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NSTX

Gyrokinetic simulations of NSTX L-mode plasmas

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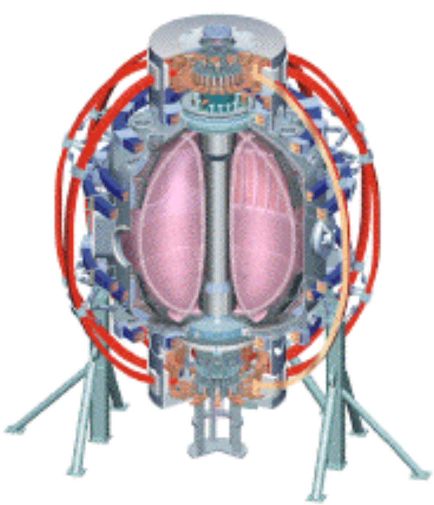

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Historical Background

Kotschenreuther and Rewoldt – using model profiles –found the linear ExB quench rule is more easily satisfied for low-k modes in STs. Bourdelle – using experimental profiles – found that $\omega_{ExB} > \gamma_{linear}$ is indeed common for low-k modes in NSTX plasmas.

But application of linear ExB "quench rule" is of questionable validity:
"*We cannot be confident of these modifications and limitations on the quenching condition for general profiles at finite ρ* without nonlinear simulations. These cannot be done with the fast flux tube codes and require three dimensional (3-D) full radius codes* ..."
Waltz, et al., Phys. Plasmas 5 (1998) 1784.

We use the GYRO code (*a 'full radius' code*) to simulate low-k turbulence in NSTX. The major highlights are:
- Kinetic electron effects are very destabilizing.
- ExB shearing is very important, but low-k transport can be large.

Important Issues for NSTX Simulations

Low k_θ modes require 'full radius' simulation to include profile effects.
Parameters vary significantly in a radial domain of only 50 ρ_i .

Kinetic electron effects enhance ITG mode turbulence,
so a non-adiabatic electron model is needed.
Need to model electron collisions, which are stabilizing.
TEM effects are significant in most tokamak plasmas,
but they are more important than usual in these simulations.

It is necessary to include the background ExB sheared flow,
because it strongly limits turbulent transport.

NSTX is highly shaped, with very low aspect ratio.
Need realistic geometry, not the high-aspect ratio s-α model.

β~10% well below ballooning limit, begin with electrostatic simulations.
Electromagnetic effects likely important in higher β NSTX plasmas.

Preparation of experimental data

TRANSP uses LRDFIT equilibria to map profile data from R to r/a .
LRDFIT uses MSE data to constrain the q profile.
Use "outer side only" mapping of density and temperature.
this guarantees that n_e, T_i, T_e at the same R map to the same r/a.

Simulations of older shots (2004) use TRANSP's equilibrium; no MSE data is available.

Estimate of background E_r is based on measured v_{tor} and NCLASS calculation of v_{pol} used for E_r shown here. (V_{pol} measurements in '07)

GTC-neo includes finite orbit effects to estimate neoclassical E_r, but it does not include impurities yet (W. Wang and G. Rewoldt).
These E_r estimates will be used also in future.

Characteritics of GYRO Simulations of NSTX

1) "Pure" ITG simulations (adiabatic electron response) with no ExB shear have transport fluxes near the actual power levels. However,

2) A kinetic electron treatment greatly increases the long-wavelength transport by more than an order of magnitude. This is not ETG activity, it is only TEM boosting the ITG - a well established synergy.

3) Including ExB shear derived from the measured v_{tor} can completely quench the turbulence driven with kinetic electrons in some plasmas. In other cases the strongly quenched transport fluxes are quite significant: comparable to the actual heating power.

4) Predicted ion heat flux is higher than the electron heat flux, but
the experimental analysis reverses that ordering.
Including higher $k_\theta \rho_s$ modes could raise Q_e/Q_i;
significant increases would apparently require modes with $k_\theta \rho_s > 2$.

New results show complete ExB quenching

New L-modes with MSE-derived monotonic and reversed q profiles.
New discharges are similar to previously simulated plasmas, but some systematic differences are noted on the following pages.

Simulations of the new discharges show complete quenching of $k_\theta \rho_i < 1$ turbulence by the ExB shear – previously saw finite residual transport.

Modest variations in ExB shearing rate and temperature gradients do not produce significant transport: not close to stability boundary.

In some cases TRANSP $\chi_i \sim \chi_i^{neo}$, but $\chi_i >> \chi_i^{neo}$ in others.

Apparent conclusion is that residual electron transport is caused by shorter scale turbulence with $k_\theta \rho_s > 1$.

Search for new/old diffferences

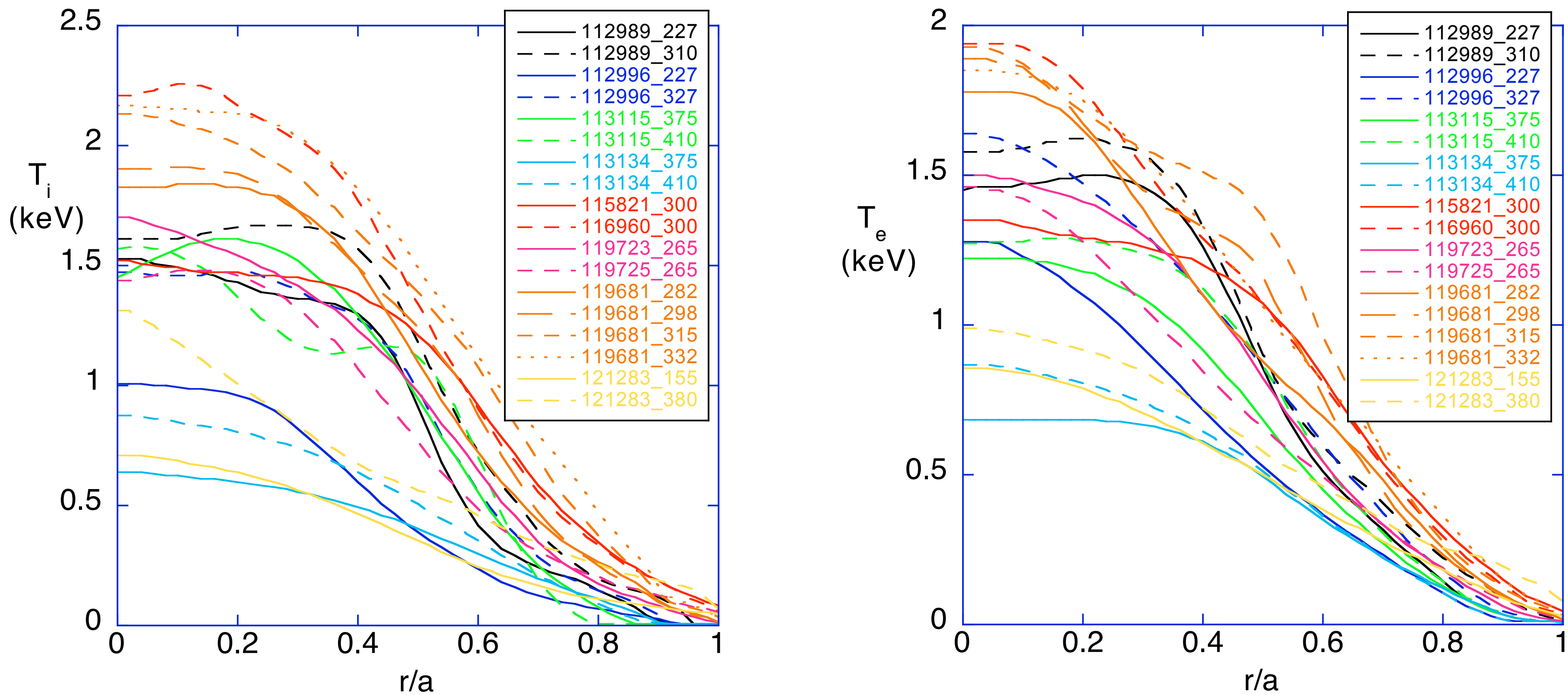
Many parameters seem to be systematically different;

- most significant are: R/L_{Ti}, q, magnetic shear
- no single difference seems dominant

Significant overlap (of the new and old ranges) occurs even for the parameters that changed the most.

- Nevertheless, there are some systematic differences.

Recent temperatures are generally higher

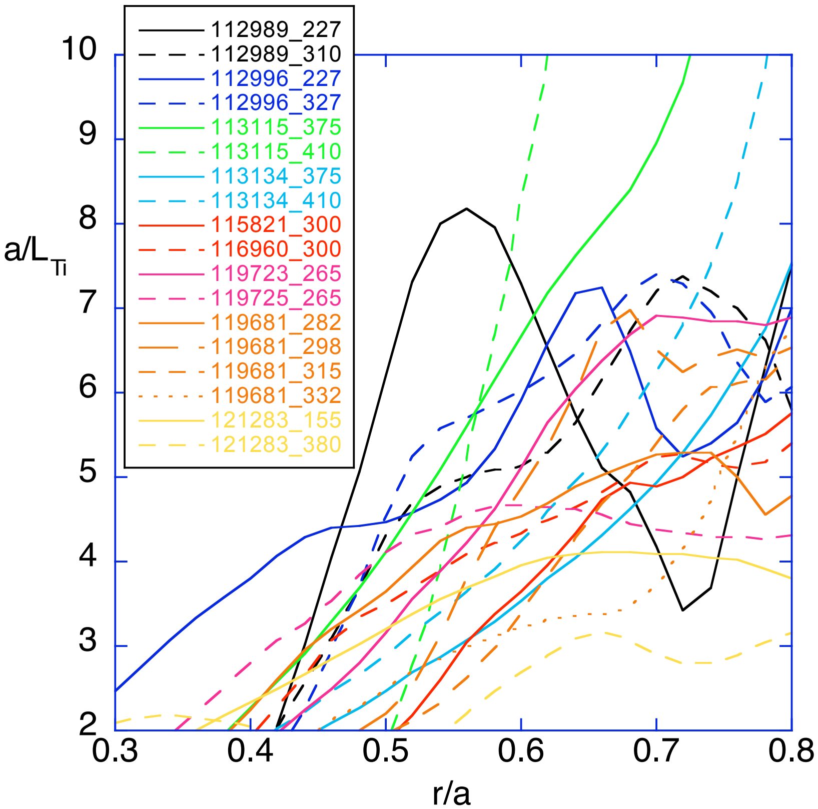


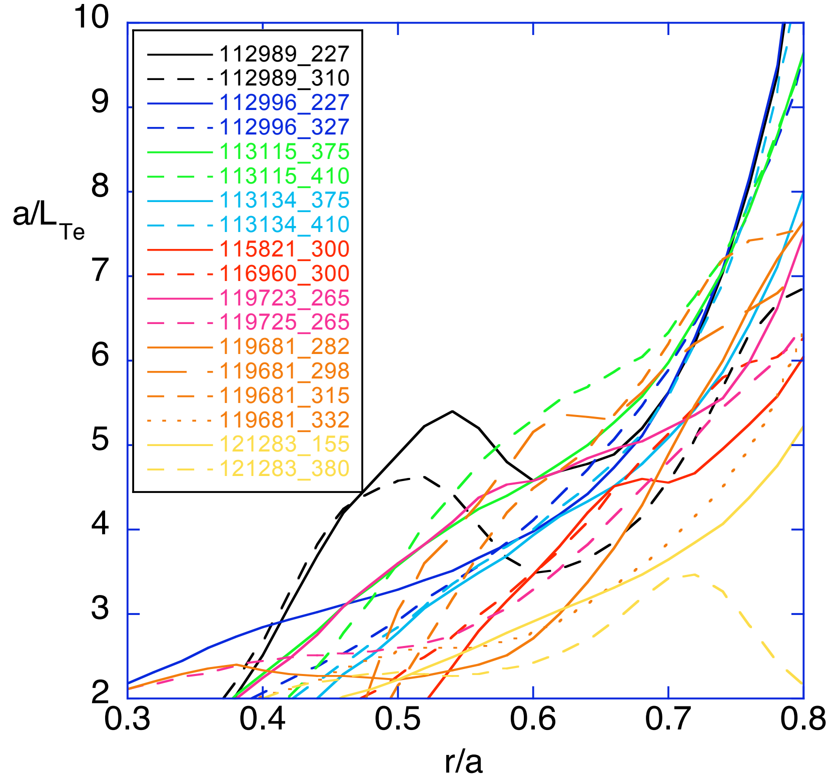
Older plasmas are black/blue/green;
newer are red/orange/gold.

Ion temperature rose more than electron temperature?

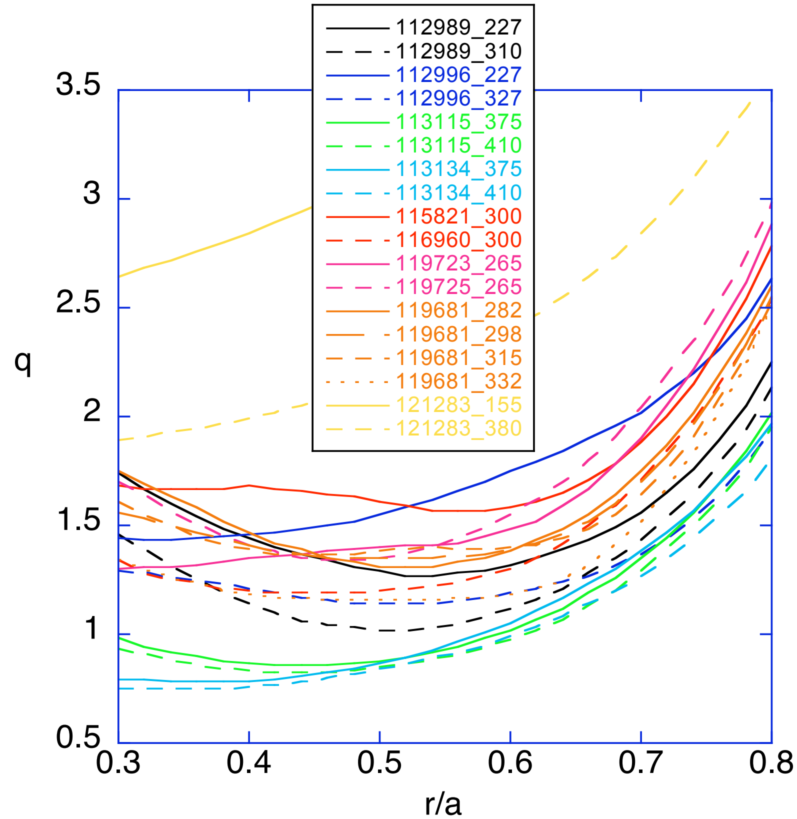
Higher Ti/Te is stabilizing for ITG/TEM modes.

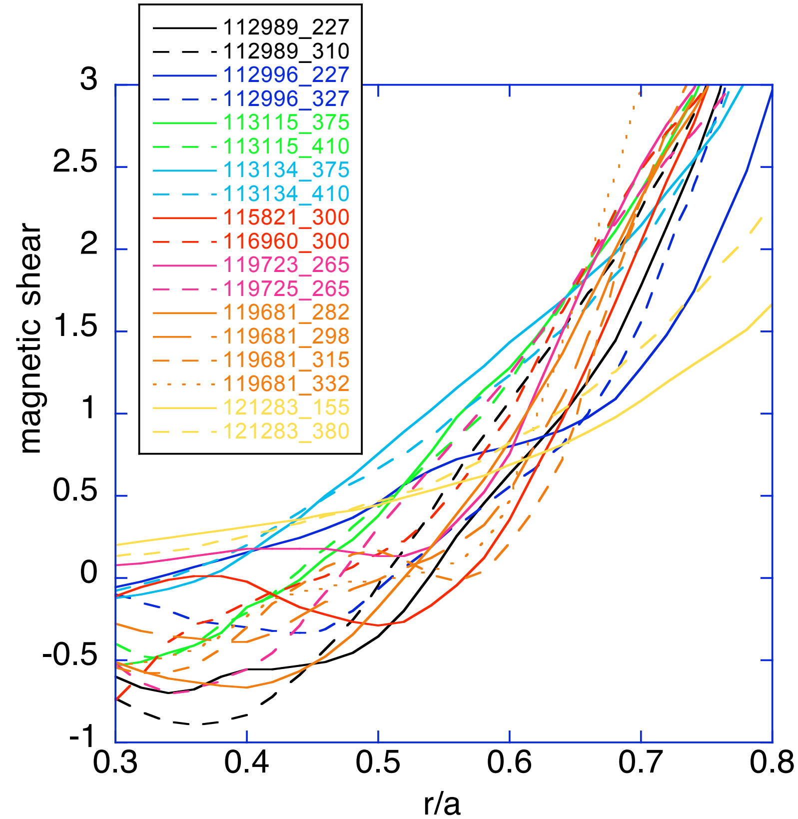
Temperature gradients went down



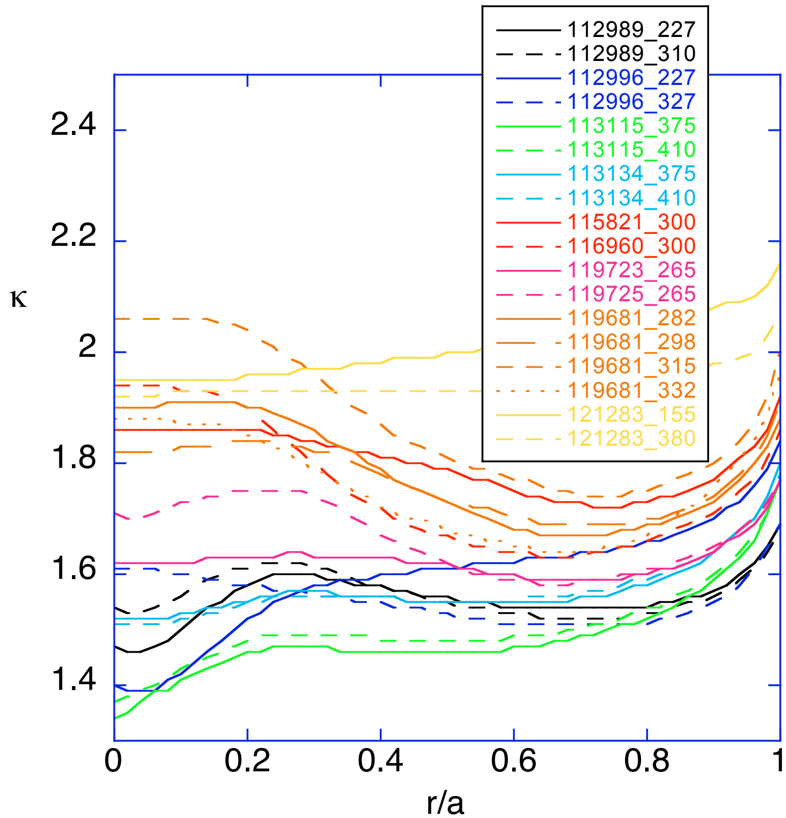


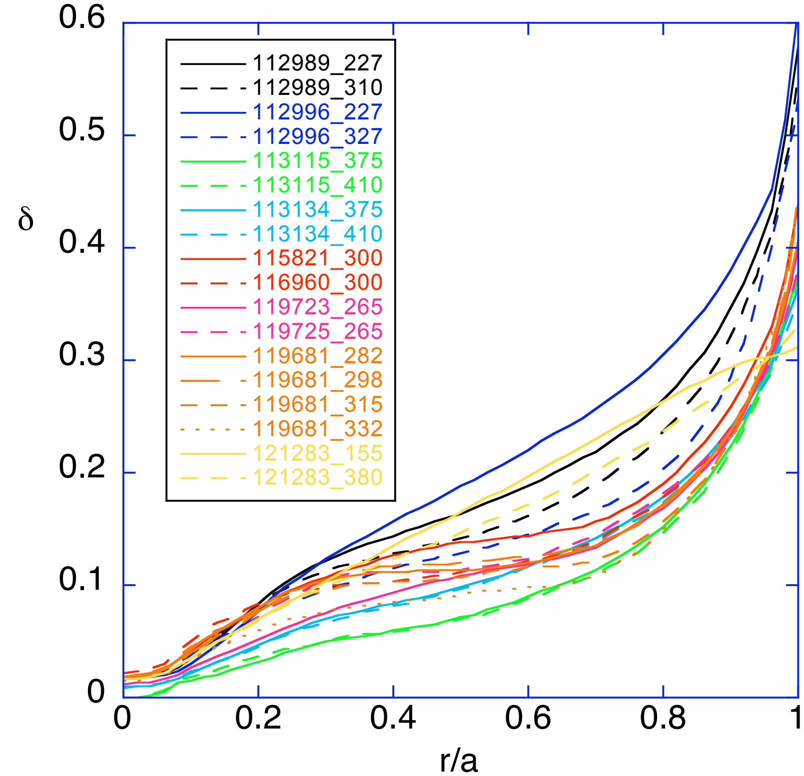
q rose and magnetic shear dropped



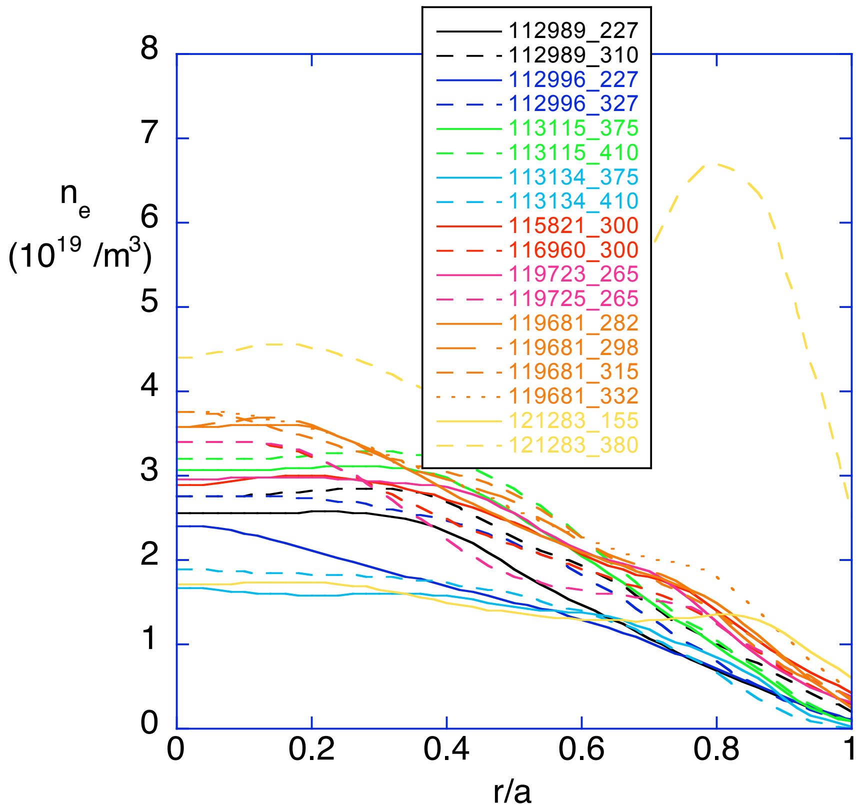


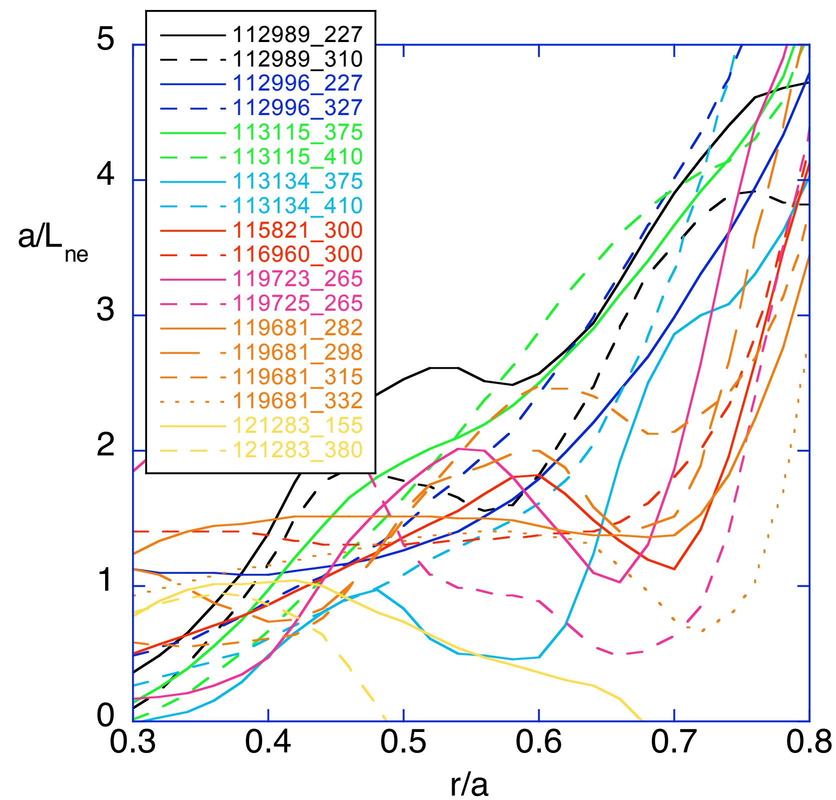
Elongation rose; triangularity similar





Density higher, but gradients lower





Adaptive Source Needs Shorter Averaging Time

The 'adaptive source' model fails to preserve the T_i gradient when the default averaging time is used in high-transport large-ρ* simulations.

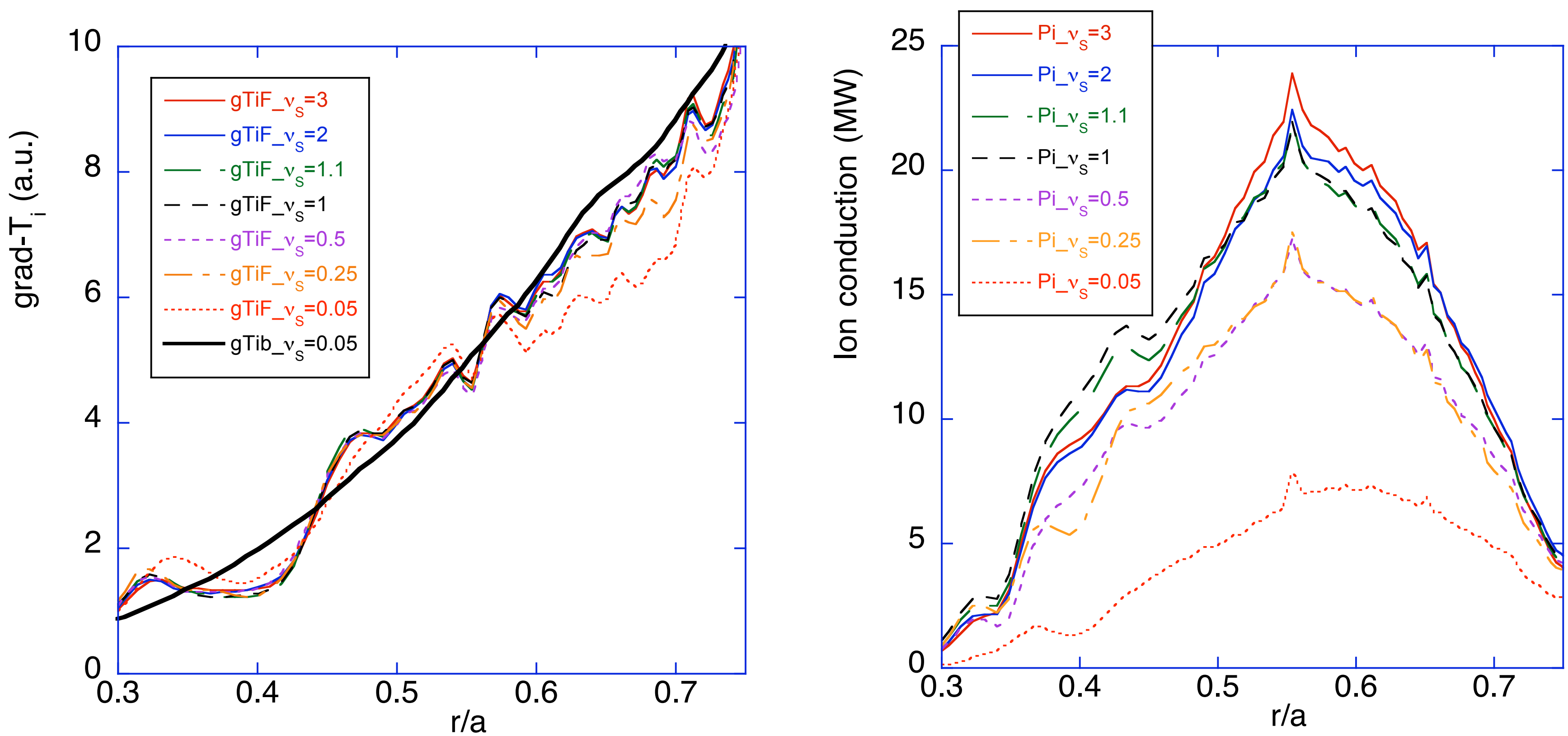
The old source model also can't recover from initial failure. It reduces only changes in the large-scale features of the n=0 component of $\tilde{n}$ and $\tilde{T}$. After the T_i gradient has relaxed it doesn't change anymore.

A new source model can recover from initial failure. It reduces the large-scale features of the n=0 component of $\tilde{n}$ and $\tilde{T}$ by adding a decay term proportional to those features.

With short averaging times, both the old and new source models prevent relaxation of T_i gradient.
Flows depend oddly on averaging time, however, needs more study.

Searched for 'danger zone' where the model controls the turbulence!
This is possible if small-scale n=0 features are removed: zonal flows!
Don't use N_SOURCE>1 and NU_SOURCE $\geq$ 1 in these conditions.

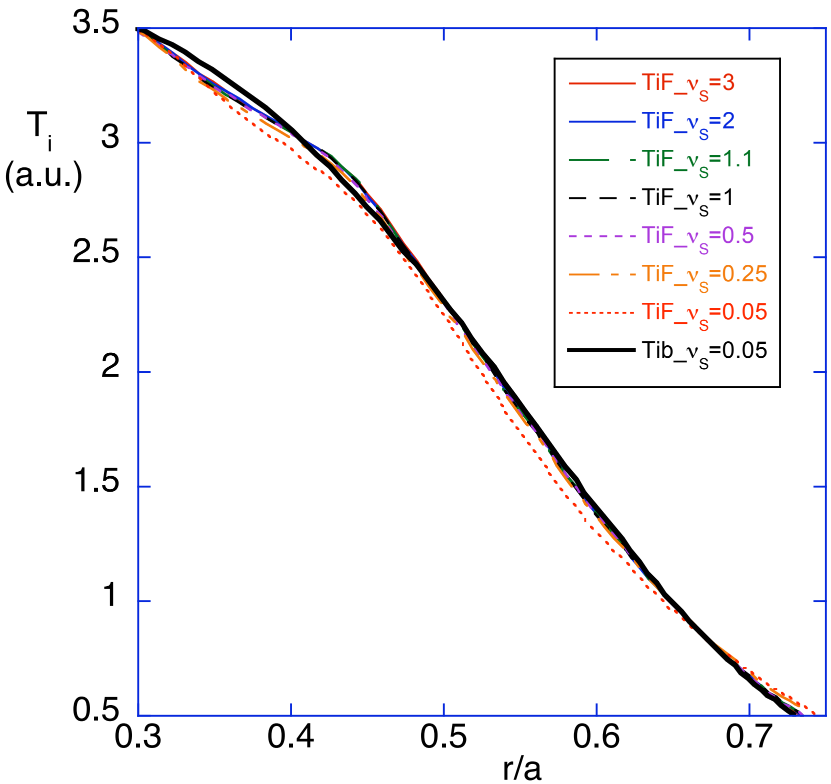
Convergence with Reduced Averaging Time



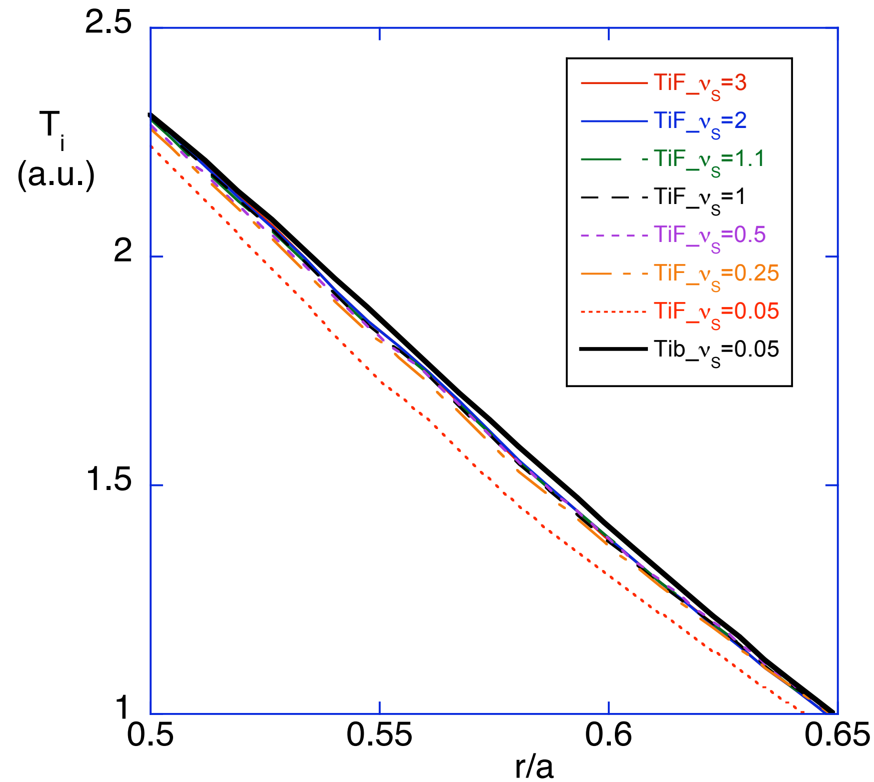
Temperature gradient approaches exptl. gradient.

Conducted power profile converges.

Very small $\tilde{T}_i$ causes the relaxation



Zoomed



$\tilde{T}_i$ is very small, but its local gradients are significant.

Verification: convergence testing

Varied grid resolution, usually see only small changes:
(standard settings in green, variation in red)

Number of toroidal modes: 8 $\Rightarrow$ 16 $\Rightarrow$ 32
some cases require 16 modes for converged results.
Maximum $k_\theta \rho_s$=0.85 $\Rightarrow$ 1.7 (electron transport increases a bit).
Number of trapped/passing pitch angles: 4 $\Rightarrow$ 8
Number of orbit segments (error $\propto 1/N^4$): 9 $\Rightarrow$ 6
Number of energies in modified Gauss-Laguerre integration: 8 $\Rightarrow$ 16

New convergence tests

Increase the radial resolution, reduce spacing: 3/4 $\rho_s \Rightarrow$ 3/8 ρ_s
small change
Extend the radial domain: $0.5 < r/a < 0.8 \Rightarrow 0.3 < r/a < 0.8$
small change

Summary and Further Work

Simulations of more recent NSTX plasmas are all fully quenched by ExB shear, but simulations of 2004 plasmas are not.
Need to identify the parameters responsible for this change.
MSE is available only in newer plasmas, but other parameters have changed, too.

Fully quenched predictions often contradict TRANSP's ion power balance: need significant 'anomalous' ion transport.
Significant ion transport probably requires low-$k_\theta\rho_s$ turbulence.
Is the ExB quenching formulation too strong?

Could include impurity in simulations, likely to be more stabilizing.

Low-k simulations always predict $Q_i \sim 3\ Q_e$: TRANSP disagrees!
Raising maximum $k_\theta\rho_s$ should increase electron thermal transport.
Would need to increase $k_\theta\rho_s$ well beyond 2 to have a large effect.
Might raise the predicted Q_e above Q_i? TRANSP has $Q_e > Q_i$.
Such runs will be much more computationally expensive.