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[REGULAR POSTER TWIN] Experimental investigation and gyrokinetic simulations of multi-scale electron heat transport in JET, AUG and TCV

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Core transport in present tokamaks is mostly ascribed to micro-turbulence driven by the non-linear saturation of ion-scale ITG-TEM [1] instabilities ($k_\theta \rho_i \leq 1$, where k_θ is the poloidal wave number and ρ_i the ion Larmor radius). It has been shown that electron-scale ETGs [2] ($k_\theta \rho_e \leq 1$) can also impact the heat transport, also exchanging energy with ITG-TEM turbulence by multi-scale coupling [3-9]. This topic of investigation gains a particular relevance due to its potential impact on devices like ITER, dominated by electron heating. ETG modes have been shown to play a role in plasmas with mixed ion and electron heating, since a proper balance of ion heating, decreasing the ETG threshold in T_e gradient (which increases with increasing T_e/T_i [10]), and electron heating (pushing T_e gradient towards threshold while increasing the threshold due to T_e/T_i increase), could destabilize them. Also all mechanisms that stabilize ITGs, such $E \times B$ or fast ions from neutral beams (NBI) and/or ion cyclotron resonance heating (ICRH), due to multiscale interactions open a window favourable for ETG destabilization.

The response of the T_e profiles to the applied heating can be experimentally investigated by performing normalized electron heat flux scans and/or RF power modulation analysis. The two methods can be used in conjunction to extract information on the dependence of the gyro-Bohm normalized electron heat flux q_{egB} on the normalised T_e logarithmic gradient R/L_{Te}, yielding experimental values for the threshold $R/L_{Te,crit}$ for the onset of turbulent transport and for the 'electron stiffness'$\partial q_{egB}/\partial R/L_{Te}$. The experimental results can be compared with the output of gyrokinetic (GK) simulations, which infer both $R/L_{Te,crit}$ (fast linear runs), and the dependence of the saturated heat flux on R/L_{Te} (more costly nonlinear runs). Resolving both ion and electron scales (i.e. performing nonlinear multi-scale simulations) is computationally very demanding and just became possible in the last years.

In order to access a broad range of parameters, a great effort is actually devoted to analyse different machines, comparing experimental and numerical results, within the framework of EUROfusion and of the ITPA Transport & Confinement group. In this paper, the analysis of plasmas of three different tokamaks, i.e. the Joint European Torus (JET, at Culham, UK), ASDEX Upgrade (AUG, at Garching, DE) and the Tokamak à Configuration Variable (TCV, at Lausanne, CH), is presented. Dedicated plasma discharges have been analysed experimentally and modelled numerically, by means of GK codes (GENE [11] and GKW [12]) and reduced quasi-linear models (TGLF [13] and QuaLiKiz [14]). The results of the different tokamaks concur to make a general picture indicating that ETGs could also be important for electron heat transport in fusion relevant conditions, in particular when $T_e \sim T_i$ with consistent fast ion density.

TCV is equipped with an NBI system, that allows the plasma to achieve $T_e \sim T_i$ in conjunction with high R/L_{Te} (due to ECRH), allowing to access parameters compatible with ETGs. Two dedicated L-mode discharges, with $B_0 = 1.41$ T, $I_p = 170$ kA have been performed with a different proportion of deposited ECRH power on- vs off-axis to perform a heat flux scan. Each pulse presented different phases corresponding to a different proportion of NBI/ECRH power to vary T_e/T_i, with ECRH both steady and modulated to allow a perturbative analysis. Both the experimental analysis and GK modelling (linear multi-scale and nonlinear ion-scale simulations) tend to indicate a possible role of ETGs at mid-radius when both ECRH and NBI are injected simultaneously, and at a larger toroidal radius $_{tor} = 0.7$ also when only ECRH is injected. In the former case, the main mechanism which explains the failure of ion scales alone to explain the experimental fluxes, is the stabilisation of ion-scales by the fast ions that are produced by the NBI. These results, published in [6], provide hints of a contribution of ETGs to electron heat transport in TCV plasmas.

Experiments on the AUG tokamak to study electron heat transport [5] have produced H-mode discharges with $B_0 = 2.5$ T, $I_p = 0.8$ MA, injecting 2.5 MW of ECRH (steady and modulated to perform the perturbative analysis) and 5 MW of NBI in order to have $T_e \sim T_i$. Different discharges had different proportions of ECRH power deposition on- vs off-axis, in order to obtain the heat flux scan. At mid-radius, both the electron heat pulse diffusivity ^{HP} (from perturbative analysis) and q_{egB} (from steady state scan), indicate strong turbulence levels above $R/L_{Te} \sim$ 6-7, leading to a moderate/high electron stiffness, consistent with the possible presence of ETGs. Both GENE and GKW linear-gyrokinetic simulations predict a role for ETGs for $R/L_{Te} > 6$, based on an effective model for nonlinear turbulence saturation [15]. Both ion-scale and multi-scale simulations are being performed in order to analyse the most representative AUG pulse, to test the existence of an ETG 'wall' limiting the achievable R/L_{Te}. The preliminary multi-scale results are in agreement with TGLF in indicating a >30% contribution of ETGs to the electron heat flux for the cases close to threshold, setting high electron stiffness above it (see figure 1-2).

Following early results pointing to an important role of ETGs in JET [4], very recently dedicated sessions on ETGs have been performed at JET. Both L- and H-mode plasmas have been obtained, with $B_T = 3.3\,\mathrm{T}$, $I_p = 2$ MA, injecting 0-20 MW of NBI and up to 6 MW of ICRH (H minority, mainly heating electrons), achieving heat flux scans for a range of T_e/T_i values. The preliminary analysis of the experimental data indicates that JET results are very similar to the AUG ones, with a strong increase of the electron stiffness for $R/L_{Te} > 6$ (see figure 3). L-mode cases, in particular, allow to obtain sufficiently large values of q_{egB} at large $R/L_{Te} > 6$, giving the hint of a possible ETG 'wall'. In parallel, high performance hybrid discharges are analyzed in order to study the ETG impact on these scenarios. Both sets of data are being modelled by means of single scale GK simulations and reduced models, in order to set the basis for heavier multi-scale GK simulations.

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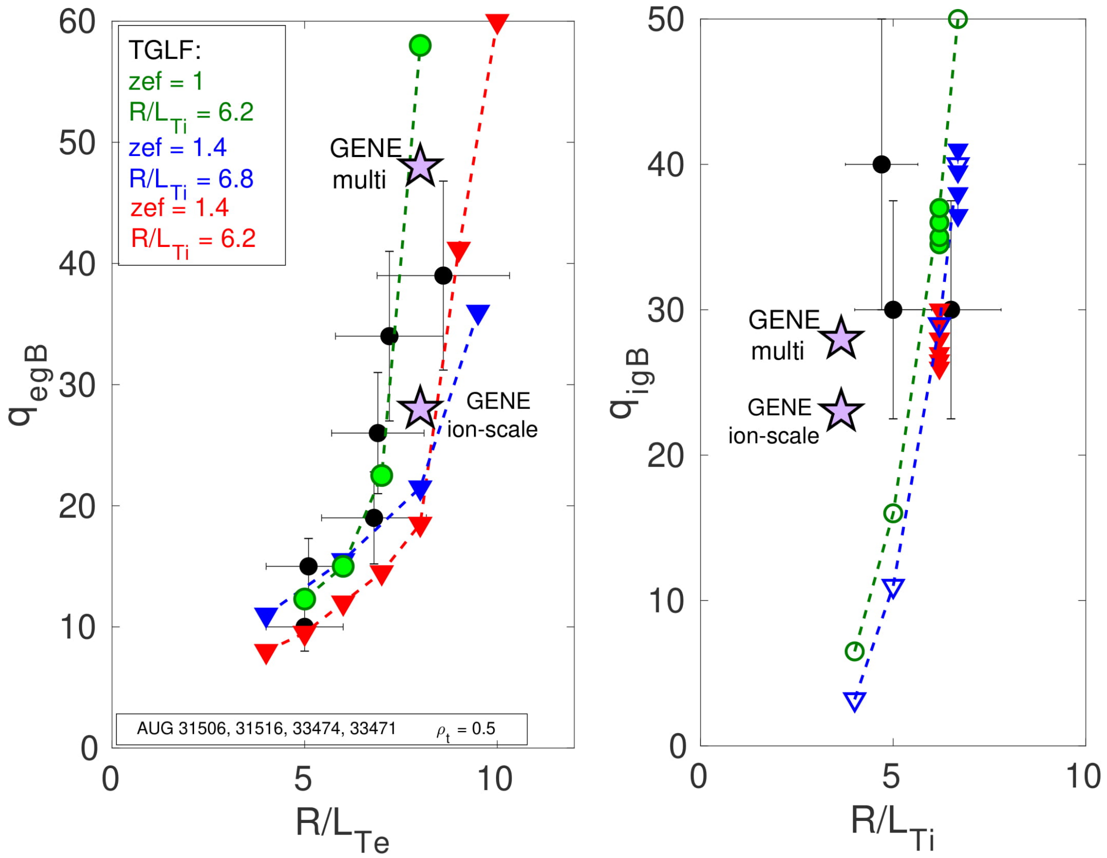

Figure 1: $q_{e,i,gB}$ vs $R/L_{Te,i}$ for AUG at mid-radius, comparing exp. with GENE ion/multi-scale and TGLF.

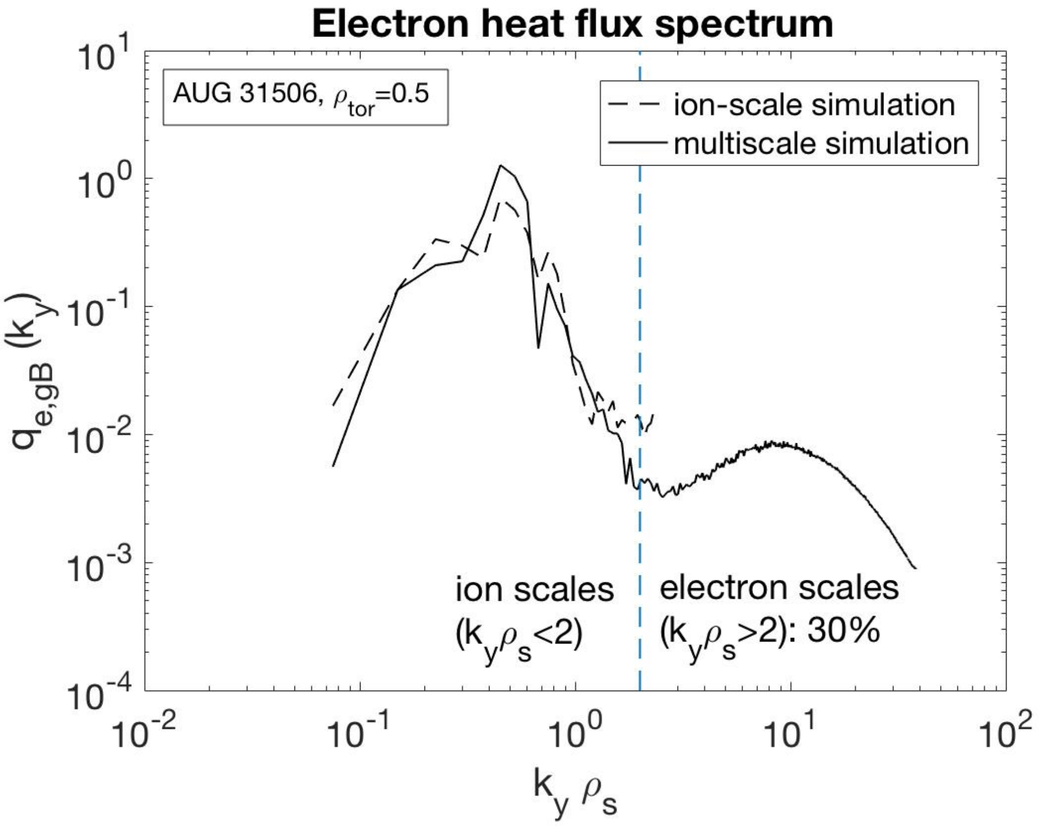

Figure 2: GENE ion/multi-scale q_{eGB} spectra.

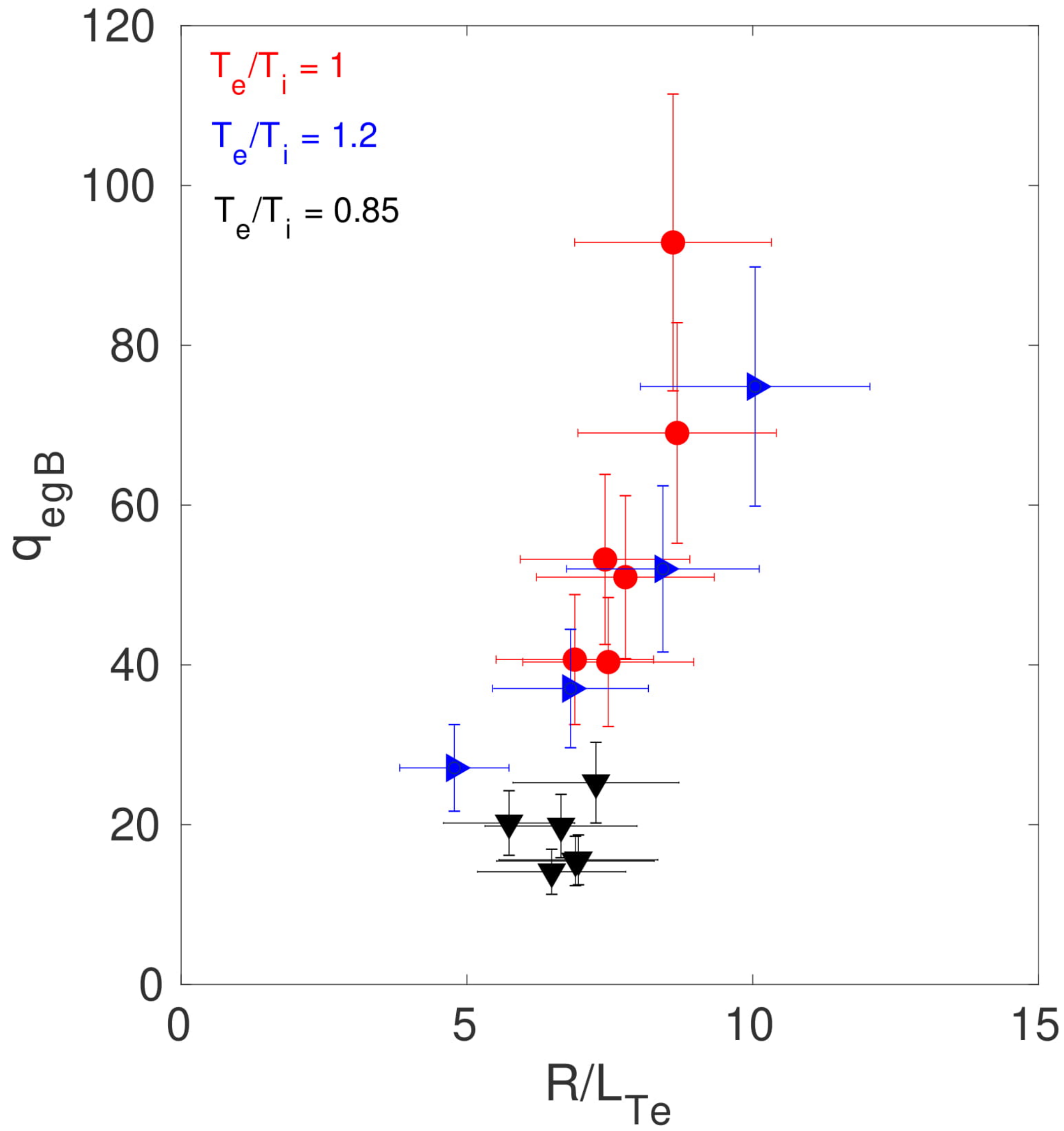

Figure 3: Experimental q_{egB} vs R/LTe (JET).

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