GYRO simulations of turbulence in NSTX L-mode plasmas

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News since the last Results Review

Large change when varying width of radial domain now understood.
The 'adaptive source' model was failing to preserve T_i gradient.
The failure was greater in the wider domain, caused less transport.
Failure is to be expected in larger □* simulations, especially those in which the unstable region is only part of the radial domain.

Re-tuned the old and new adaptive source model to more aggressively remove the large scale perturbations; both models give converged results that are independent of the size of the radial domain.

Tested whether the model also removes turbulence itself! This is possible if smaller scale effects of turbulence are removed – zonal flows – but results are robust when only larger scales are removed.

New plasmas with complete ExB quenching

Discharges with MSE derived q profiles have become available.

New discharges are similar to previously simulated plasmas
L-modes with monotonic and reversed q profiles.

Simulations of these discharges show complete quenching of low-k turbulence by the ExB shear – previously saw finite transport.

Will modest variations in ExB shearing rate and temperature gradients produce significant transport? Are plasmas near stability boundary?

Will also consider GTC-neo produced E_r.

Features 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) Finally, including ExB shear derived from the measured v_{tor} can completely quench the turbulence found in 2) but in other cases the predicted transport fluxes are 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 increases Q_e/Q_i; need $k_\theta \rho_s > 2$.

Summary and Further Work

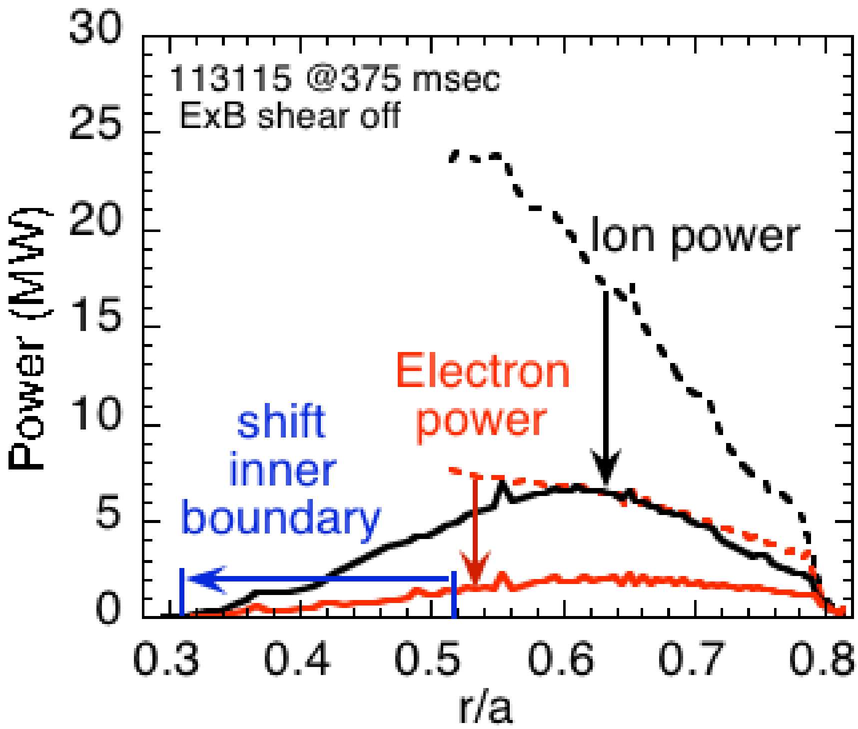
Need to understand change in effectiveness of ExB shearing rates
check E_r supplied to GYRO from TRANSP runs; changed in Jan.

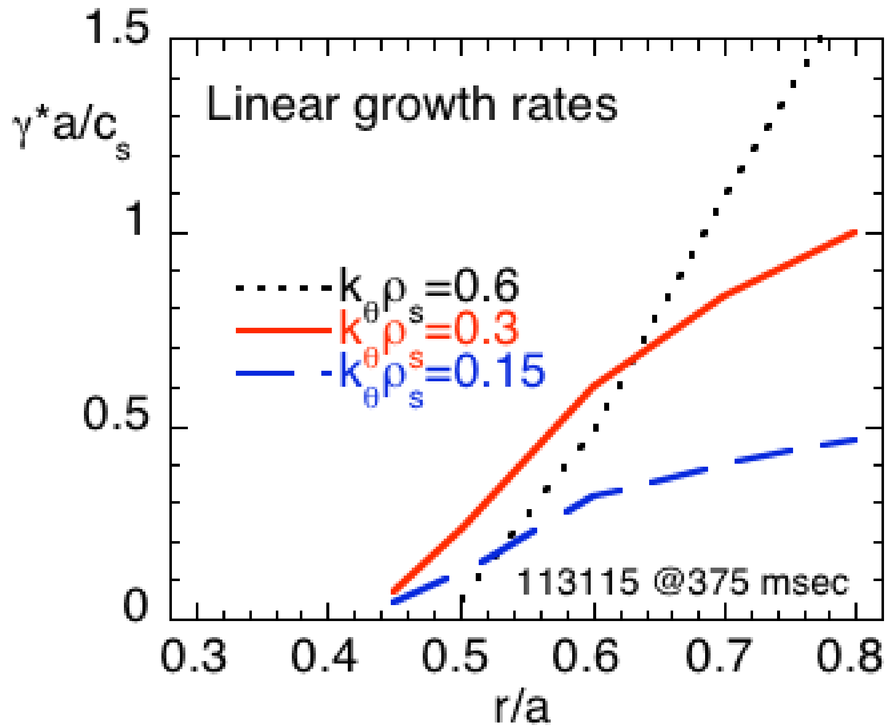
Include impurity in simulation (likely to be more stabilizing).

Begin to look at electromagnetic effects.

Raising maximum $k_{\perp}\rho_s$ increases electron thermal transport.
Would need to increase $k_{\perp}\rho_s$ 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.

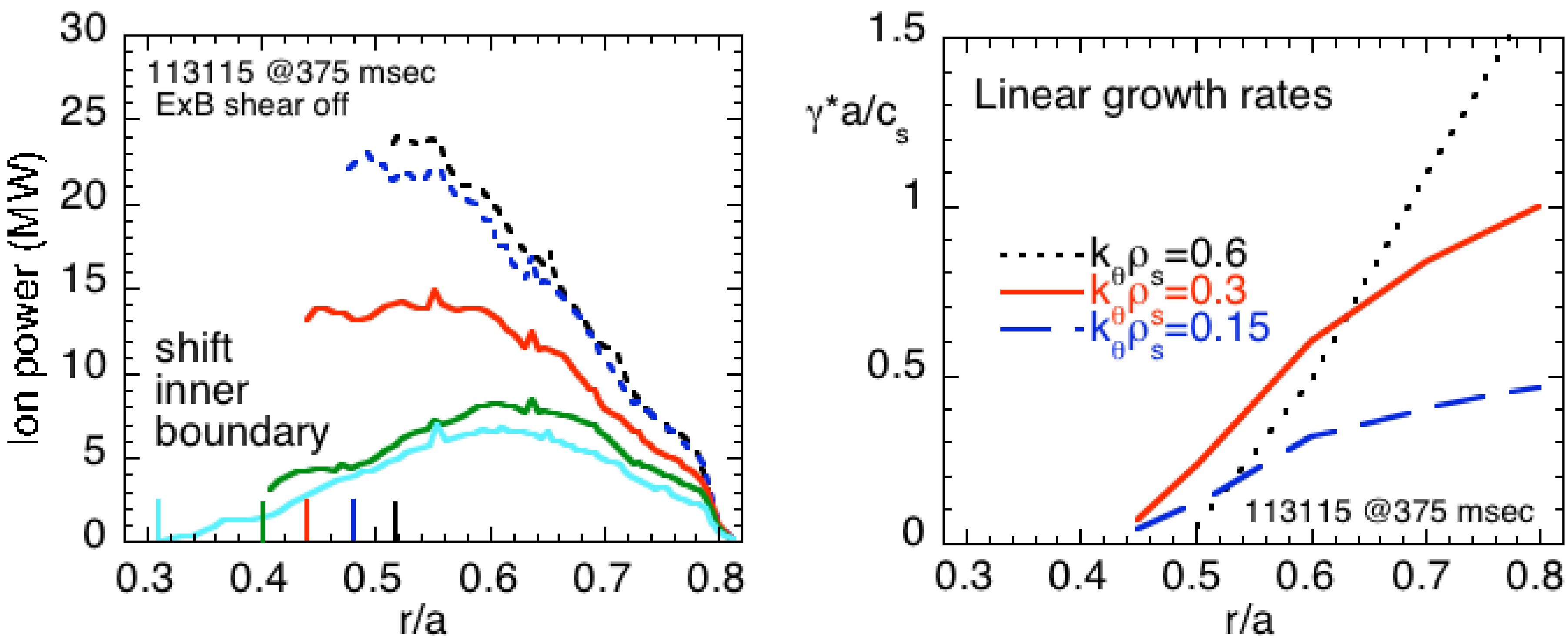
Stable Inner Core Drains Unstable region





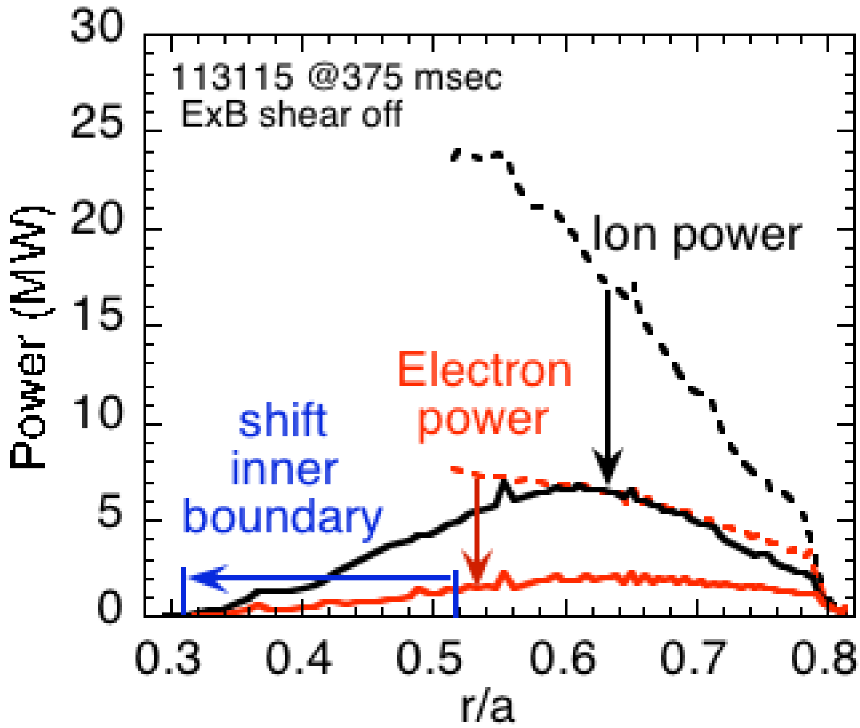
Shift inner boundary to include the stable inner core, r/a<0.45
turbulence is reduced most near the boundary of stable region, but
turbulence is strongly reduced everywhere in original $54\rho_s$ domain.
Turbulence draining: Waltz-Candy, Phys. Plasmas 12 (2005) 72303.

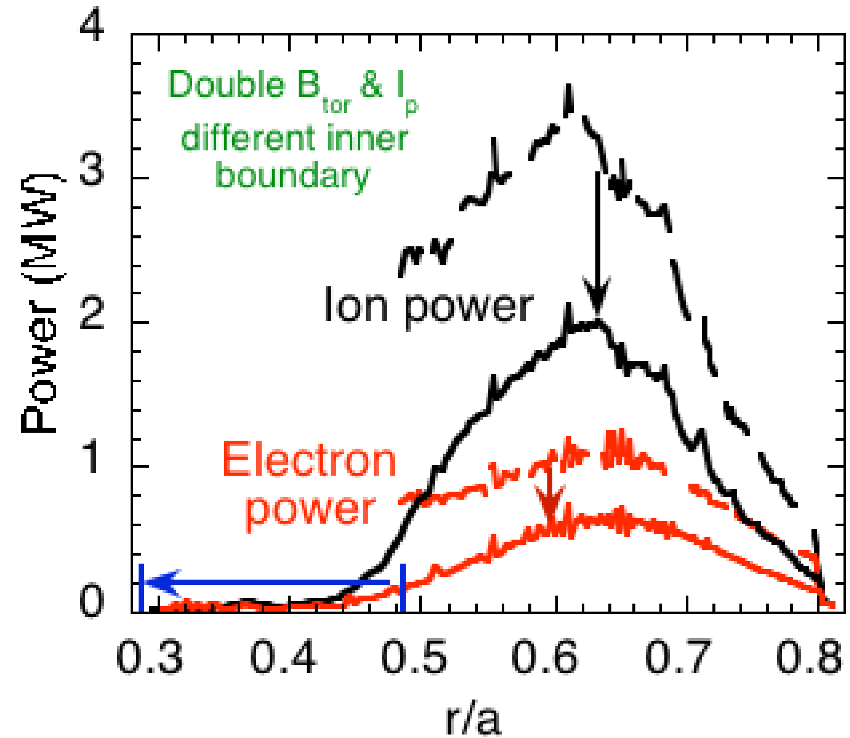
Draining Saturates Quickly



Scan inside boundary across the edge of the stable inner core,
see small effect until boundary is near the edge of stable region, but
turbulence is quickly reduced when boundary is inside stable region.
Most important drive region is narrow and near r/a~0.5 ?
Damping of low-k or high-k is most important?

Less Change with Smaller ρ_s





Double B_{tor} and I_p - constant q(r) - to reduce ρ_s.

in narrow domain, near r/a~0.6, turbulent power drops ρ_s^2; and range of the spreading in the stable region is smaller, and transport reduction factor with wider domain is much smaller.

Finite ρ* ‘draining’ effect diminishes as expected.

Important Issues for NSTX Simulations

Low $k_\perp$ 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 flows,
these are expected to be a major stabilizing factor.

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

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

Verification: convergence testing

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

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

New convergence tests

Increase the radial resolution, reduce spacing: 3/4 ρ_s → 3/8 ρ_s
small change
Extend the radial domain: $0.5 < r/a < 0.8$ → $0.3 < r/a < 0.8$
BIG CHANGE !

Overview

Kotschenreuther and Rewoldt – using model profiles – generally found the linear ExB quench rule is satisfied for low-k modes in STs.
Clarisse Bourdelle – using experimental profiles – found that $\gamma_{ExB} > \gamma_{linear}$ 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 an L-mode NSTX plasma. The major highlights are:
- ExB shearing is very important, but low-k transport is large.
- Kinetic electrons effects are very destabilizing.
- Finite ρ_s coupling of stable and unstable regions is very important.

Preparation of experimental profile data

Map profile data from R to r/a with TRANSP.
Use TRANSP calculation of the magnetic equilibrium for the map.
Used "outer side only" mapping of density and temperature.
  this guarantees that n_e, T_i, T_e at same R map to same r.

EFIT and TRANSP maps from R to r are similar for these shots.
Could use equilibria based on MSE in TRANSP;
  this will be done when the equilibria are available.
q near r/a~0.5 is uncertain without data from MSE.
  Use similar plasmas in 2005/6 with multi-channel MSE data.

Estimate of background E_r is based on measured v_{tor} and NCLASS calculation of v_{pol} used for E_r shown here. More complete neoclassical E_r from W. Wang and G. Rewoldt to be used in future.