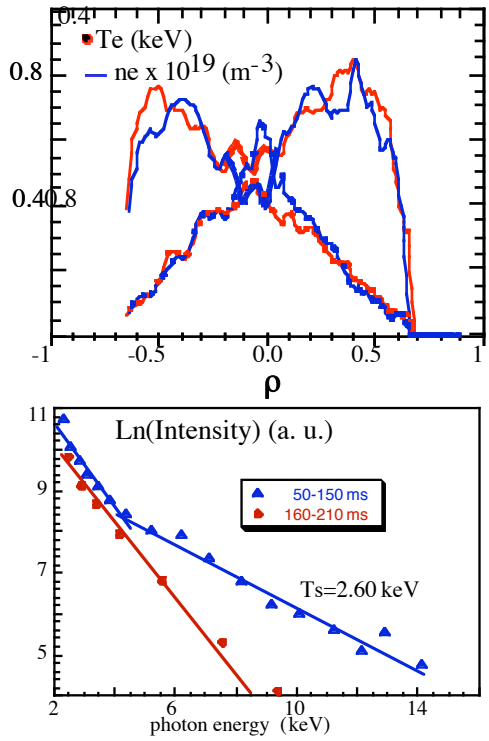

Figure 4. Electron density and temperature profiles for the cases with (blue) and without (red) enhanced losses (Top). SXR spectra show a superthermal tail in the case without enhanced losses.

3.- Kinetic effects.

Fast changes of emissivity profiles correlated with changes in the electron distribution function, as deduced from soft X-ray spectra, take place at well defined radial positions, close to low order rational surfaces. These changes in emissivity have been identified as signatures of transitions between high and low direct losses regimes that are also manifested in a more hollow density profile (see Fig. 4). Here, rational surfaces seem to be modifying the trapping/detrapping rate of ripple-trapped suprathermal electrons [5]. But also magnetic topology affects the radial transport of fast passing electrons, than can be confined near rational surfaces more than 50 ms [6]. All these facts and the ones shown in the previous Section point to kinetic effects induced by ECH and the presence of rational surfaces as the key ingredients to explain the transport modification.

The electron flux, which is much larger than the ion one, is given by: $\Gamma_e(E_r) = \Gamma_e^{NC}(E_r) + \Gamma_e^{TURB}(E_r) + \Gamma_e^{ECH}(E_r) + \Gamma_e^{ISLAND}(E_r)$. In this expression, the neoclassical, the turbulent, the ECH-induced fluxes and the induced by the rational surface are considered.

The experimental results of TJ-II show that the cooperation of the third and fourth terms is necessary to create the radial electric field able to reduce heat transport.

The estimation of the flux through the magnetic surface needs a detailed knowledge of magnetic topology but an approach based on Langevin equations has been recently developed to estimate the ECH induced flux [7]. We have estimated the linear instantaneous ECH-induced flux (created when ECH is switched on in a hot plasma) assuming that all the particles that enter the loss cone are lost and disregarding the evolution of distribution function (assumed Maxwellian), the effect of collisions and viscosity. The flux and its divergence are plotted in Fig. 5. This extra flux causes the onset of an electric field that tends to stop the particle flux and to increase the heat confinement. As a first step to estimate the time evolution of the flux and the field, we evolve the coupled equations: $m\,d\Gamma/dt = -enE - p'$; $dE/dt = (e/\varepsilon)\Gamma$; $(3/2)(dp'/dt) = -\left(q'' + q'/r - q/r^2\right) + w'$. Here p is the plasma pressure, and q is the heat flux ($q = (5/2)(p/n)\Gamma - \chi p'$). In absence of collisions and viscosity and keeping constant the distribution function, an oscillating behaviour of particle flux and electric field with the plasma frequency appears, therefore the typical time scale for the modification of the field is $\tau \sim 1/\omega_p$, according to this model. The experimental results show a much longer typical time (100 μs)[8].

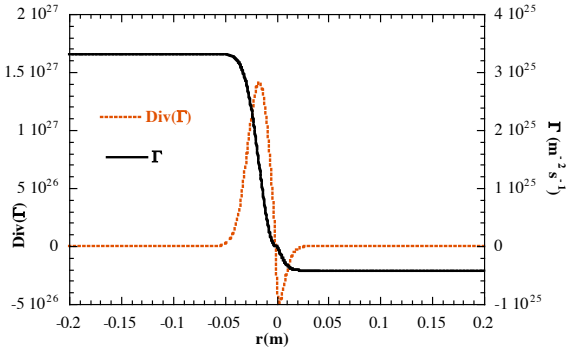

Figure 5. ECH-induced electron flux and its divergence

5.- Conclusions.

All the mentioned TJ-II results offer wide and valuable information to assess multiple mechanisms based on neoclassical/turbulent bifurcations and kinetic effects as candidates to explain the impact of magnetic topology on radial electric fields and confinement.

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