Electron Heat Transport in JET from Ion to Electron scales: Experimental Investigation and Gyro-kinetic Simulations

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INTRODUCTION

- Electron heat transport in tokamak devices has been mostly ascribed to large (ion) scale ITG-TEM turbulence ($k_\theta\rho_i<1$). Extensive studies in ECRH heated devices with $T_e/T_i>>1$ (AUG, TCV, DIII-D, RTP). Good agreement of experimental threshold with linear GK simulations.
- In JET, the parameter $\tau = Z_{eff} \cdot T_e/T_i$, which stabilizes the small (electron) scale ($k_\theta\rho_i>>1$) ETG instabilities, is generally lower than in ECRH dominated machines
- TEM and ETG thresholds are comparable in JET plasmas (Fig.1), so it is not possible to determine which instability contributes most to the electron heat flux without investigating the electron stiffness and comparing with non-linear GK simulations
- This exercise shows that the experimental electron stiffness is higher than predicted by ITG/TEM GK simulations [1].
- This poster investigates whether the ETGs could be carrying the missing flux, based on new experimental work on JET and GENE [2] single- and multi-scale NL simulations.

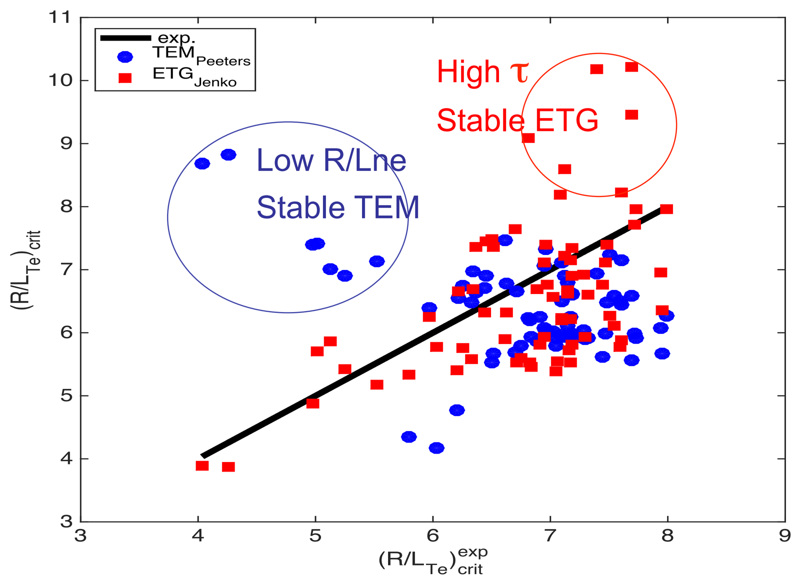

Fig. 1: *Critical R/L_{Te} predicted for TEM and ETG by analytical formulae derived in [xx] and [xx] vs experimental critical R/L_{Te}.*

EXPERIMENTAL OBSERVATIONS

Dataset from JET C-wall, L-mode plasmas. B_0~3.3–3.4 T, ICRH~1-6 MW on--axis in (3He)-D minority and MC scheme, NBI~1.7-10 MW, I_p~ 1.5 - 2 MA, $n_{e,0}$~ 2.5-4·10^{19} m^{-3}, $T_{e,0}$~ 2-8 keV, $T_{i,0}$~2.5-10 keV.

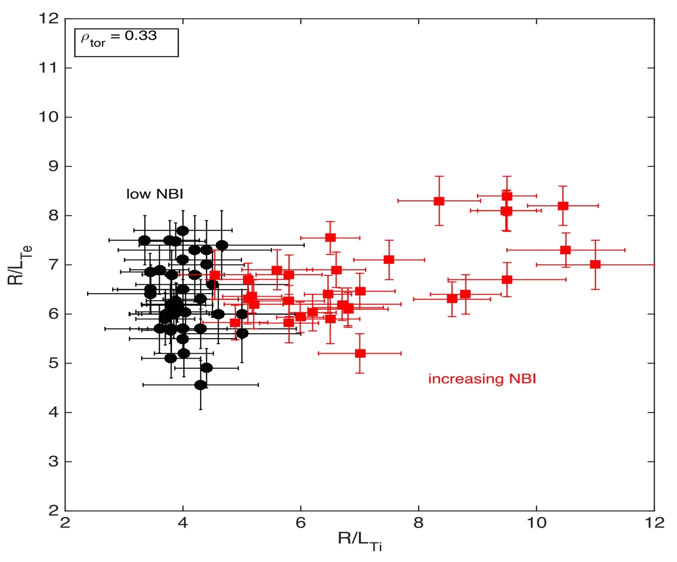

Fig.2: *R/L_{Te} vs R/L_{Ti} at ρ_{tor}=0.33 for a series of JET L-mode plasmas*

- R/L_{Ti} can vary significantly, from 3 to 12 (which has been ascribed to non-linear e.m. stabilization [3]), whilst R/L_{te} remains rather constant, in the range 5-8.
- The parameter that orders best the R/L_{Te} values is clearly τ, as seen in Figs.2, although other dependencies are also in place, and causing the scatter in the plot, particularly the one on s.

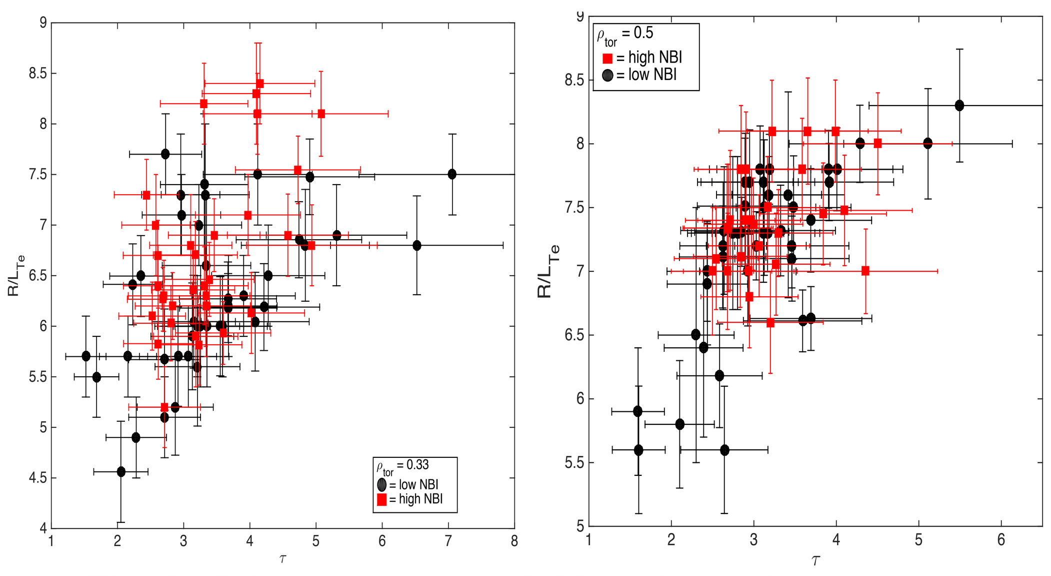

Fig. 3: *R/L_{Te} vs τ at ρ_{tor}=0.33 and ρ_{tor}=0.5*

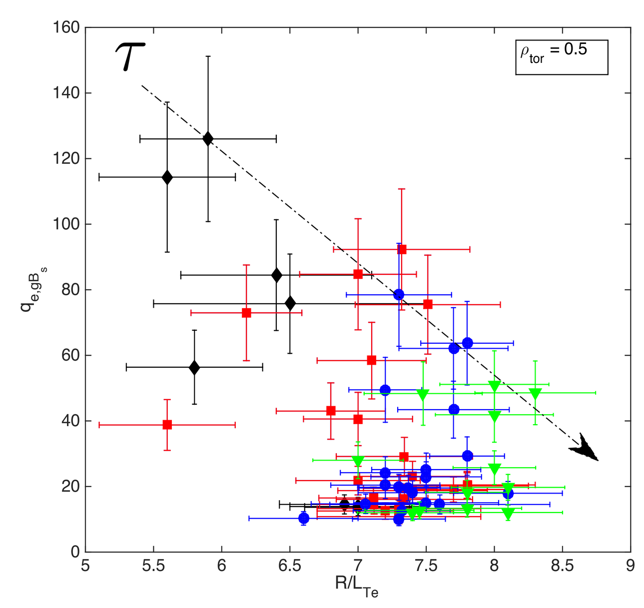

Fig. 4: *q_{gB} vs R/L_T for different τ values*

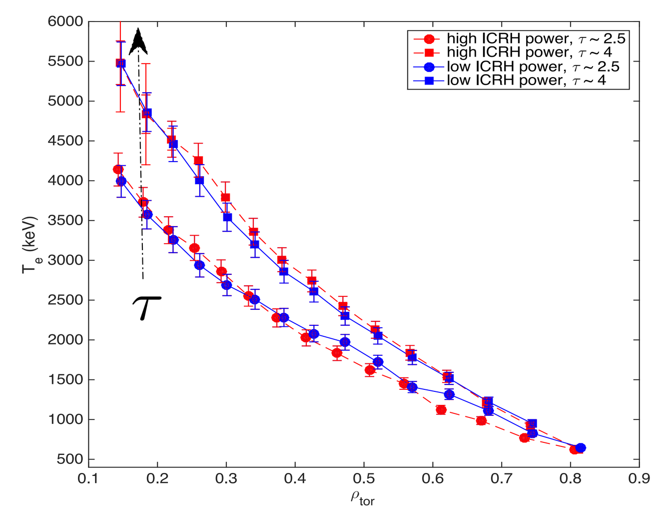

Fig. 5: *T_e profiles from 4 shots with fixed s, s/q, n_e and with high and low ICRH power to electrons and different τ values*

- T_e peaking is more sensitive to τ then to power or other parameters
- The marked dependence of T_e peaking on τ is a strong experimental indication of a role of ETGs in electron heat transport

SINGLE SCALE GYROKINETIC SIMULATIONS

Four shots were chosen as input for linear gyrokinetic simulations with GENE. The simulations include Miller geometry, kinetic ions & electrons (also Carbon in some simulations), collisions, e.m. effects, Debye length shield (important for ETG).

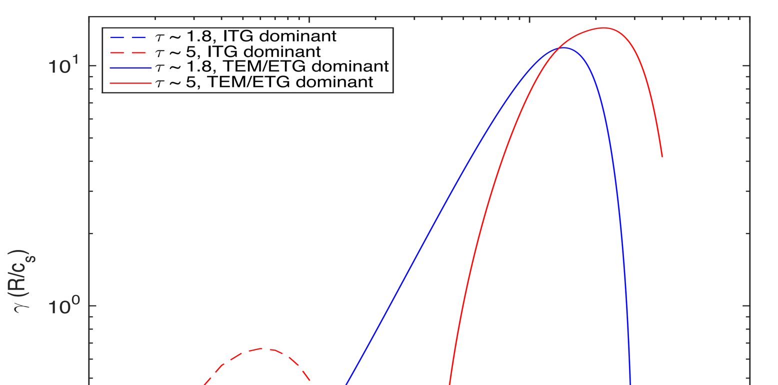

Fig. 6: *linear growth rate spectra at two values of τ*

- Scan in 0.1 < $\rho_s k_y$ < 42 at different radii. Scan in the main parameters to see the effects on the ITG/TEM/ETG thresholds.
- **LOW k_y**: ITG dominant at higher τ, while at lower τ ITG tend to be less unstable and TEM are dominant for k_y > 0.5.
- **HIGH k_y**: ETG are unstable in the studied region 0.33 < ρ_{tor}< 0.6. The strong effect of $\tau = Z_{eff} \cdot T_e/T_i$ on the ETG threshold is confirmed and also the correlation between the ETG threshold and other plasma parameters (such as s, q, R/L_n, α_{MHD}) found in [4].

Nonlinear GK simulations with GENE have been carried out for 2 representative shots at ρ_{tor}~0.53, one with ICRH + low NBI and one with ICRH + high NBI. Miller geometry, kinetic ions, kinetic electrons, kinetic C and fast D are retained as well as e.m. effects in the high NBI case.

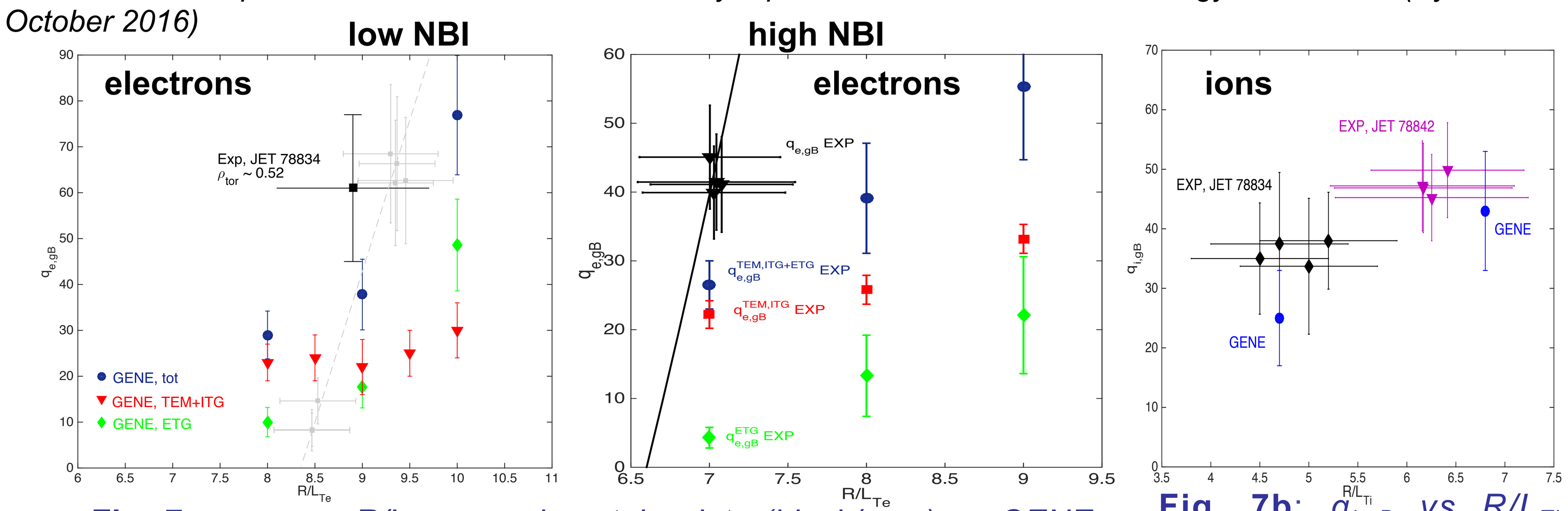

Fig. 7a: *$q_{e,gB}$ vs R/L_{Te}, experimental points (black/grey) vs GENE simulations. Red triangles are ion-scale simulations, green diamonds are electron single scale simulations, blue circles are the total simulated electron heat flux.*

Fig. 7b: *$q_{i,gB}$ vs R/L_{Ti}, experimental points vs GENE (blue) for both low and high NBI cases*

- The ion-scale simulations cannot reproduce the experimental fluxes and the electron stiffness. Adding the electron-scale simulations helps reproducing the experimental fluxes and stiffness.
- The ion heat fluxes could be reproduced in both cases with the ion-scale simulations.
- In these simulations we use the external flow shear as an actuator for reducing box-size effects due to the ETG streamer, allowing for physical saturation to occur
- With a sufficiently large radial box size ETG can be saturated by electron scale ZF. However ETG ZF saturation seems to depend on many factors (kinetic ions, Lx/Ly, e.m. effects…). Recent results [5,6,7] show that ETG are strongly saturated by ITG ZF and can have an important impact on ion scale instabilities → **strong interaction between different scales, calling for multi-scale GK simulations!**

MULTISCALE GYROKINETIC SIMULATION

Experimental parameters of JET shot 78834 (ICRH + low NBI) at ρ_{tor}~0.52 and t ~ 7 s. Miller geometry, collisions, kinetic ions and electrons, 0.1 < $\rho_s k_y$ < 48. Perpendicular box sizes: [Lx, Ly] ~ [64, 64] ρ_s. Grid points [nx, ny, nz, nv, nw] = [1200, 448, 32, 32, 12] (~ 7e+09 points in the phase space, x = radial, y=binormal, z=parallel (to B_0), v = parallel velocity, w= magnetic momentum). ~9 10^6 CPUh.

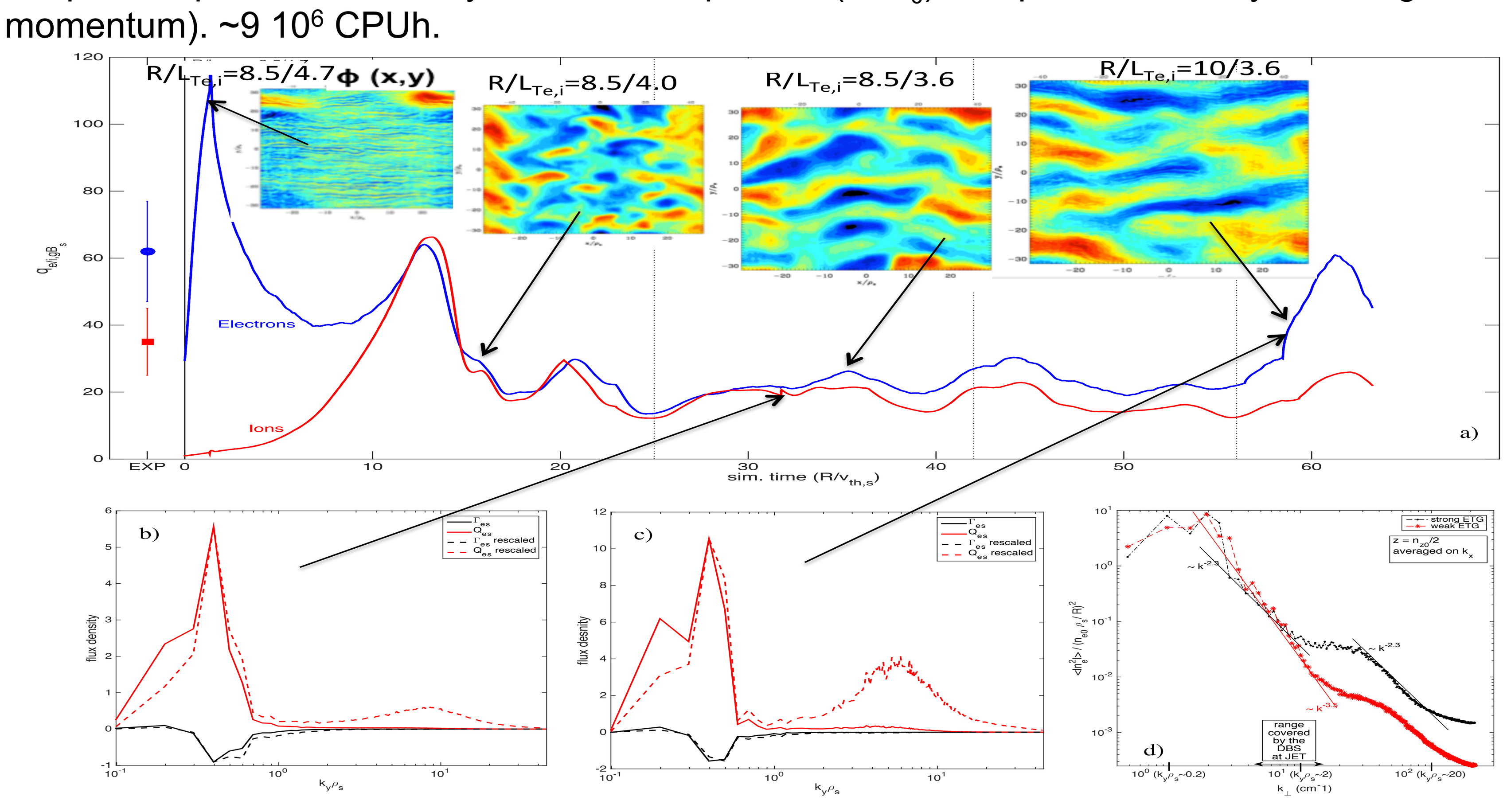

Fig. 8: *electron and ion q_{gB} vs sim. time from the multi-scale simulation (top). Experimental fluxes are the dots on the left side. The counterparts of the electrostatic potential are shown for different times. Heat and particle flux spectra at two different times (bottom left). Density fluctuation spectra at two different times (bottom right).*

- In the initial phase ion zonal flows are not yet established and ETG streamers are well developed, carrying a huge electron heat flux.
- This decays away whilst ITG zonal flows are established, until a rather stable condition is reached in which ETGs carry ~15% of the flux, with similar total electron and ion heat flux.
- Then a small R/L_{te} increase causes a sharp increase of the electron heat flux at high k_y, clearly decoupling electron from ion flux, and approaching the experimental levels.
- The simulation is still not stationary and we cannot anticipate the final level. It suggests a relevant fraction of electron heat flux carried by ETGs, with a sharp dependence on the R/L_{Te} value.
- The increase in high k_y electron flux is accompanied by a (smaller) increase of the low k_y ion heat flux, which was also observed in [6].

CONCLUSIONS

- T_e peaking strongly correlated with τ indicates role of ETG in JET
- High electron stiffness cannot be reproduced by ITG/TEM non-linear GK simulations
- ETG are linearly unstable in most of the discharges analyzed
- Adding ETG flux from single scale high k_y simulations (using ExB to help saturation) allows matching the experimental levels
- Multi-scale simulations indicate high sensitivity of the high k_y flux to R/L_{Te} and the possibility of an important electron heat flux contribution by the ETG

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