Turbulent transport analysis of JET H-mode and hybrid plasmas using QuaLiKiz, TGLF and GLF23

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Introduction The construction of the future tokamaks as ITER or DEMO highly depends on the prediction capability of the performance of the main operation scenarios. For this purpose, the validation of the main models available for the plasma simulation is mandatory. QuaLiKiz [1] and TGLF [2] are two of the newest and more sophisticated quasi-linear transport models derived from first principles. QuaLiKiz is based on an electrostatic gyrokinetic eigenvalue code, in the s-α geometry. In the version here used QuaLiKiz does not take plasma rotation effects into account. TGLF is a gyro-Landau fluid model. It contains two models for the ExB rotation shear: the quench rule and the spectral shift model [3]. It can run using s-α or Miller geometry. Both models take into account passing and trapped particles. These models contain many physics effects, and are fast enough to be inserted in integrated modeling codes (QuaLiKiz is however slower than TGLF and it is parallelized). They then can play a fundamental role in understanding and predicting the transport of plasma particle and heat in present and future machines. QuaLiKiz and TGLF have been first compared in their stand-alone versions. They show good agreement. Then they are used coupled in the CRONOS suite of codes [4] to study heat transport in H-mode and hybrid plasmas of JET. The aim is to validate the models with the experimental data, to compare the results with the well known and faster even more approximated transport model GLF23 [5] and to investigate the possible physical reasons of the resulting discrepancies.

H-mode analysis The carbon wall JET H-mode discharges 73344 (standard) and 73342 (high density, $n_0 = 12\ 10^{19}\ m^{-3}$) are simulated. The temperatures and the current diffusion are modelled, the other quantities are taken from the experimental data. The temperature pedestal is taken fixed, according to the experimental measurements. A good agreement among the transport models and the experimental data is obtained in the core region, as we can see in fig. 1 where the resulting ion and electron temperature profiles together with the q and the n_e profiles are shown for the shot 73344. Looking at the spectra of the growth rates obtained from the experimental profiles through the stand-alone version of QuaLiKiz and TGLF (as it is shown in fig. 2 for 73344), we find that both transport models predict the dominance of the ITG instabilities. In addition the two models give an ITG threshold clearly under the experimental R/L_{Ti} values of these discharges, as expected for typical JET H-modes that are usually in ITG dominated regime.

[A] *See the Appendix of* G. Falchetto *et al.*, “The European Integrated Tokamak Modelling (ITM) effort: achievements and first physics results”, submitted to Nucl. Fusion.
[B] *See the Appendix of F. Romanelli et al., Proceedings of the 24th IAEA Fusion Energy Conference, San Diego, USA, 2012.*

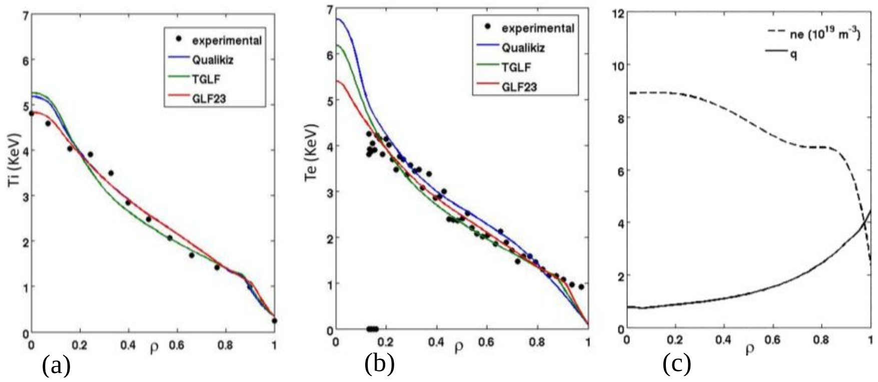


Fig 1: Ion (a), electron (b), n_e and q (c) profiles of the JET H-mode 73344 at 8.8 s. The n_e profile is taken fromthe data, the q profile is evolving. No sawtooth model has been utilized in the simulations

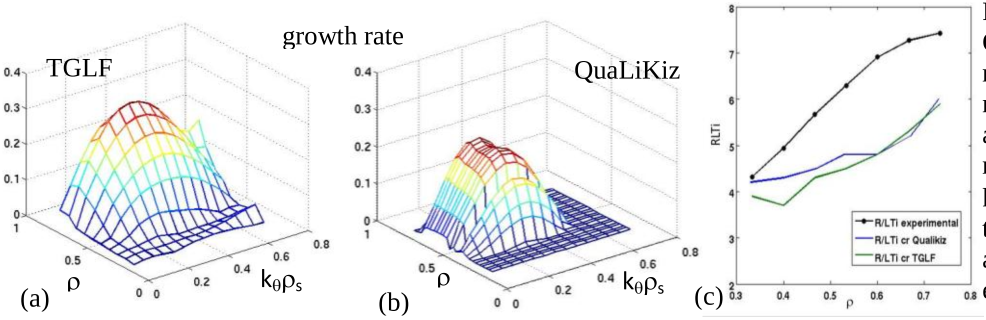


Fig 2: TGLF (a) and QuaLiKiz (b) growth rates of the JET H-mode 73344 at 8.8 s as functions of the radial coordinate and $k_\theta\rho_s$. (c) ITG thresholds from TGLF and QuaLiKiz vs experimental R/L_{Ti}

Hybrid modeling The same modelling is carried out for the JET hybrid 75225 [6], characterized by low triangularity (δ=0.23), low density (n_0=5 10^{19} m^{-3}) and high rotation (v_{tor}=10^5 rad/s). As shown in fig. 3 there is much less agreement among the transport models and the experimental T profiles.

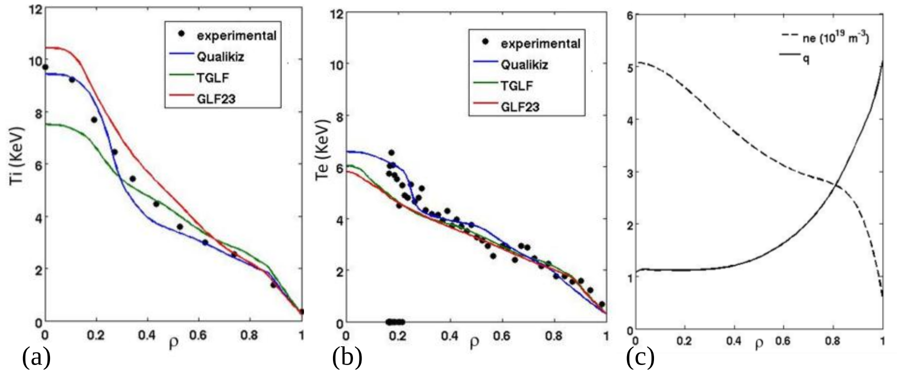


Fig 3: Ion (a), electron (b), n_e and q (c) profiles of the JET hybrid 75225 at 6 s. The n_e profile is taken fromthe data, the q profile is evolving.

From the study of the instabilities growth rates spectrum shown in fig. 4 and looking at the frequencies of the modes QuaLiKiz predicts an ITG dominated turbulence. TGLF shows also the existence of modes drifting in the electron direction, TEM dominated, in the outer radial part of the plasma (for ρ>0.7). They are also present in the plasma region with magnetic shear=0, where QuaLiKiz is completely stable. This is consistent with the fact that, outside ρ=0.4, TGLF and QuaLiKiz give similar R/L_{Ti} threshold, while for ρ<0.4 QuaLiKiz threshold becomes larger than experimental R/L_{Ti} (fig. 4c). The difference of the behavior of the two models in the inner part of the plasma could be due to the fact that the experimental R/L_{Ti} is closer to the threshold in this region, and it will be further investigated. Since TGLF is used with Miller geometry and with ExB shear effect, and QuaLiKiz does not include yet these effects, the impact of the equilibrium and the ExB shear is studied in TGLF in comparison with GLF23, which is in s-α geometry and includes the ExB shear factor.

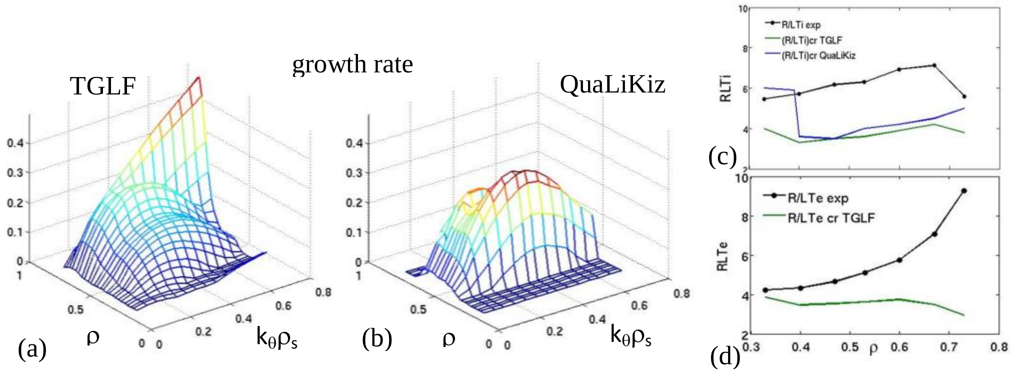
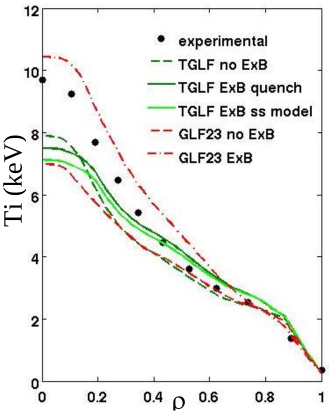


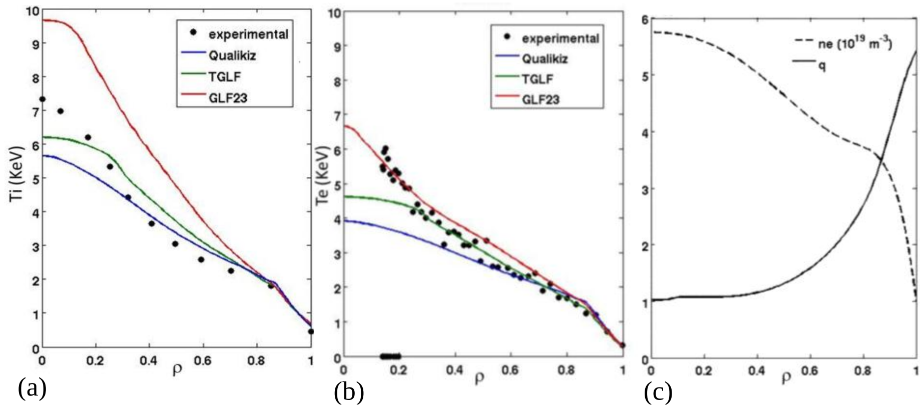
Fig 4: TGLF (a) and Qualikiz (b) maxima growth rates of the JET hybrid 75225 at 6 s as functions of the radial coordinate and $k_\theta\rho_s$. (c) ITG thresholds vs experimental R/L_{Ti}. (d) TEM threshold of TGLF vs experimental R/L_{Te}.

In fig. 5 the study of the ExB shear effect is shown for the shot 75225. From the agreement between GLF23 and TGLF without the rotation shear effect outside ρ=0.3 (inside it the difference can be due to the different treatment of the TEM in the two models) it is clear that the effect of the rotation shear as predicted by GLF23 (α_e is = 1.35) is largely overestimated, according to [7]. Since we found no difference between two simulations of TGLF with Miller and s-α geometry, the impact of the equilibrium is week in this low δ plasma. The two models of the ExB shear included in TGLF give a relevant and similar influence on the ion temperature, as expected for this discharge, characterized by low density and high rotation. For the hybrids modelled in this work it has been necessary to use assumed heat transport coefficients near the axis because of the too small transport predicted by TGLF in the cases with the effect of the rotational shear. However, even taking into account this factor, TGLF with the ExB shear effect does not seem enough to reproduce correctly the central part of the profile. QualiKiz, which does not include the effect of the ExB shear yet, is in agreement with GLF23 and TGLF without the shear effect outside ρ=0.4. Therefore the discrepancy between the critical T gradients for ρ<0.4 are not due to different equilibrium or to the ExB shear effect. The reason for the discrepancy will be further investigated in the future.

Fig 5: TGLF (green) and GLF23 (red) ion T of the hybrid JET shot 75225 at 6 s with and without the ExB shear effect compared with experimental data.



The high δ hybrid 77922 [8] is now studied. In this high triangularity case (δ=0.38), a major effect of the geometry is expected. The temperatures obtained by the models for this shot are shown in fig. 6. The stand alone turbulence analysis carried out by TGLF gives a growth rate spectrum similar to the previous shot, with a more important presence of TEM even for $k_\theta\rho_s \leq 0.5$, that seem to dominate in the plasma outside ρ=0.5. QuaLiKiz predicts the presence of ITG dominated modes both in the outer and in the central part of the plasma. Studying the effect of the ExB shear we find that it is always overestimated by GLF23, instead is nearly negligible for both the two models of TGLF, as expected for a high density discharge as the 77922. On the other hand the effect of the geometry is significant, as it is shown in fig. 7.

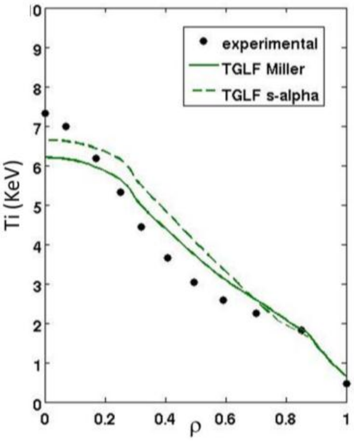


(a) (b) (c)

Fig 6: Ion (a), electron (b), ne and q (c) profiles of the JET hybrid 77922 at 7 s. The n_e profile is taken from the data, the q profile is evolving.

Conclusions From this first study we can conclude that QuaLiKiz and TGLF well describe the heat transport of the ITG dominated JET H-modes, for which the geometry and the ExB shear effect do not seem to play a large role. For JET hybrids TGLF gives T profiles closer to the experimental data than QuaLiKiz, and the inclusion of the ExB shear effect and of the Miller geometry possible in TGLF contribute to give better results. Note that these two effects are not included in QuaLiKiz yet, they will be added soon. We foresee to go ahead and deeper in the analysis of hybrid discharges to analyze the effect of the parameters studied here and to use a more complete gyrokinetic code such as GENE for the stand alone comparison, in order to understand the physical reason for the TGLF and QuaLiKiz differences when not due to the geometry and to the ExB shear effects. In fact there are many factors that play an important role in hybrid plasmas. The magnetic shear is known to be a candidate to explain the confinement improvement, and seems to influence directly the ITG thresholds [9]. Very recent studies [10] have shown the importance that fast ions can have in discharges as the 75225. A very preliminary and qualitative study using TGLF and including the effect of fast ions on the heat transport has shown that they can play a relevant role particularly in the region inside ρ=0.4, exactly where TGLF seems to fail in reproducing the experimental data.

Fig 7: Ion T profile of the JET hybrid 77922 at 7 s as obtained by TGLF with Miller (solid line) and with s-α (dashed line) geometry



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