Quasilinear flux-driven gyrokinetic LOC-SOC transition

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The quasilinear gyrokinetic code QuaLiKiz [1] is coupled to the integrated modelling platform JETTO [2]. Flux driven heat, particle and angular momentum predictive simulations are now being performed [3,4] over multiple energy confinement times. In the present ohmic case, QuaLiKiz turbulent fluxes in JETTO are predicted up to the separatrix. For the treatment of the particle source due to neutrals, the code FRANTIC [5], interfaced with JETTO, has been used. A density ramp up mimicking an existing JET pulse is modelled over a few seconds. Over multiple confinement times, the ohmic heat source, the current, the electron and ion temperatures, the D density profiles and the magnetic equilibrium are self-consistently evolved. In the studied JET pulse, a transition from Linear Ohmic Confinement to Saturated Ohmic Confinement [6-9] is observed. A similar transition is reproduced by the modelling but at a density higher than the experimentally observed value.

1. Description of the modelled JET-ILW ohmic pulse

In the pulse #87756, the density is ramped up over 3s, between 5.5 and 8.5 s, from a line average electron density of 1.4 to 2.5×10^{19} m^{-3}. The effective charge, Z_{eff}, is reduced from 1.5 to 1 during the density ramp-up. The plasma is on an inner limiter, the magnetic field is 2.15 T and the plasma current 1.8 MA, q_{95} is around 3.5. The pulse was performed during the H campaign in 2014. During the studied time interval, the ohmic power ranges between 1.2 and 1.5 MW and the total energy content measured by the magnetics is 0.8-0.9 MJ. The energy confinement time increases from 0.2 s up to about 0.45 s in the LOC phase until it saturates in the SOC phase, see figure 1. Frequency fluctuations spectra measured by reflectometer around r/a=0.3 exhibit Quasi-Coherent Modes in the LOC phase identified as being a signature of Trapped Electron Modes [11]. QCM are not observed in the SOC phase, see figure 1.

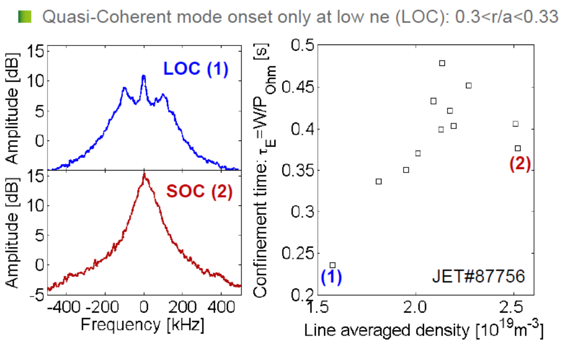

Figure 1, from Arnichand [10]:
Left: Fluctuation spectra from the reflectometer measured for 0.3 < r/a < 0.33 during #87756 (1) at 1.6×10^{19} m^{-3} with freflecto = 86.6 GHz and (2) at 2.5×10^{19} m^{-3} with freflecto = 76.4 GHz.
Right: The confinement time $\tau_E=W_{dia}/P_{ohm}$ is plotted against line average electron density.

2. JETTO settings

Only D transport is modeled, i.e. Z_{eff}=1. At t_0=5.5 s, the initial T_e and n_e profiles are fits of Thomson Scattering (LIDAR) made with Profile Maker. Due to the lack of charge exchange measurements, for the initial condition T_i=T_e is taken. The angular momentum transport is not modelled, V_φ is assumed to be null.

At first, an interpretative JETTO run with only the current diffusion and a self-consistent equilibrium (using ESCO) is performed. Between 5.5 and 8.5 s, the predicted internal inductance and loop voltage are in agreement with the measured values, within experimental uncertainties.

In predictive JETTO simulations, NCLASS is used to model the neoclassical heat and particle transport. QuaLiKiz [1] is used for heat and particle turbulent transport. QuaLiKiz includes unstable modes from ITG, TEM to ETG, a Krook collision operator is acting on the trapped electrons. In the present JETTO case, the QuaLiKiz fluxes are predicted from the magnetic axis up to the Last Closed Flux Surface. At first, the density remains interpretative and the temperature evolution only is predicted. Due to JETTO forcing QuaLiKiz predicted fluxes down to 0 at the separatrix, an artificial pedestal is observed. This issue is fixed by taking the boundary condition at ρ=0.95. In this case, QuaLiKiz heat fluxes allow reproducing the measured T_e from ρ=0.5 up to 0.95, see figure 2. No "shortfall" of the predicted heat flux is observed unlike in other attempts to predict L modes [12]. The central overestimation of T_e in the core is expected as no sawteeth model is included in the present JETTO modelling. For predictive modelling of both heat and particle transport, a particle source model has to be included in JETTO runs, FRANTIC [5]. The density ramp up is fixed by initial and final line average and separatrix density values. The neutral energy and fluxes at the separatrix are also given by the modeler. The neutral energy has been fixed to 100eV, corresponding to the measured T_e at the separatrix. Various fluxes have been tested, none of which allowed to model simultaneously the density ramp rate and the density profile in the region of the source: ρ=0.8-1 as illustrated by figure 3.

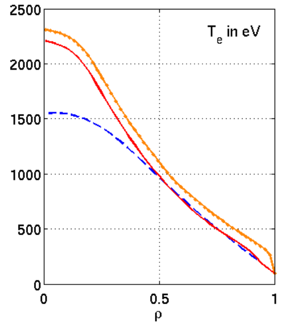

Figure 2:
Electron temperature profiles at t_0+1s, 6.5 s, in blue dashed the fit of TS data, in orange the predicted T_e with QuaLiKiz up to the separatrix, in red with QuaLiKiz up to ρ=0.95.

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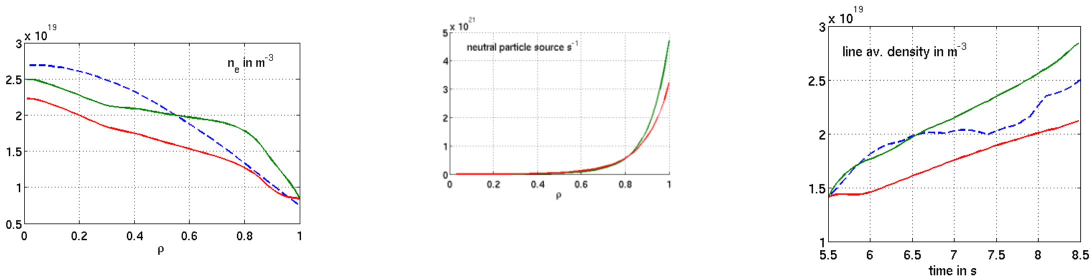

Figure 3: a: Electron density profiles at t_0+1s, 6.5 s, in blue dashed the fit of TS data, in red the predicted n_e with a neutral flux = 1×10^{21}/s, in green the predicted n_e with a neutral flux = 2×10^{21}/s.b: the neutral particle source profile at t_0+1s, 6.5 s. c: the experimental line averaged density versus time, blue dashed. In red, the modelled line averaged density with a neutral flux of 1×10^{21}/s and in green with a neutral flux of 2×10^{21}/s.

The predictive JETTO runs with heat transport only can be quantitatively compared to the experimentally observed LOC-SOC transition. The predictive JETTO runs with both heat and particle transport, being unable to reproduce quantitatively the experimental density ramp up, can only be studied qualitatively. In both cases a LOC-SOC transition is observed.

3. Modelled LOC-SOC transitions

a. JETTO with QuaLiKiz, predictive heat flux only

Due to the lack of T_i measurements, at 5.5s when the predictive modelling starts, the initial T_i is arbitrary taken equal to T_e. To avoid being impacted by initial conditions, it is essential to wait for an energy confinement time before analyzing the predicted confinement, i.e. t_0+~0.5s hence 6s, or 1.8×10^{19}m^{-3}. With the heat transport modelled by QuaLiKiz up to ρ=0.95, the confinement time saturates as the density is increased for line averaged densities similar to experimental values, see figure 4. The LOC phase takes place during the first 0.5 s of the modelling, when the chosen initial conditions impact the predictions.

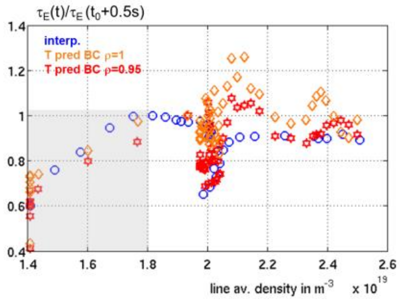

Figure 4:
Normalized confinement times to their value at 6.5 s plotted versus line average electron density.
Blue dashed: JETTO interpretative run.
Orange: JETTO predictive run for heat only, with QuaLiKiz up to the separatrix
Red: with QuaLiKiz up to ρ=0.95
(same colour code as on figure 2)

b. JETTO with QuaLiKiz, predictive heat and particle fluxes

The predictive JETTO runs with both heat and particle transport, being unable to reproduce quantitatively the experimental density ramp up, can only be studied qualitatively. The density ramp up is pushed further in density (from 1.4 to $4\times10^{19}m^{-3}$, instead of $2.5\times10^{19}m^{-3}$) and in time (from 5.5 s to 10.5 s, instead of 8.5 s). A transition between the LOC and the SOC phases is observed at $3\times10^{19}m^{-3}$, see figure 5. This transition is shifted towards a larger density if I_p is increased from 1.8 MA to 2.4 MA, in qualitative agreement with a universally reported LOC-SOC trend [7-10].

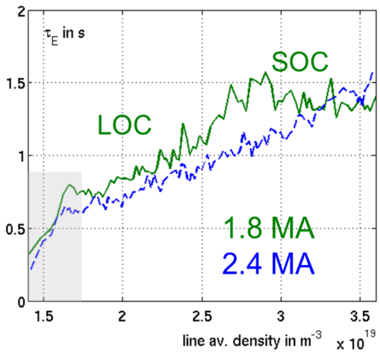

Figure 5:
Energy confinement time in s versus the line averaged electron density as predicted by JETTO with QuaLiKiz for heat and particle over 5 s and a density ramp up. For two values of I_p, 1.8 MA in green (same case as green lines on figure 3) and 2.4MA in blue.

4. Perspectives

The detailed understanding underlying the observed confinement time transition from LOC to SOC is on-going. To improve the predictive modelling, the neutral impact on the density ramp up will further explored, BC for QuaLiKiz turbulent fluxes at the separatrix will be improved and the toroidal rotation will be predicted.

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