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NSTX

Multi-Scale Transport and Turbulence Physics in NSTX

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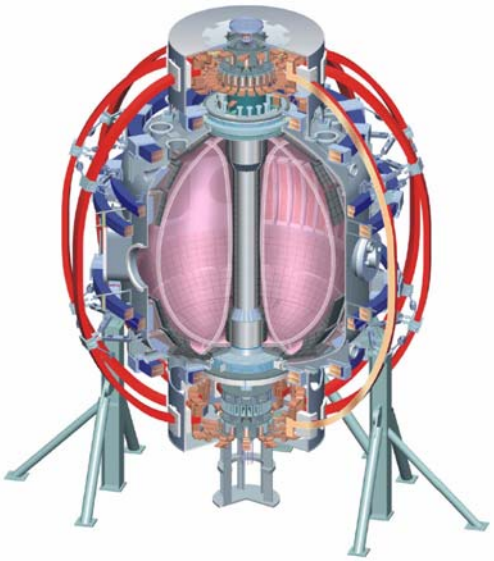
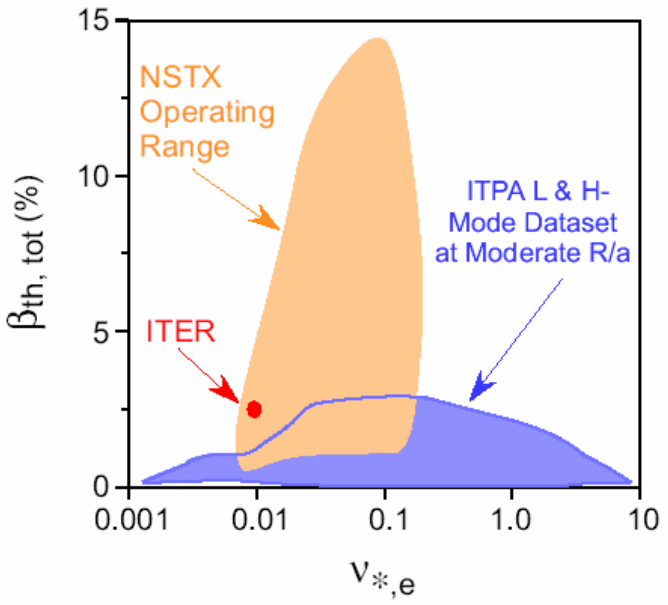
Mid Five-Year Plan Assessment
Sept 21, 2006

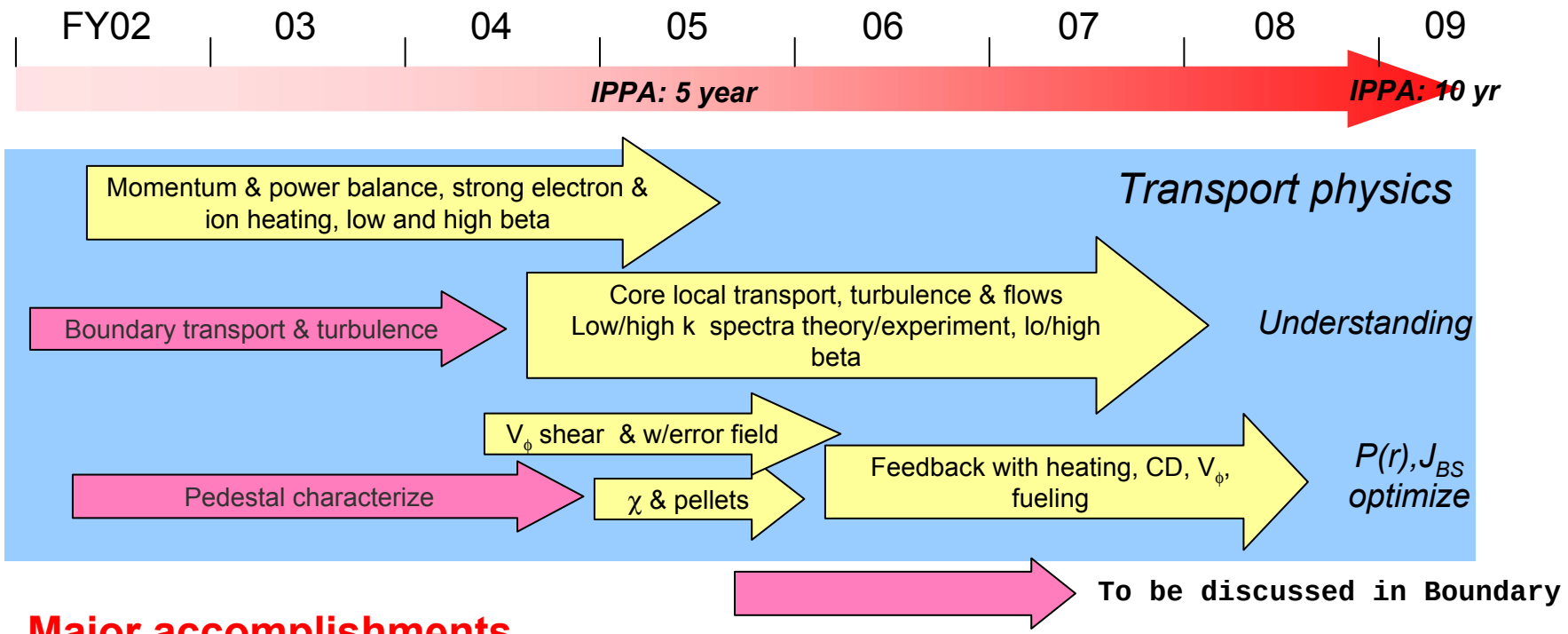


NSTX Addresses T&T Issues Critical to Both Basic Toroidal Confinement and Future Devices

- NSTX offers a unique view into plasma T&T properties
  - NSTX operates in a unique dimensionless parameter space: R/a, β_T, (ρ_*, ν_*)
  - Dominant electron heating with NBI: relevant to α-heating in ITER
  - Anomalous electron transport regimes: ions close to neoclassical
  - Large range of β_T spanning e-s to e-m turbulence regimes
  - Strong rotational shear that can influence transport
  - Localized electron-scale turbulence measurable



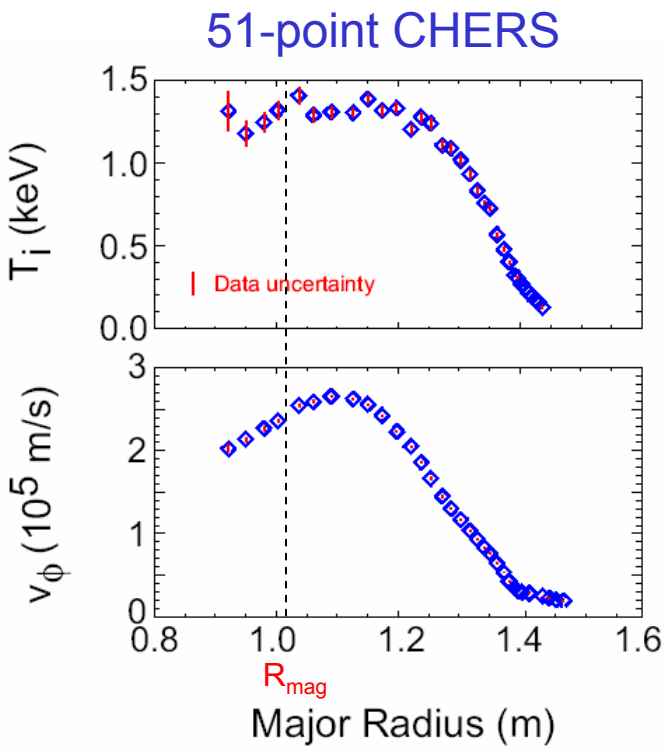
Transport and Turbulence Five-Year Plan (as of 2003)

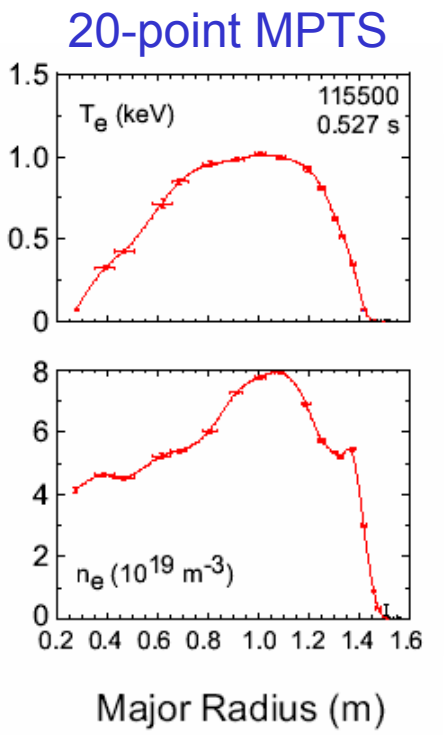


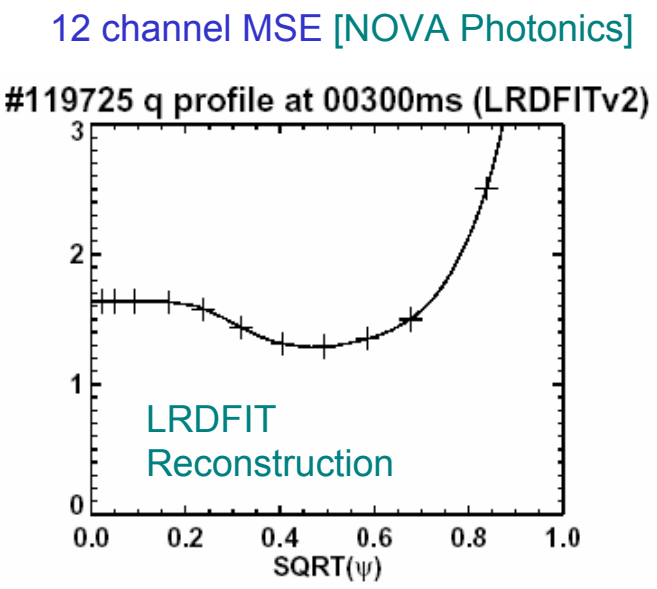
Major accomplishments

- Key confinement and transport dependences established (B_T, I_p, β, ν^*,…)
  - Data contributed to ITPA database to address high priority ITPA tasks
- Role of E_r and magnetic shear on transport identified
- Localized turbulence characteristics being assessed across wide range of k (ITG/TEM to ETG)
- Theory/simulations have indicated potential importance of ETG in controlling electron transport

World-Leading Diagnostic Capabilities Have Facilitated Rapid Progress in T&T Research







Rapid availability of profile data allows for:

- *Equilibrium reconstruction between shots (EFIT)* [Columbia Univ.]
- *Stability analysis (DCON)* [Columbia Univ., LANL]
- *Transport analysis (TRANSP) within 20 min of data availability*

Dedicated H-mode Confinement Scaling Experiments Have Revealed Some Surprises

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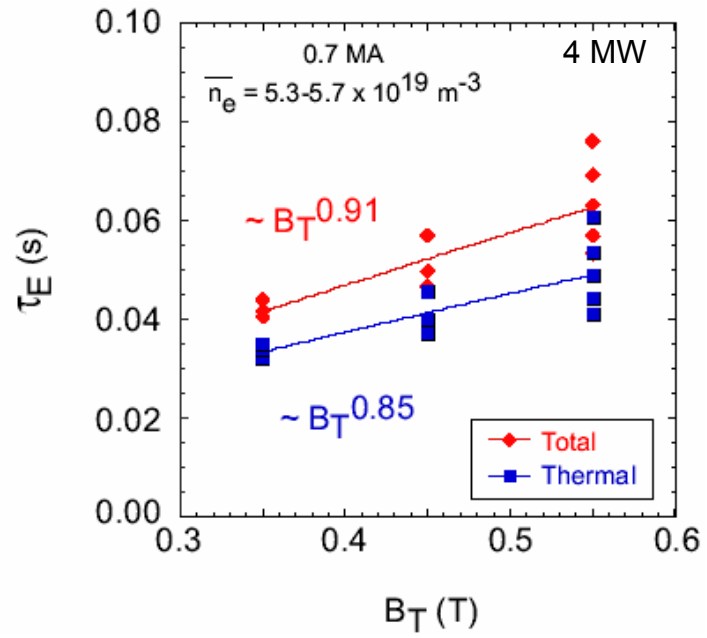
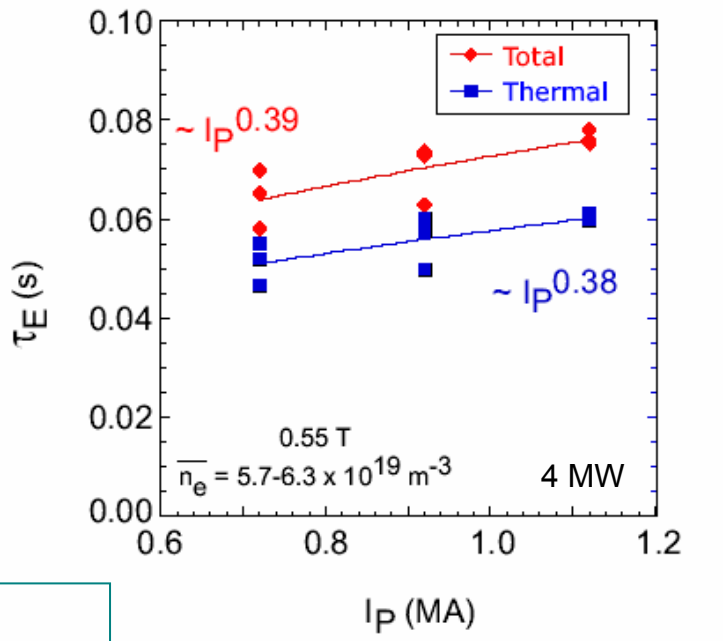
Strong dependence on B_T

$H_{98y,2}$ ~ 0.9 → 1.1 → 1.4



Weaker dependence on I_p

$H_{98y,2}$ ~ 1.4 → 1.3 → 1.1



(Kaye et al, NF **46** [2006] 848)

$\tau_{E,98y,2} \sim B_T^{0.15}$

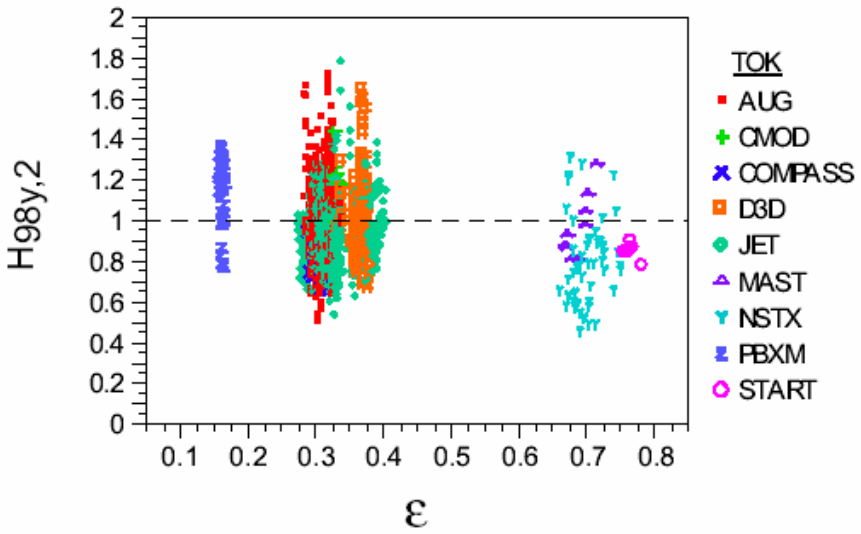
$\tau_{E,98y,2} \sim I_p^{0.93}$

$\tau_E \sim I_p^{1.3\text{-}1.5}$ at fixed q

$\tau_{E,98y,2} \sim I_p^{1.1}$ at fixed q

NSTX Data Key to Addressing High-Priority ITPA Tasks

ITER98PB(y,2) scaling does not represent low R/a data well



NSTX data used in conjunction with higher R/a data to establish ε (=a/R) scaling with more confidence

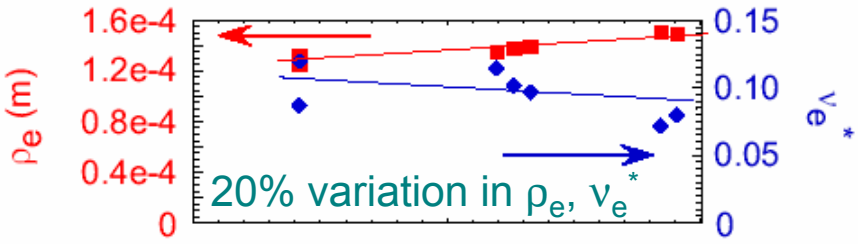
$\tau_{98y2} \sim \varepsilon^{0.58}$

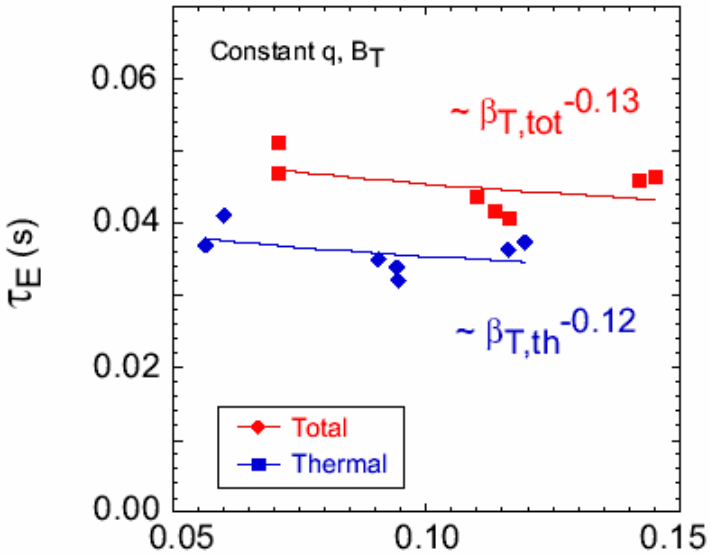
$\tau_{new} \sim \varepsilon^{1.03}$

(Kaye et al., PPCF **48** [2006] A429)

β-scan at fixed ρ_e, ν_e^*

- β-dependence important to ITER advanced scenarios ($B\tau_{98y2} \sim \beta^{-0.9}$)
- Degradation of τ_E with β weak on NSTX



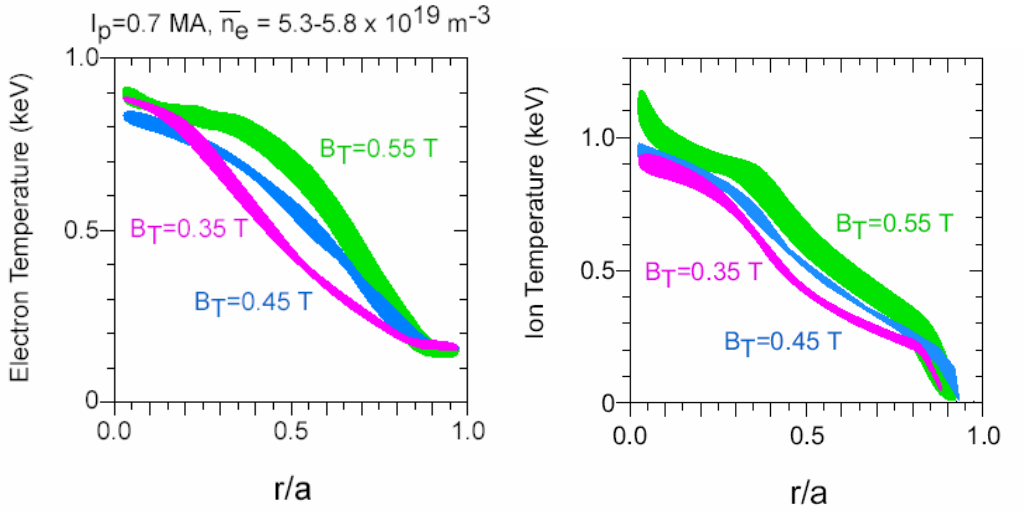


2-2.5 variation in β_T

Local Transport Studies Reveal Sources of Confinement Trends

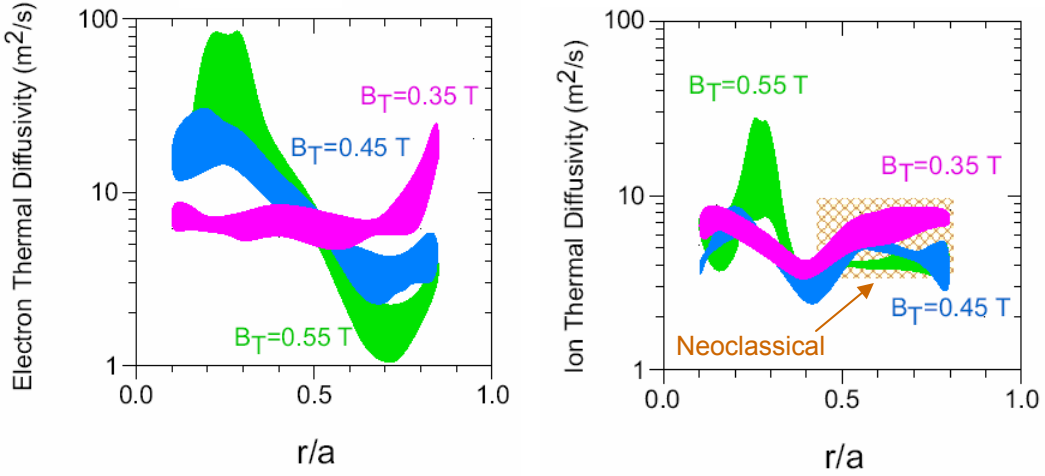
NSTX

Broadening of T_e & reduction in χ_e outside r/a=0.5 with increasing B_T

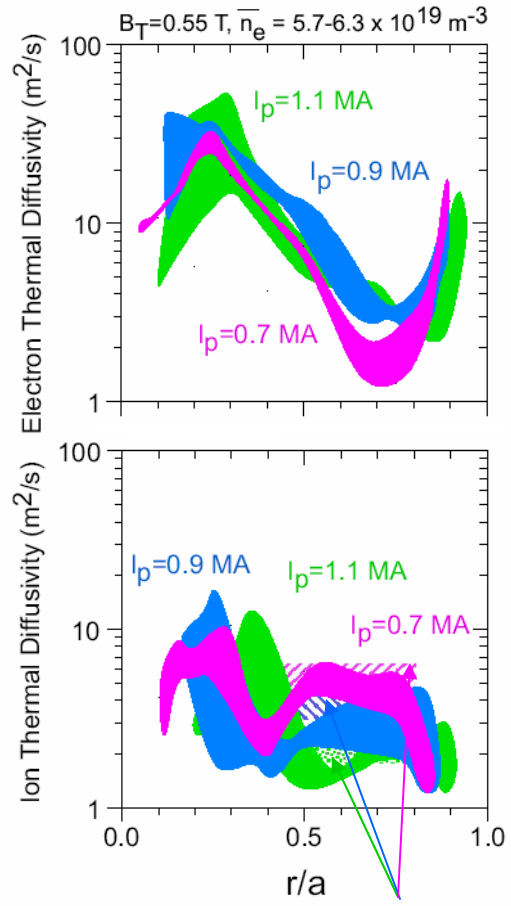


Electrons anomalous

Ions near neoclassical



Reduction in ion transport primarily responsible for I_p scaling (consistent with neoclassical transport)

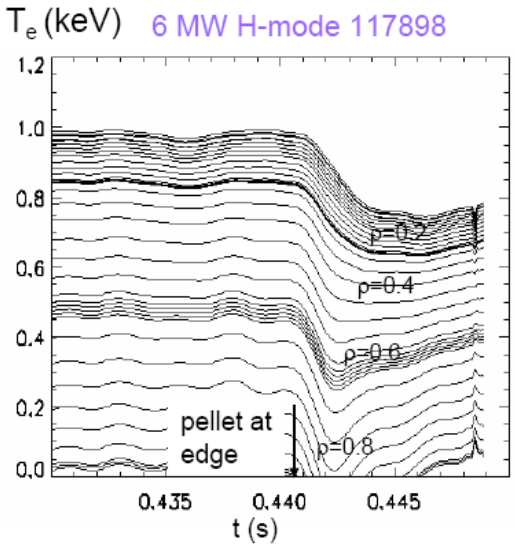


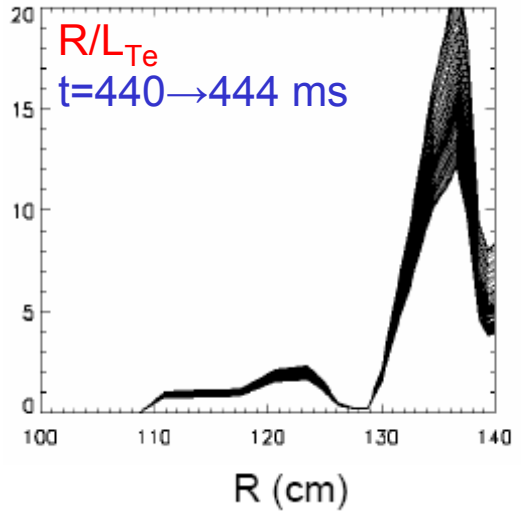
Neoclassical levels determined from GTC-Neo: includes finite banana width effects (non-local)

Pellet Perturbations Are Being Used to Probe Local Transport Properties and Critical Gradient Physics

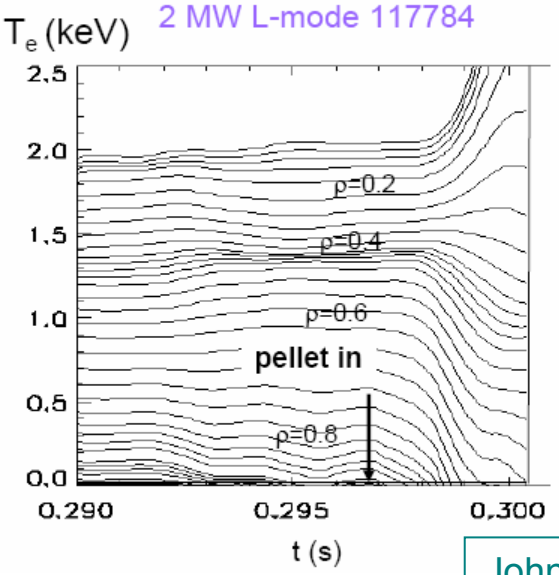
Soft X-ray array diagnoses fast T_e changes in response to Li pellet injection

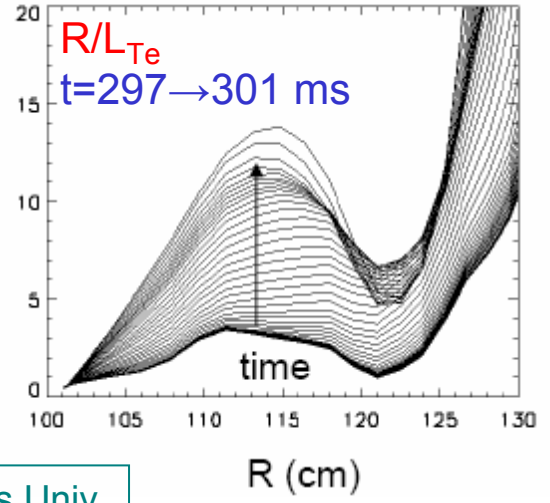
H-mode with monotonic q-profile exhibits stiff profile behavior
→ T_e close to marginal stability





T_e in *reversed magnetic shear L-mode* responds to pellet perturbation over several ms



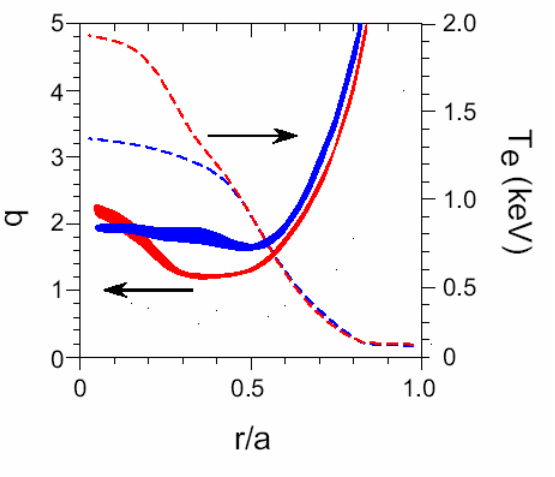


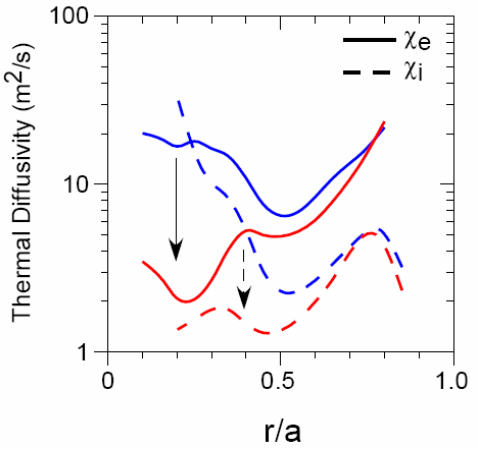
Stutman et al., accepted in Phys. Plasmas (Oct. 2006)

Johns Hopkins Univ.

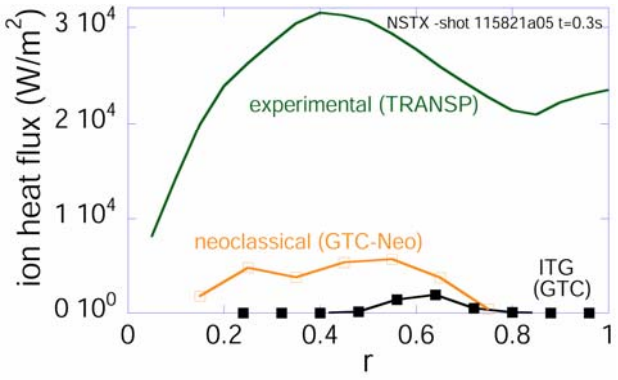
Increased Magnetic and E_r Shear Are Associated with Reduced Transport

Weak vs Reverse-Shear L-mode





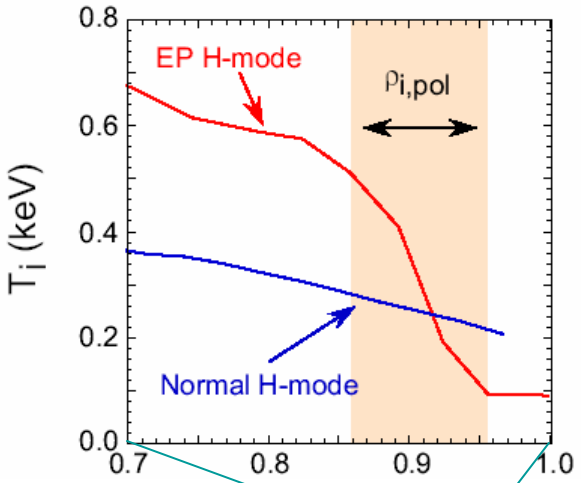
Global non-linear GTC simulations show that the ITG mode drives little transport in these L-modes

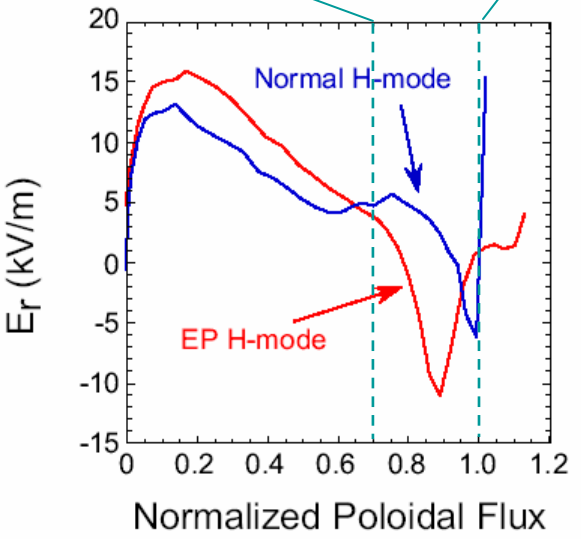


v_θ term not included in E_r

Poloidal CHERS (2007) will measure v_θ, giving total E_r

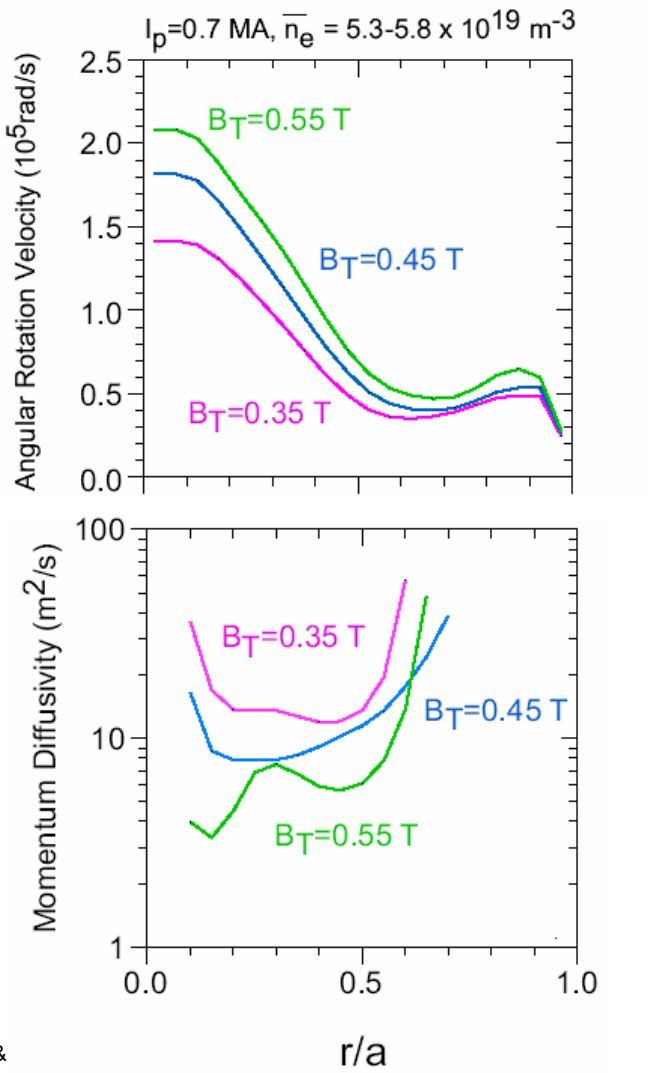
Enhanced Pedestal H-mode

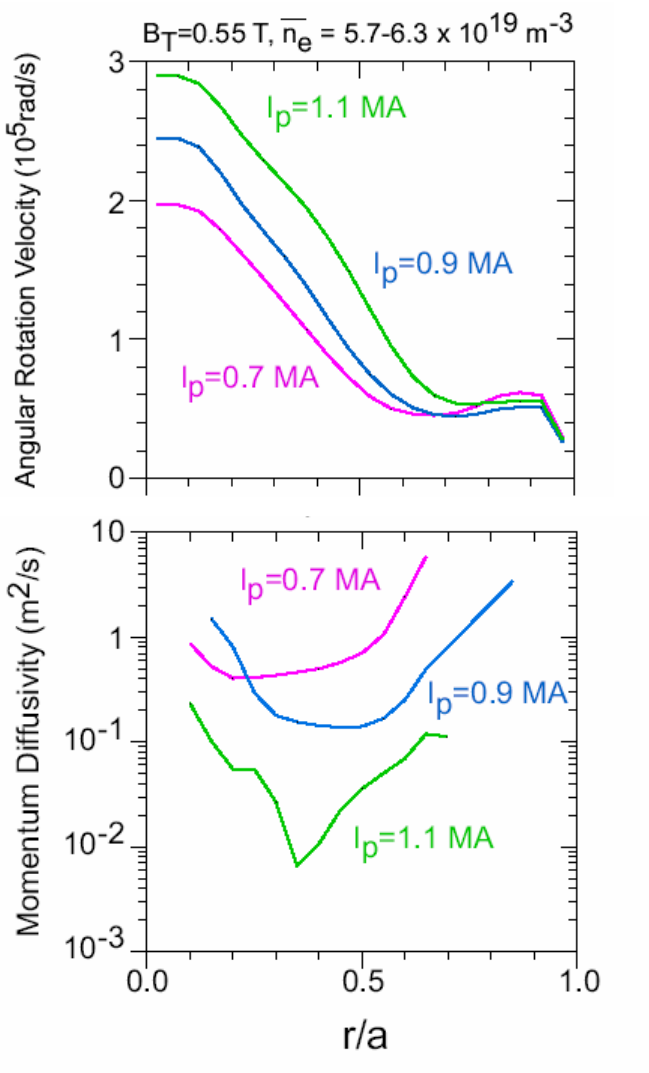




Core Momentum Diffusivities Track Neither Electron Nor Ion Thermal Diffusivities Exclusively

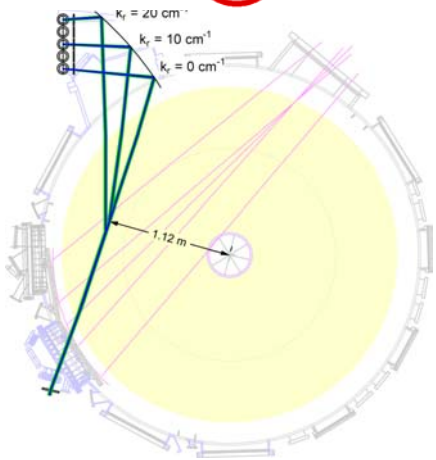
χ_ϕ decreases as B_T and/or I_p increase





Tangential Scattering Diagnostic Measures Localized Electron-Scale Turbulence

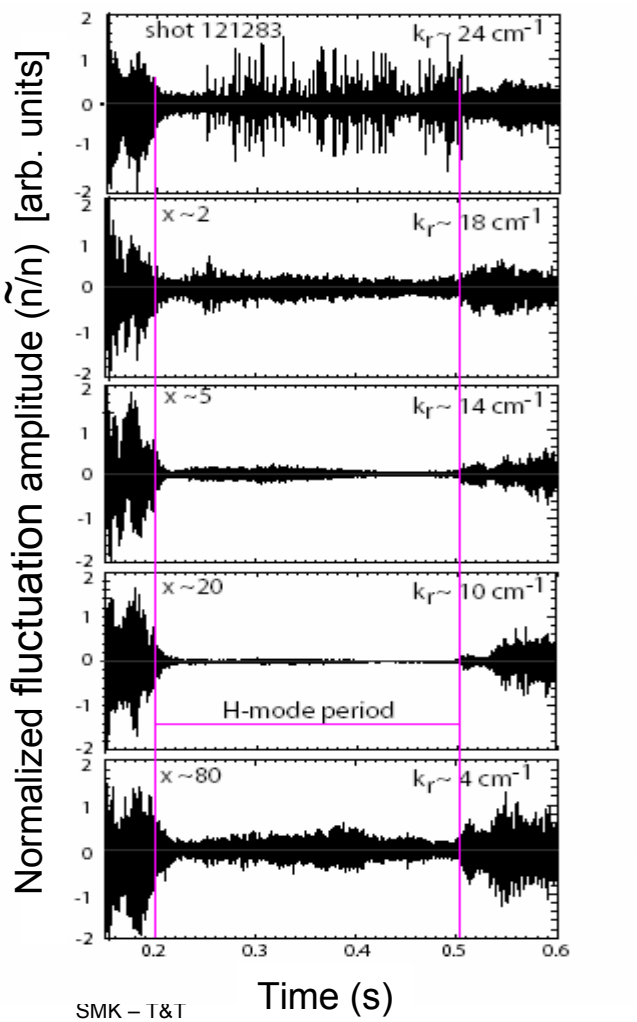
- Wave fluctuation ⊥ B
  - k_r since probe beam, detectors on mid-plane
- Measurements will range from k_r=2 (ITG/TEM) to ~24 cm^{-1} (ETG)
  - ρ_e ~ .01 cm
- Large spatial scales due to low B_T
- Large mode amplitudes expected; $\delta n/n \sim 10^{-3}$
  - Detection limit due to noise; 2×10^{-5}
- Large port access/tangential view
  - Radial resolution for k_r>4 cm^{-1}; 6 cm
  - Excellent k-resolution; Δk~1 cm^{-1}
  - Can vary location of scattering volume (near magnetic axis to near edge)



Fluctuations	
Correlation Reflectometry	Fixed (3), Swept, k_r up to 5 cm^{-1} k_θ up to 0.5 cm^{-1} (MHD to ion scale)
USXR	3 arrays, 600 kHz sampling for fast $T_e(r)$
1 mm Polarimetry	Upgrade of interferometer Low-k density, B fluctuations
Tangential Scattering	mm-wave, 280 GHz, k_r~2-20 cm^{-1} (ion to electron-scale), localized measurement
Microwave Back-Scattering	High-k_θ turbulence
Doppler Reflectometry	Localized poloidal velocity, zonal flows (low-k)

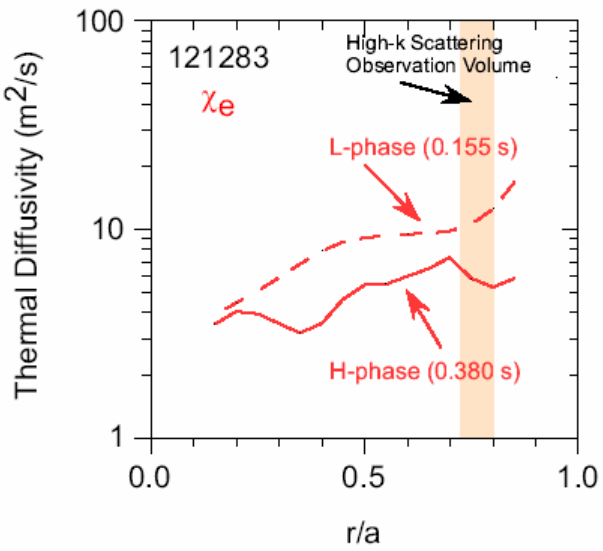
Turbulence Measurements and Gyrokinetic Calculations Have Helped Identify Possible Sources of Transport

Tangential scattering system measures reduced fluctuations ($\tilde{n}/n$) in both ITG/TEM and ETG ranges during H-mode

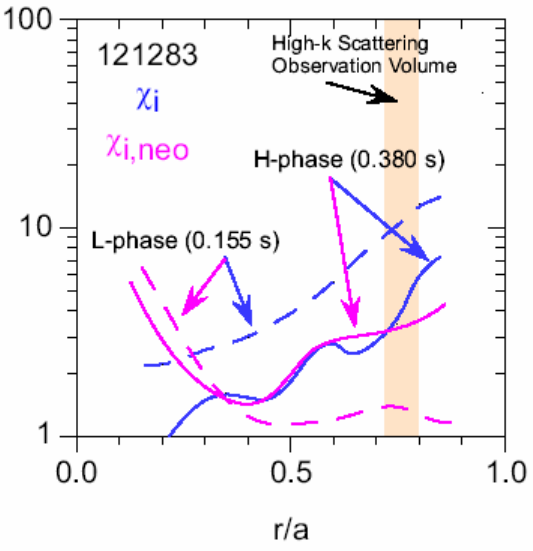


Ion and electron transport change going from L- to H-modes

Electron transport reduced, but remains anomalous

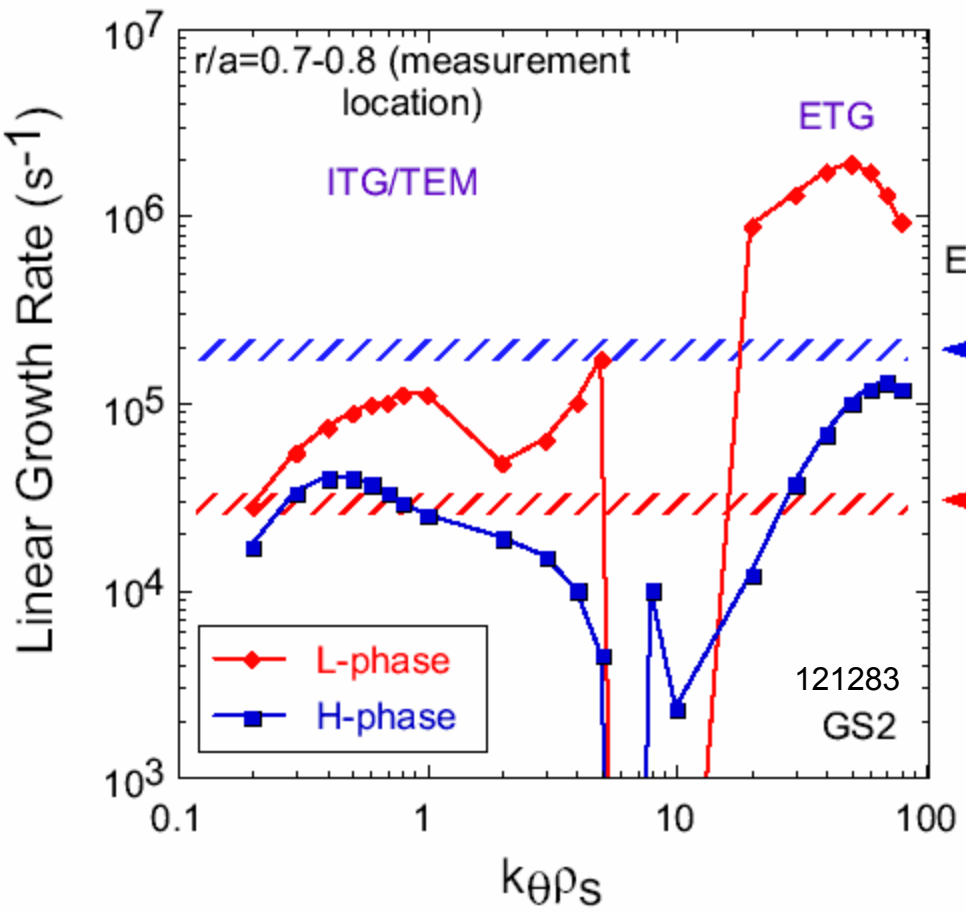


Ion transport during H-phase at neoclassical level



Theory/Gyrokinetic Calculations Indicate Both ITG/TEM and ETG are Possible Candidates for Electron Transport

GS2 calculations indicate lower linear growth rates at all wavenumbers during H-phase: *ETG unstable*



$\gamma_{lin} >> \gamma_{ExB}$ during L-phase for all $k_\theta\rho_s$

$\gamma_{lin} << \gamma_{ExB}$ during H-phase for ITG/TEM

$\gamma_{lin} \sim \gamma_{ExB}$ during H-phase for ETG

ExB Shearing Rate (s-1)

H-phase

L-phase

Non-linear GTC results indicate ITG modes stable during H-phase

Experimental χ_e profile consistent with that predicted by e-s ETG theory (Horton et al, Phys. Plasmas [2006])

Theory/Gyrokinetic Calculations Suggest ETG May Also Play an Important Role in Determining Electron Transport at Low B_T

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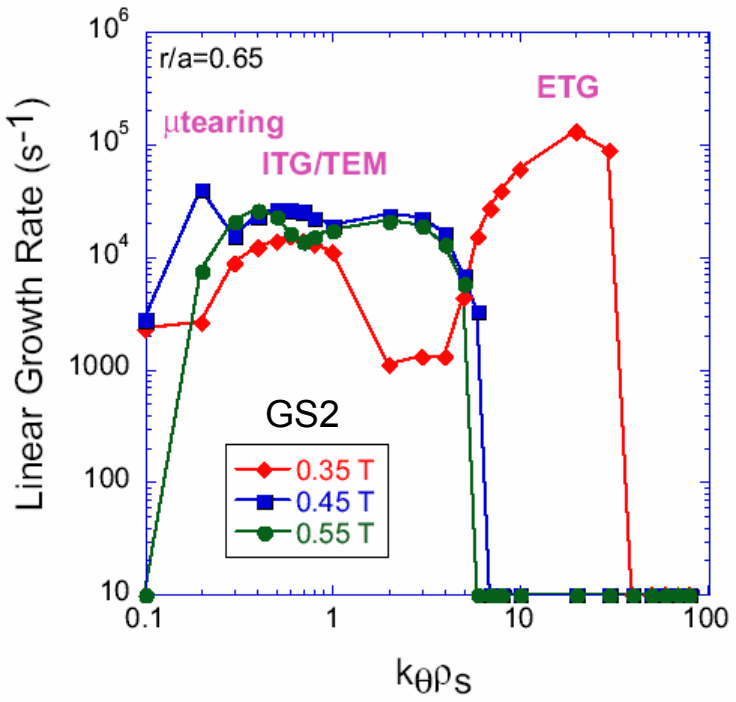
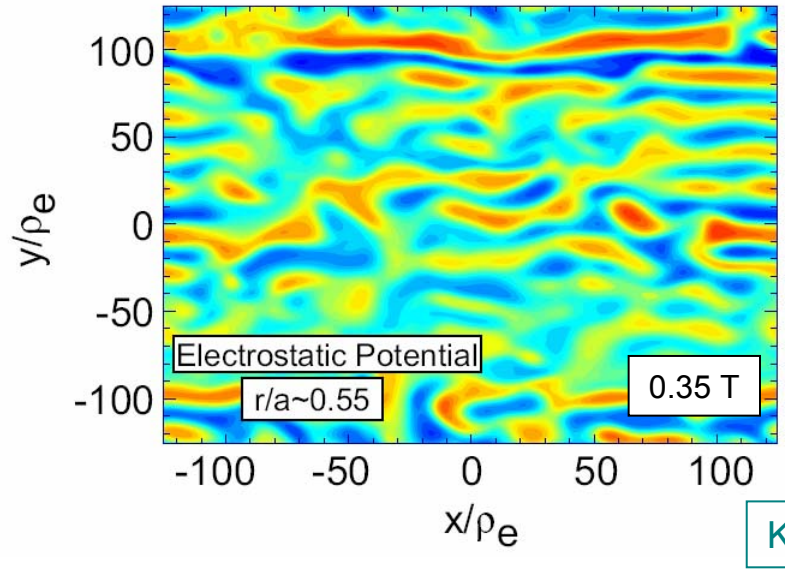
ETG linearly unstable only at lowest B_T

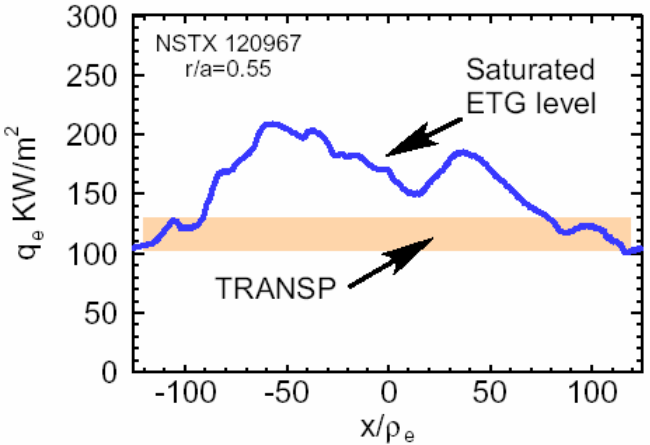


Non-linear simulations indicate formation of radial streamers (up to $200\rho_e$): FLR-modified fluid code



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 at 0.35 T
  - Not at higher B_T



Summary and *Plans*

- Confinement and transport dependences
  - Confinement and transport trends found to differ from those at higher R/a
  - Dimensionless scans show no degradation of $B\tau_E$ with β_T
  - Data provided to ITPA H-mode database for R/a and β_T scalings
  - Perturbative pellet experiments investigating critical gradient physics show stark differences between L- and H-modes possibly related to the q-profile
  - Understand the source of the difference in confinement trends at different R/a
    - Submit additional data to ITPA database (2006-2007)
  - Develop understanding of role of q(r), microinstability driving terms [T_i/T_e, η_e, η_i,..] (2007-2008)
  - Complete similarity experiments with DIII-D, MAST to address the role of toroidicity on confinement through the R/a dependence (2007-2008)
- Role of rotation, E_r
  - Momentum transport decoupled from that of ions and electrons
  - Increased E_r shear associated with reduced transport
  - Establish momentum flux dependences and controlling physics (2007-2008)
  - Understand causal relation between E_r shear and reduced transport (2007-2008)
    - Magnetic braking with EF/RWM coils, poloidal/toroidal CHERS
  - Use flow shear to control transport (2007-2008)
  - Study zonal flows (2008-2009)

Summary and Plans (cont'd)

- Role of low- and high-k turbulence
  - Localized turbulence levels decrease going from L- to H-mode across k_r range from 2 to 24 cm^{-1} (ITG/TEM to ETG) – associated with reduction in transport
  - Relate changes in turbulence to changes in transport over range of operating conditions (2007-2008)
  - Integrate measurements from different turbulence diagnostics for comprehensive picture across full wavenumber spectrum (2007-2009)
- Theoretical basis for transport and heating
  - Analytic theory and gyrokinetic calculations (linear and non-linear) have indicated the potential importance of ETG modes in governing electron transport
  - Test role of ITG, ETG, … by varying driving & stabilization terms (2007-2009)
    - Relate measurements of thermal diffusivities, critical gradients to theoretical values to identify controlling microinstabilities (2007-2009)
  - Continue experiment/gyrokinetic theory comparisons over a range of transport regimes: linear and non-linear calculations (2007-2009)
    - Relate calculated turbulence fluxes to measured values (2007-2009)
  - Develop predictive capability (2008-2009)