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

B. Baiocchi[1], J. Garcia[1], M. Beurkens[2], C. Bourdelle[1], F. Crisanti[3], C. Giroud[2], J. Hobirk[4], F. Imbeaux[1], I. Nunes[5], ITM-TF contributors[A] , ISM and JET EFDA contributors[B]

JET-EFDA, Culham Science Centre, Abingdon, OX14 3DB, UK

[1]Association Euratom-CEA, DRFC/CEA/Cadarache, 13108 St. Paul-lez-Durance, France

[2]Euratom/CCFE Association, Culham Science Centre, Abingdon, OX14 3DB, UK

[3]Associazione Euratom/ENEA sulla Fusione, CP 65-00044 Frascati, Rome, Italy

[4]Max-Planck-Institut fur Plasmaphysik, EURATOM Association, 85748 Garching, Germany

[5]IPFN, EURATOM-IST Associaçao, 1096 Lisbon, Portugal

The construction of the new future tokamaks as ITER or DEMO highly depends on the capability for the prediction 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 the electrostatic gyrokinetic code Kinezero, and it is characterized by the s-α geometry. 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 the models take into account trapped particles. These models contain many physics effects, and are enough fast to be inserted in integrated modeling codes. 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 recently coupled to the CRONOS suite of codes [4], allowing to use them self-consistently for a first study of the heat transport in H-modes and hybrids plasmas of JET, with the aim of validating the models through the comparison with the well known transport model GLF23 [5] and with the experimental data, and trying to understand the possible physical reasons of the resulting discrepancies. After a series of parametric scans carried out through the stand-alone version of the two transport models for which a substantial agreement has been found, giving then a first indication about their validity to simulate electron and ion temperature self consistently, the carbon wall JET H-mode discharges 73344 (standard) and 73342 (high density) 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 with 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 profile and the n_e profile are shown for the shot 73344.

Looking at the spectra of the growth rates obtained through the stand-alone version of QuaLiKiz and TGLF (as it is shown in fig.2 for 73344), we find both the transport models to 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 regime.

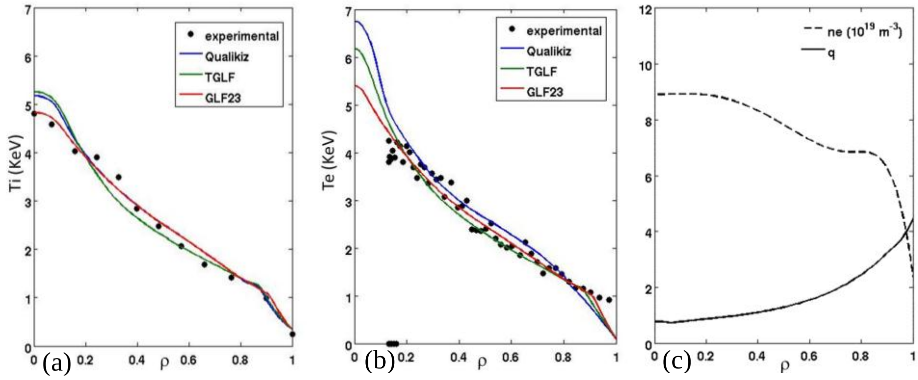


Fig 1: Ion (a), electron (b), ne and q (c) profiles of the JET H-mode 73344 at 8.8 s. The ne profile is taken fromthe data, the q profile is evolving. No sawtooth model has been utilized in the simulations

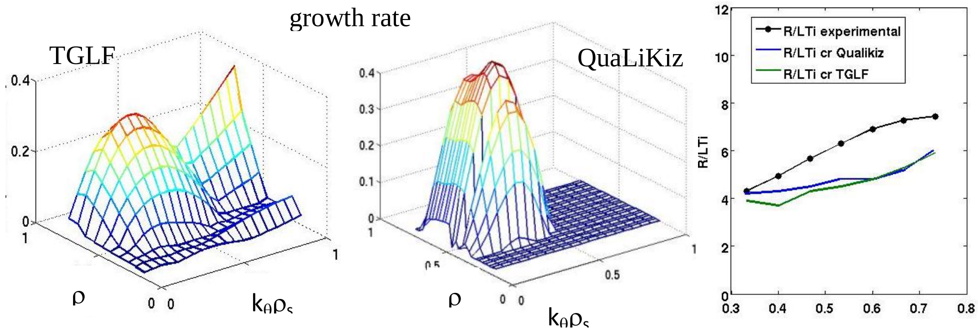


Fig 2: TGLF (a) and QuaLiKiz (b) growth rates as functions of the radial coordinate and kθ. (c) ITG thresholds

The same modelling is carried out for the JET hybrid 75225 [6], characterized by low triangularity, low density and high rotation. As shown in fig. 4 there is not much agreement among the transport models and the experimental data.

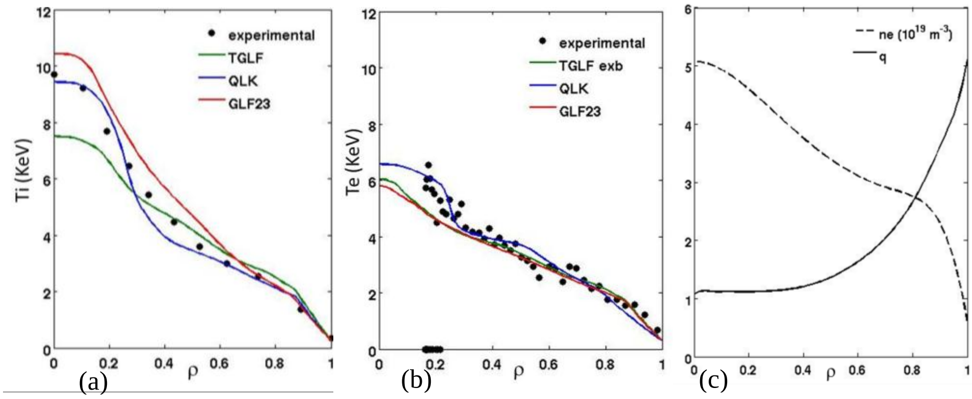


Fig 4: Ion (a), electron (b), ne and q (c) profiles of the JET hybrid 75225 at 6 s. The ne profile is taken fromthe data, the q profile is evolving.

From the turbulence analysis (fig. 5) we see that QuaLiKiz predicts only the presence of ITG modes, unlike TGLF, that shows the existence of the TEM, dominant in the outer radial part of the plasma, but even present in the plasma region with shear = 0, where QuaLiKiz is completely stable. This could explain the overestimation of the temperatures given by QuaLiKiz inside ρ = 0.4. However both the transport models give an ITG threshold that is not far from the experimental R/L_{Ti} of this discharge, making then more difficult to reproduce the experimental behavior (fig. 5c). Even little differences in the models (maybe due to numerical reasons) can lead to a situation of complete stability rather than to the instability of the modes.

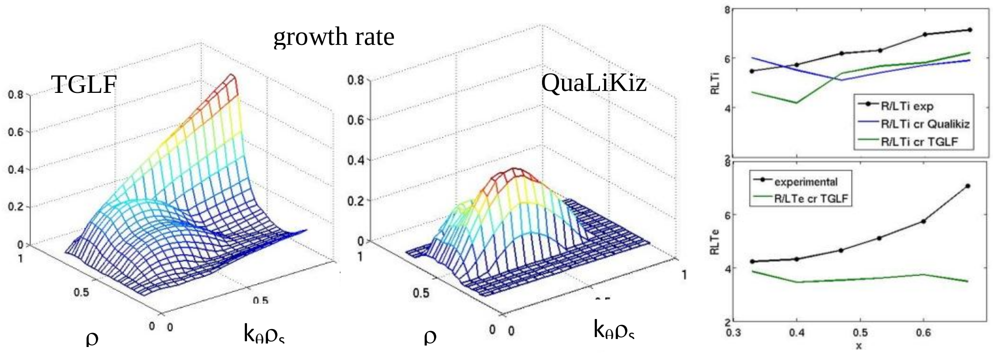
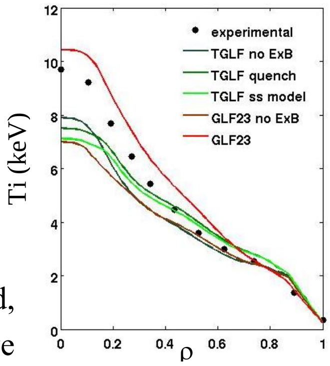


Fig 5: TGLF (a) and Qualikiz (b) maxima growth rates as functions of the radial coordinate and kθ. (c) ITG and TEM thresholds

Exploiting the possibility of using TGLF and GLF23 without some of their features we can obtain some indications about the relevance of these effects in simulating real discharges and about the possible reason of the differences resulting from using different models.

In fig. 6 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 is largely overestimated, according to [7], and the effect of the geometry is not relevant, as we found comparing two simulations of TGLF with Miller and s-α geometry. 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 doesn't seem enough to reproduce the right profile in the central part of the plasma. QualiKiz, that doesn't include the effect of the ExB shear, is in agreement with GLF23 and TGLF without the shear effect outside ρ=0.4.

Fig 6: TGLF (green) and GLF23 (red) ion temperatures with and without the ExB shear effect compared with experimental data.



A major effect of the geometry is expected in the case of the JET hybrid 77922 [8], that, unlike 75225, is characterized by high triangularity. The temperatures obtained for this shot are shown in fig.7.

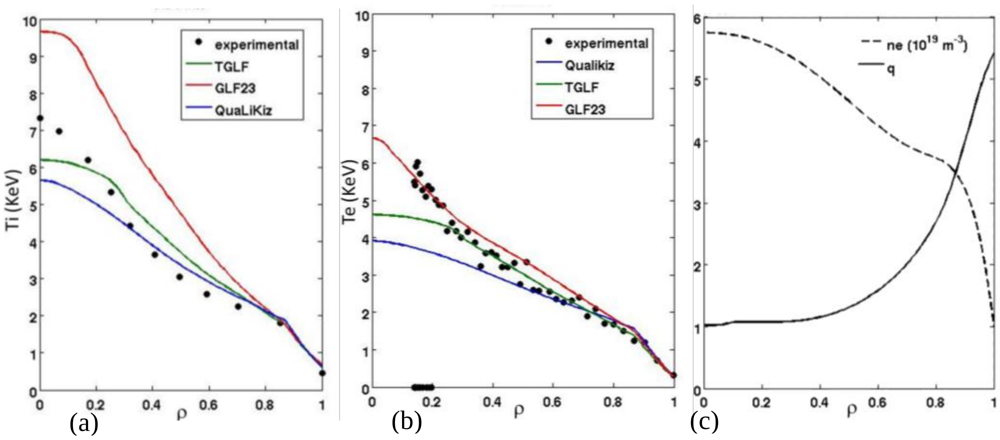


Fig 7: Ion (a), electron (b), ne and q (c) profiles of the JET hybrid 77922 at 7 s. The ne profile is taken fromthe data, the q profile is evolving.

The turbulence analysis carried out by TGLF gives a growth rate spectrum very similar to the previous shot, with an even more important presence of TEM, that seem to dominate in all the plasma outside ρ=0.5. QuaLiKiz gives no TEM, and predicts the presence of ITG modes even in the central part of the plasma, which leads to low temperature profiles. Studying the effect of the ExB shear we find that it is always overestimated by GLF23, instead is nearly absent for both the two models of TGLF, as expected for a high density discharge as the 77922. The effect of the geometry is relevant, as it is shown in fig. 8.

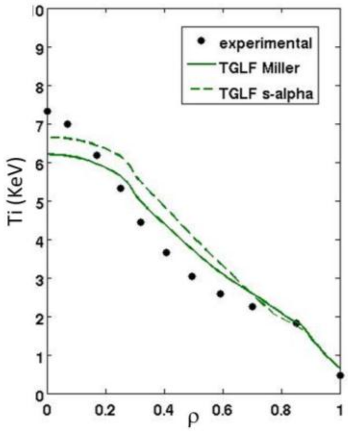


Fig 8: Ion T profile as obtained by TGLF with Miller (solid line) and with s-α (dashed line) geometry

From this first study we can conclude that QuaLiKiz and TGLF well describe the heat transport of the JET H-modes. For JET hybrids, for which the TEM seem to play an important role, QuaLiKiz shows to consider not sufficiently these instabilities, becoming stable or describing always ITG as dominant modes. TGLF gives results closer to the experimental data, and the inclusion of the ExB shear effect and of the Miller geometry contribute in a relevant way to give better results.

We foresee to go ahead and deeper in the analysis of hybrid discharges, modelling other shots and analyze the effect of the parameters here studied and the impact that can have other interesting quantities. 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.

[1] C. Bourdelle *et al* 2007 *Phys. of Plasmas* **14** 112501

[2] G. M. Staebler *et al* 2005 *Phys. of Plasmas* **12** 102508

[3] G. M. Staebler *et al 2012 Phys. Review Lett.***110** 055003

[4] J. F. Artaud *et al* 2010 *Nucl. Fusion* **50** 043001

[5] R. E. Waltz *et al* 1997 *Phys. Plasmas* **4** 2482

[6] J. Hobirk, F. Imbeaux *et al* 2012 Plasma Phys. Control. Fusion **54** 095001.

[7] I. Voitsekhovitch *et al* 2012 39th EPS (Stokholm, Sweden, 2-6 July 2011) http://ocs.ciemat.es/EPSICPP2012PAP/pdf/P4.066.pdf

[8] E. Joffrin *et al* 2010 in Fus. Energy (Proc. 23rd Int. Conf. Daejeon, 2010) (Vienna: IAEA) CD-ROM file EX/1-1.

[9] J. Citrin *et al* 2012 *Plasma Phys. Control. Fusion* **54** 065008

[10] J. Garcia *et al ITPA-IOS Meeting,* 2013 April

[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.*