What we learned about Electron Transport From Tore Supra

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Key Features of Tore Supra Transport Studies

TORE SUPRA
CEA - EURATOM

- Clean electron power balance data with accurate T_e profiles and centrally deposited electron power
- Power scans from Ohmic to 8MW giving Te up to 7kev [more recently higher P and Te up to 9kev]
- Flux Scaling with density & temperature
- Integrated System Dynamics- Chronos

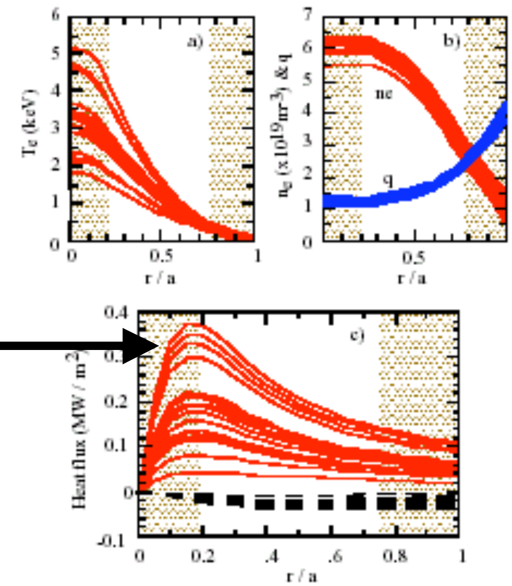
G.T. Hoang, W. Horton, C. Bourdelle et al., Phys of Plasmas **10**,405(2003)

W.Horton, Hu, Dong and Zhu, Turbulent El Transpt, www.njp.org (2003)

Outline

Fast Wave Electron Heating Database

- DB of 26 Quasi-steady state plasmas
  (duration ranging from 1 to 5 seconds ≈ 20 - 120 x τ_E)
- No fast particles, no appreciable sawteeth.
- Electron / Ion channels are decoupled ($T_e \sim 2T_i$)
- Central localization of FW deposited power
- Up to 90% of FW power coupled to the electrons: ($q_{rf}^e >> q_{ei}, q_{ohm}$)

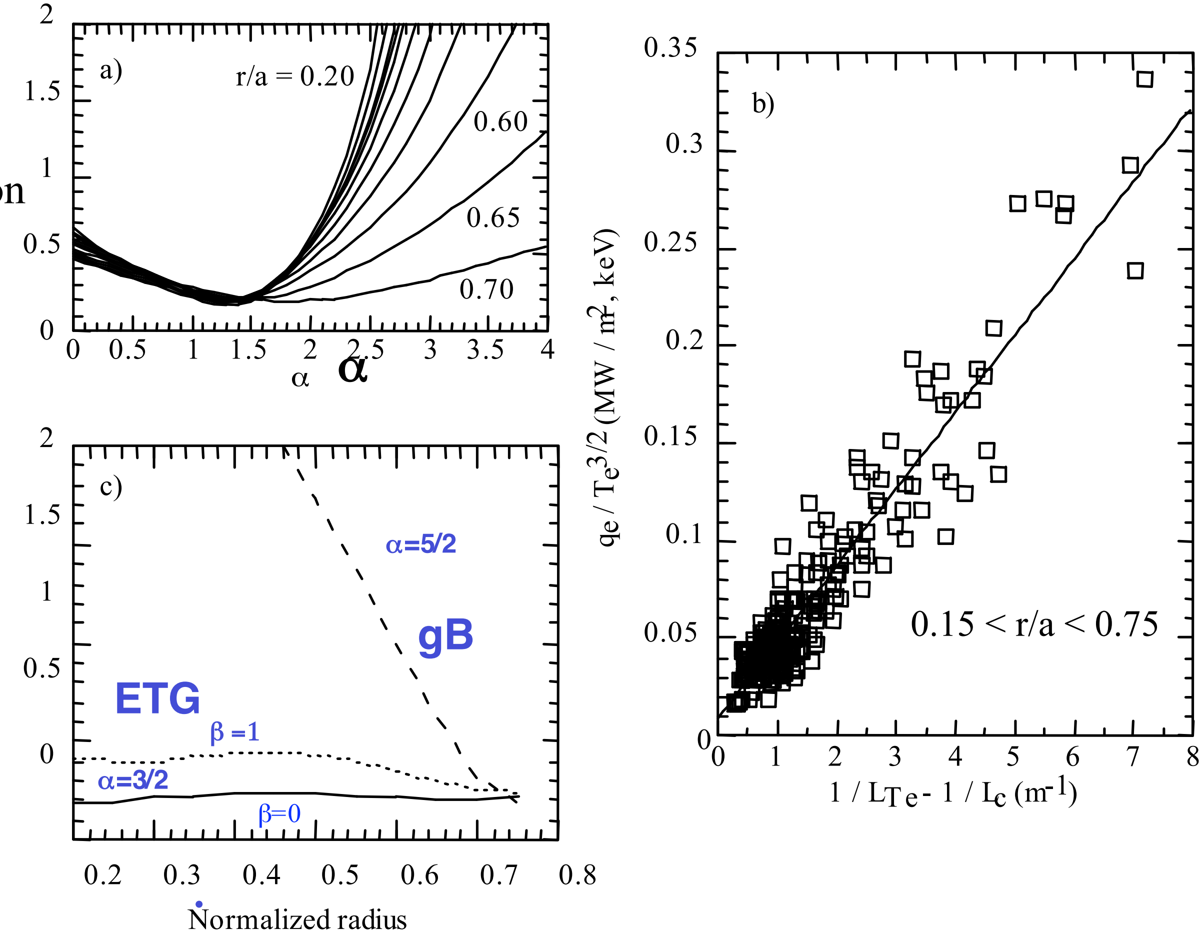


➔Good confidence in transport power balance value of $q_e(r,t)$

Parametric Dependence: $q_e = \text{const. } n^{\beta}_e T^{\alpha}_e (1/L_{Te} - 1/L_c)$

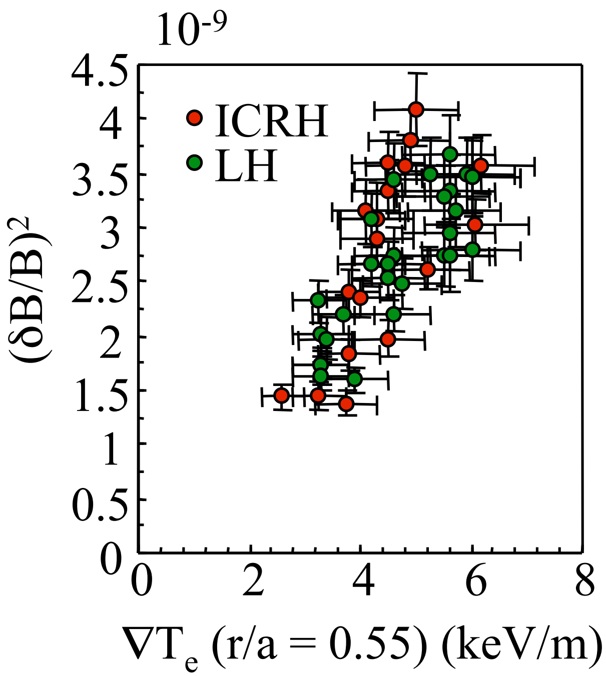
Relative deviation

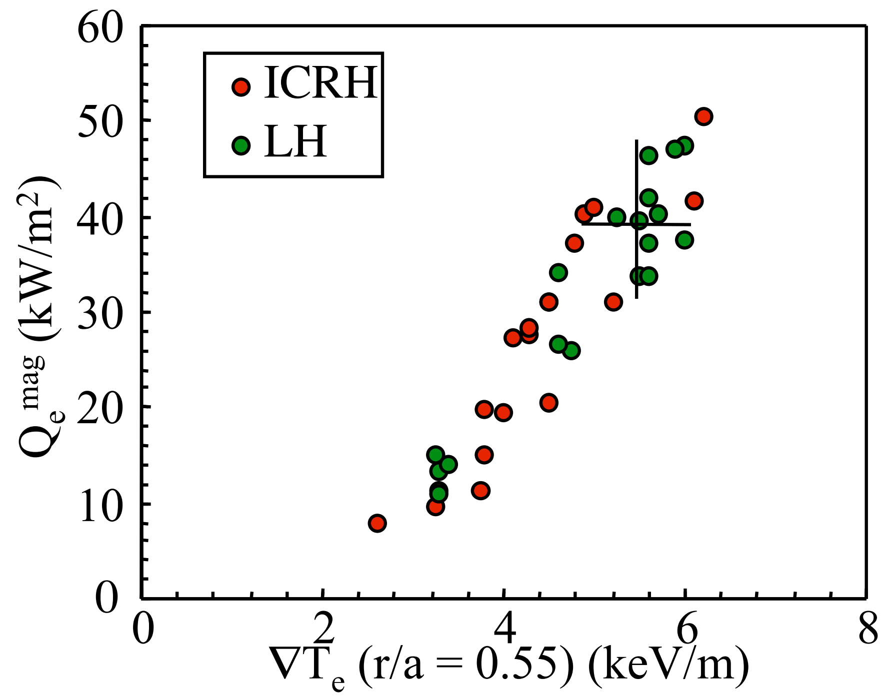
Relative deviation



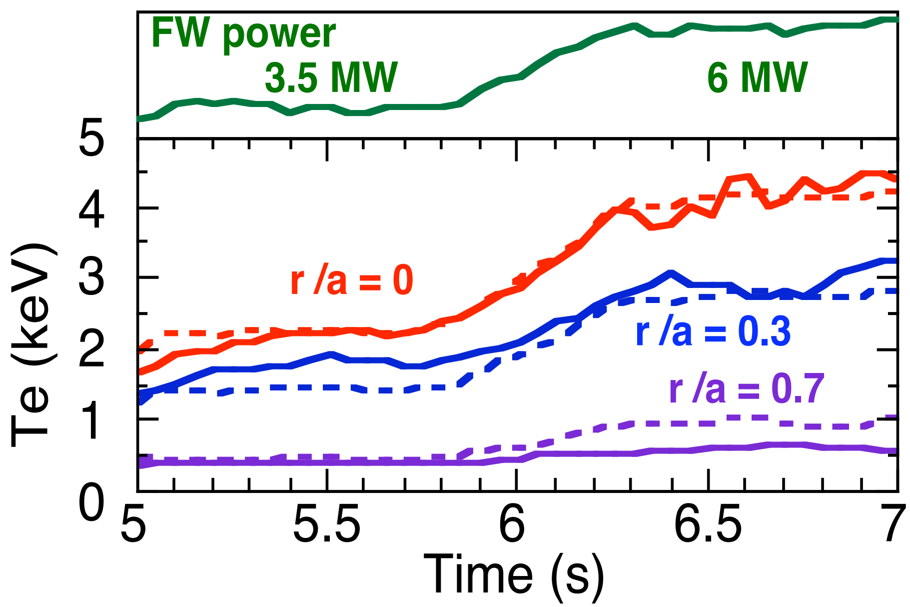
Critical Gradient and Internal Magnetic Fluctuations
δB by Cross-Polarisation Scattering

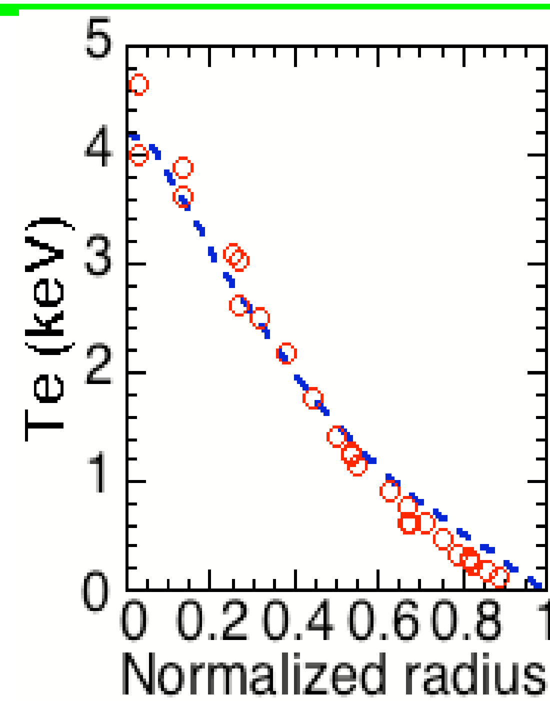
I_p =1.3MA, B=3.7T
$n_e(0)=6x10^{19}m^{-3}$
RF power =1MW -3.3MW





Electromagnetic drift wave turbulence driven by the ETG is Standard Model $T_e(r,t)$





Data full line —— model dashed line---

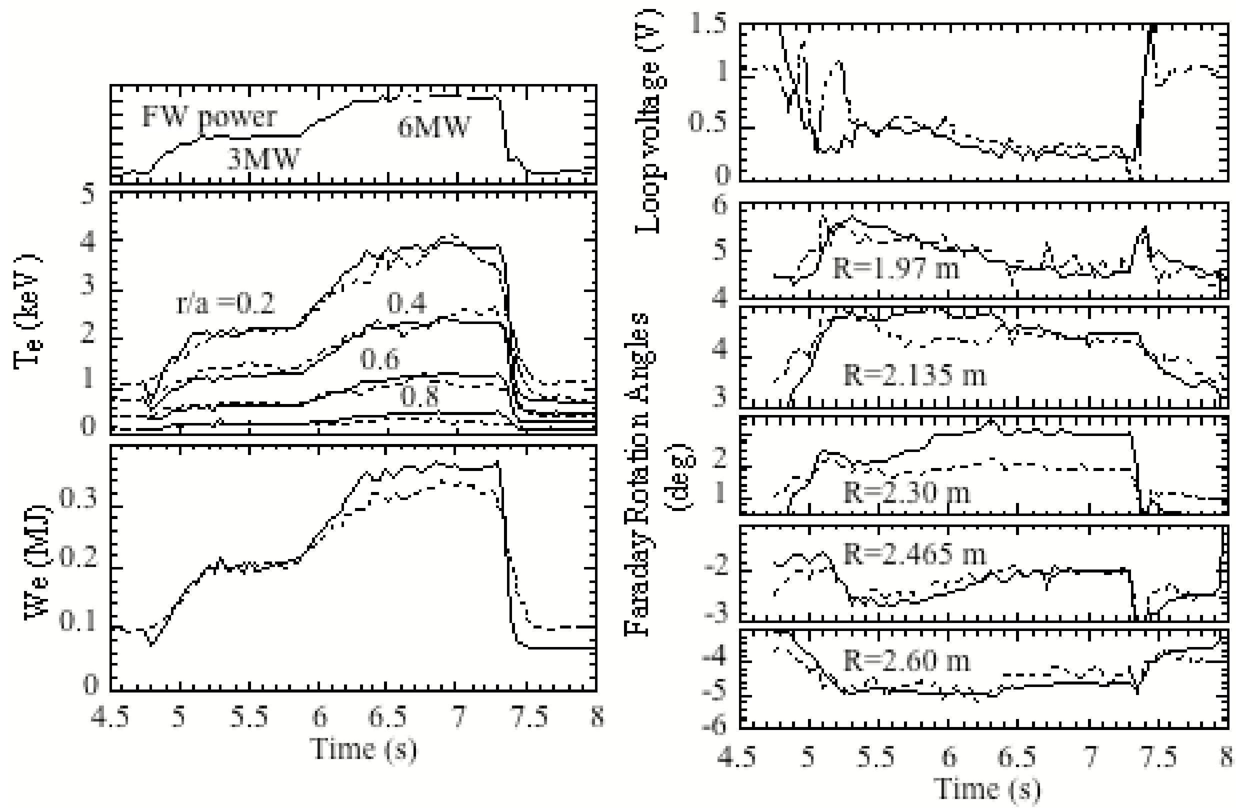
Circles: exp

Dashed: model

- Overpredicts T_e in the outerpart of plasma ($r / a \geq 0.7$)
- Thermal energy W_e over-estimated by 10%

ɔort

Predictive Simulations with ETG Model



ETG Driven Electron Thermal Fluxes: Details in Horton et a. Nucl. Fusion, p. 976, 2005 and http://orion.ph.utexas.edu/~starpower

for $\beta_e > \beta_{e,cr}$

$$q_e = C_e^{em} n_e T_e q \frac{c^2}{\omega_{pe}^2} \frac{\mathrm{v_e}}{\mathrm{R}^2} \left(\frac{R}{L_{T_e}} - \frac{R}{L_c} \right)$$

for $\beta_e < \beta_{e,cr}$

$$q_e = C_e^{es} n_e T_e q^2 \left(\frac{\rho_e^2 \mathrm{v}_e}{L_{Te}^2} \right) \left(\frac{R}{L_{Te}} - \frac{R}{L_c} \right)$$

C^{em}/C^{es}

$\beta_{e,cr}$

Given by

theory

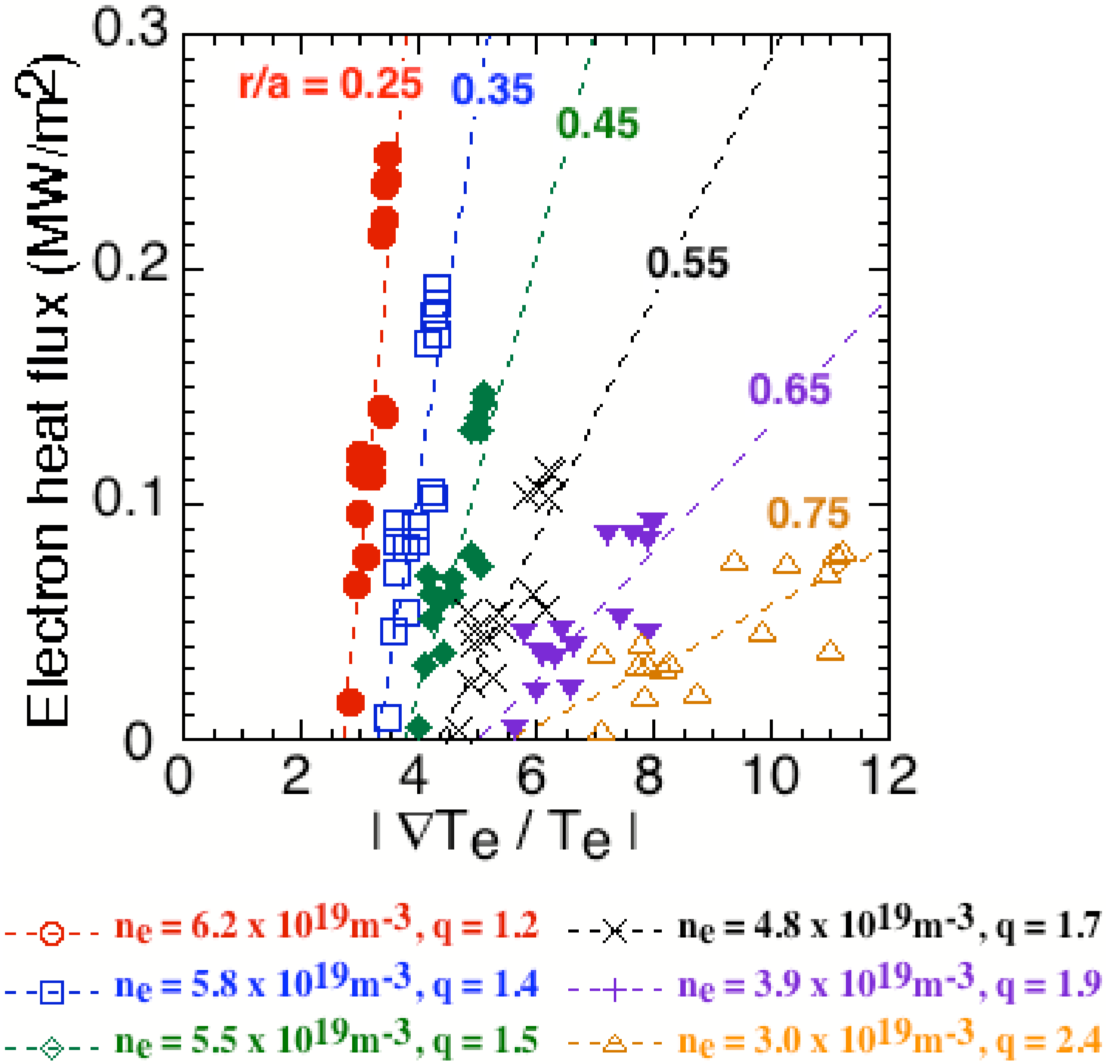
or

sims

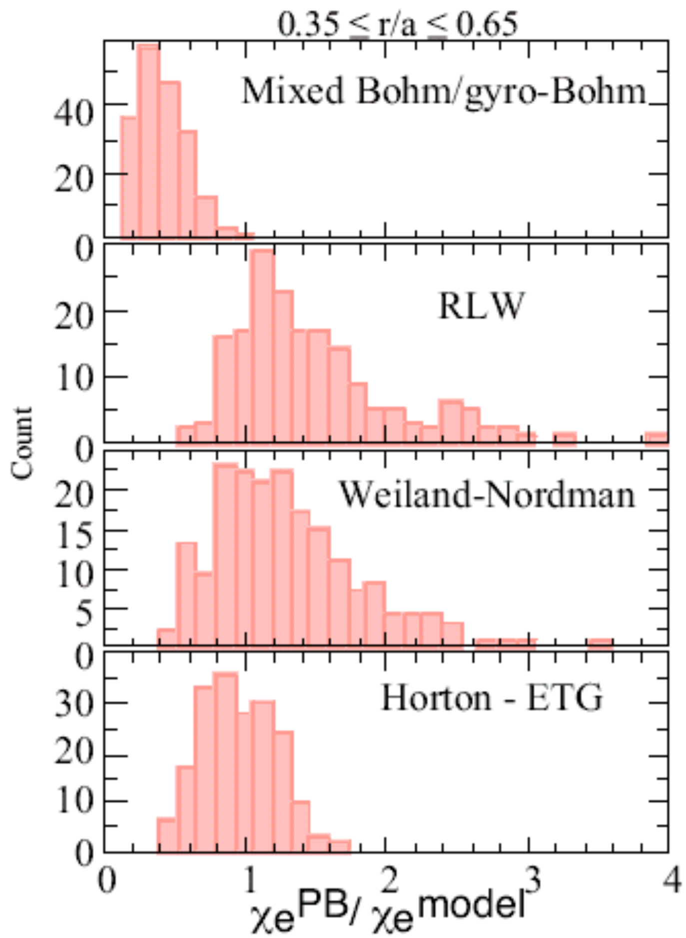
For comparison: ITG-TEM flux

$$\mathbf{q}_e = -n_e f_{tr,e} \chi^{ITG} \nabla T_i = C_e^{ITG} f_{tr,} n_e T_i \frac{c_s q^2 \rho_s^2}{L_{T_i} R} \left(\frac{R}{L_{T_i}} - \frac{R}{L_c} \right)$$

Heat Flux versus Temperature Gradient Length^{-1}



Model Comparisons



Similar results in 2008 preprint Asp, Horton, Kim, Sauter et al

for TCV plasma with 3X ECH heating

Now use ARV = variance of model from data / variance of data

ETG model explains about 70% of the data variation (ARV~0.3)

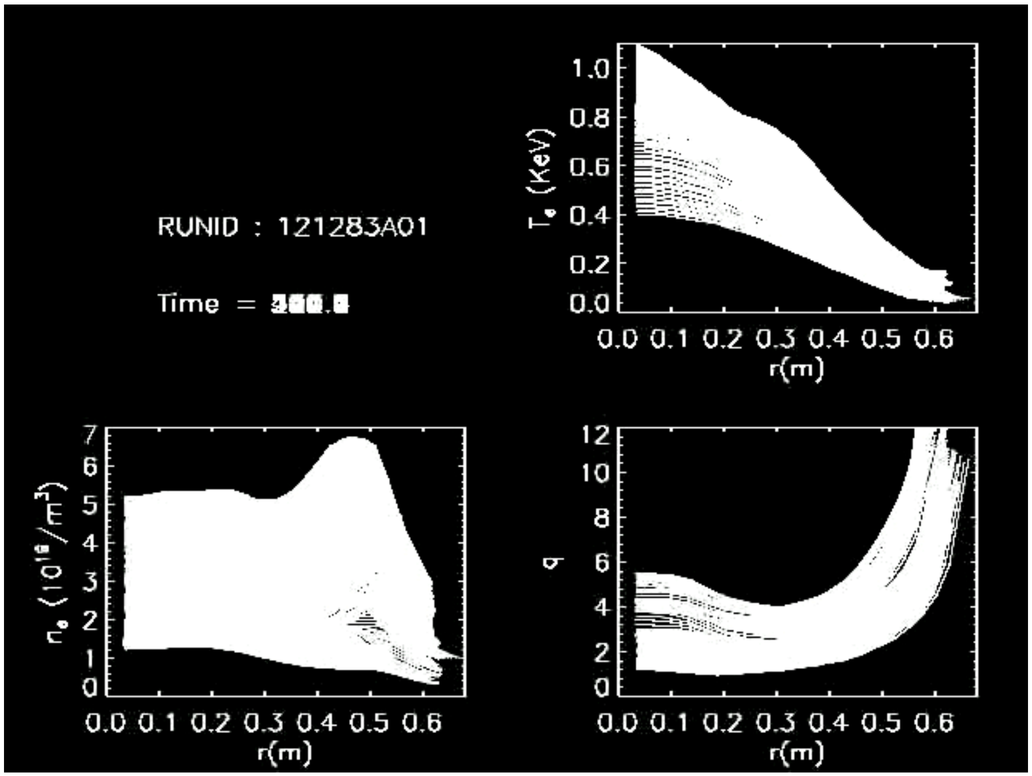
while the ARV for the ITG-TEM model has ARV ~1.3 ..worse than "persistence prediction"

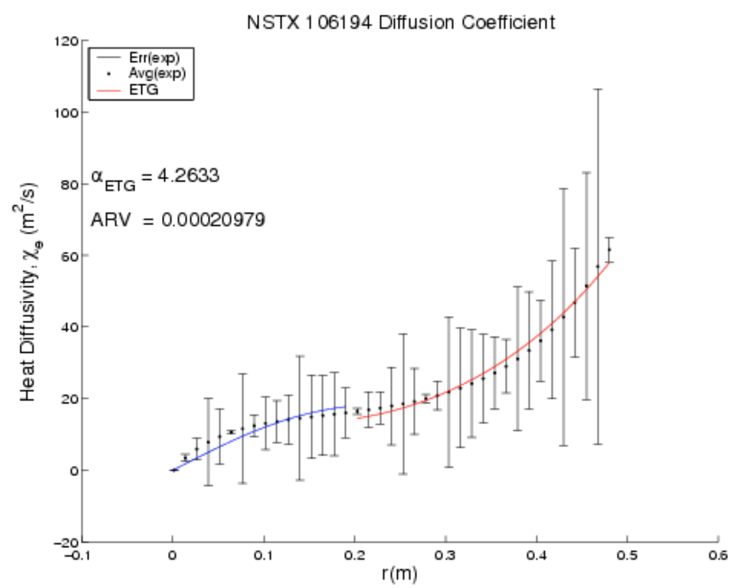
What have we learned ?

- **ETG model works well – quantitatively well.**
  Consistent with historical problem since does not depend on presence of trapped electrons.

- TCV analysis of four phases of a third-harmonic ECH driven plasma agrees with ETG predictded $q_e(r,t)$ & $T_e(r,t)$ versus poor results from ITG/TEM models.
- NSTX/HHFW and FTU show similar ETG results to TS data and agree with ETG predictions.
- ETG is [should be] the standard, baseline model of electron thermal transport for toroidal systems.

ETG flux for real-time prediction in NSTX discharge





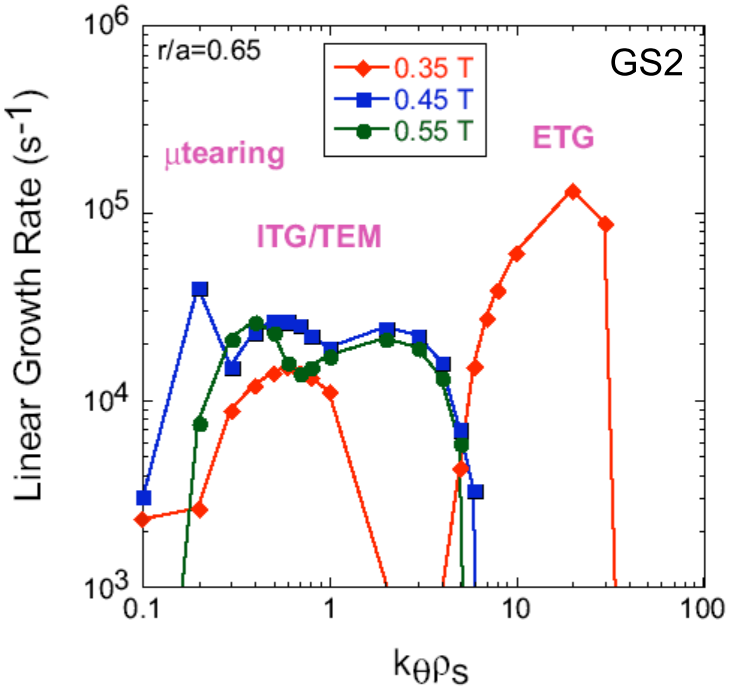
Real-Time forecasts of q_e and thus T_e my give way to predict NTMs and disruptions.

NSTX Electron Transport at Low B_T

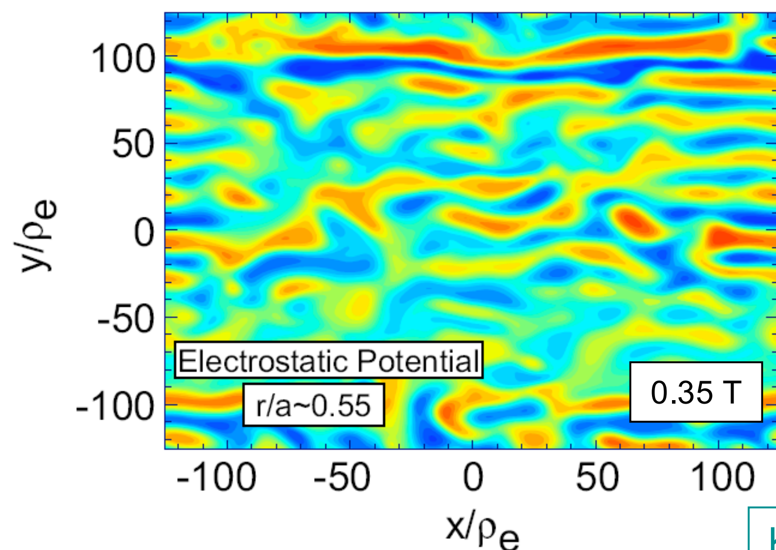
Kaye et al, Chengdu, IAEA 2006 and Nucl Fusion 2007

ETG linearly unstable only at lowest B_T

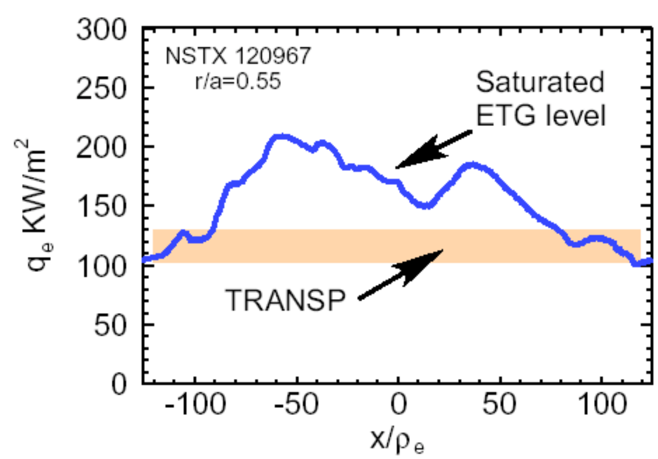
- 0.35 T: R/L_{Te} 20% above critical gradient
- 0.45, 0.55 T: R/L_{Te} 20-30% below critical gradient



Non-linear simulations indicate formation of radial streamers (up to $200\rho_e$): FLR-modified fluid code [Horton et al., PoP 2005]



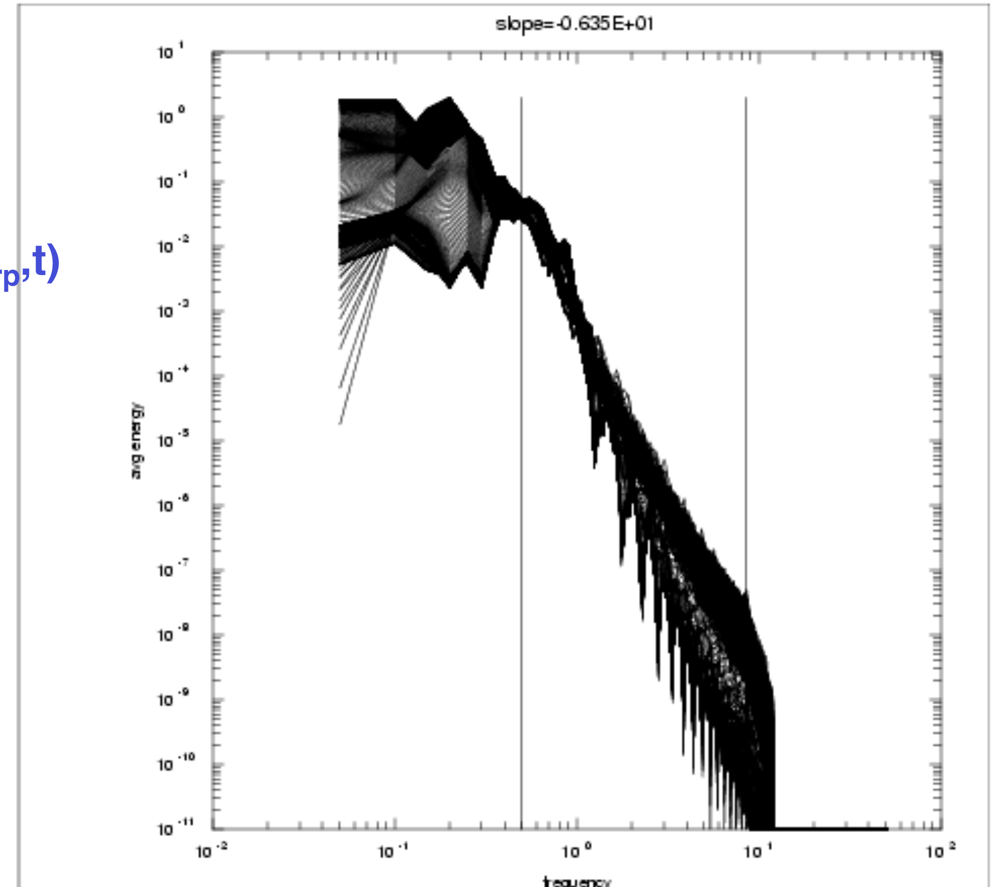
Kim, IFS



- Good agreement between experimental and theoretical saturated transport level at 0.35 T
- Experimental χ_e profile consistent with that predicted by e-m ETG theory [Horton et al., NF 2004] at 0.35 T

Inverse Cascade to Large Scale Vortices+ Scaling Turbulence

$E(k_{perp},t)$



$k_{perp}rho_e$

Diagram of Fluctuations and Mixing Length Amplitudes

Fluctuation frequency vs wavenumber

Amplitude vs wavenumber