NSTX

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Nonlinear Gyrokinetic Simulations of Reversed Shear NSTX Plasmas

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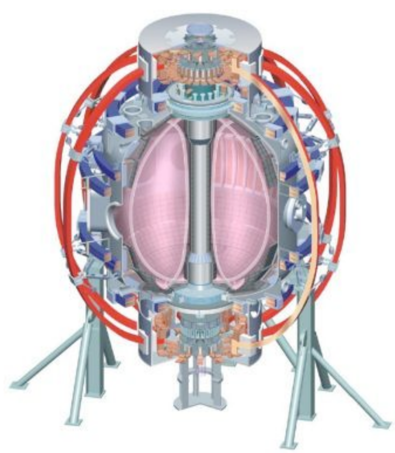

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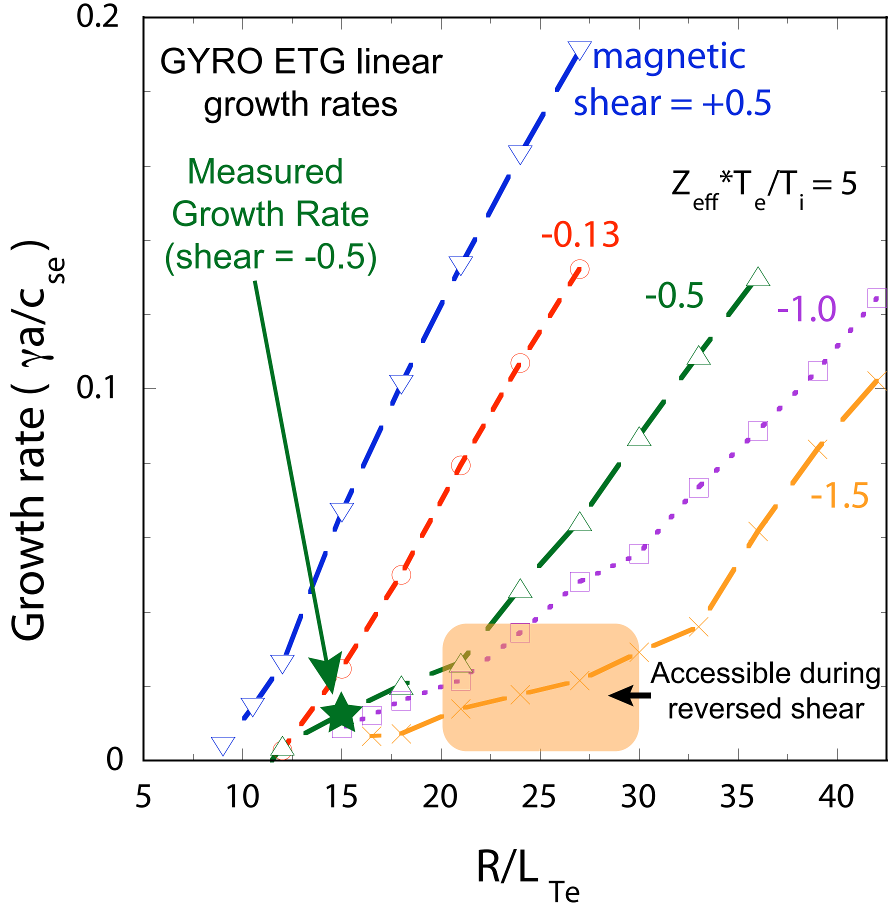
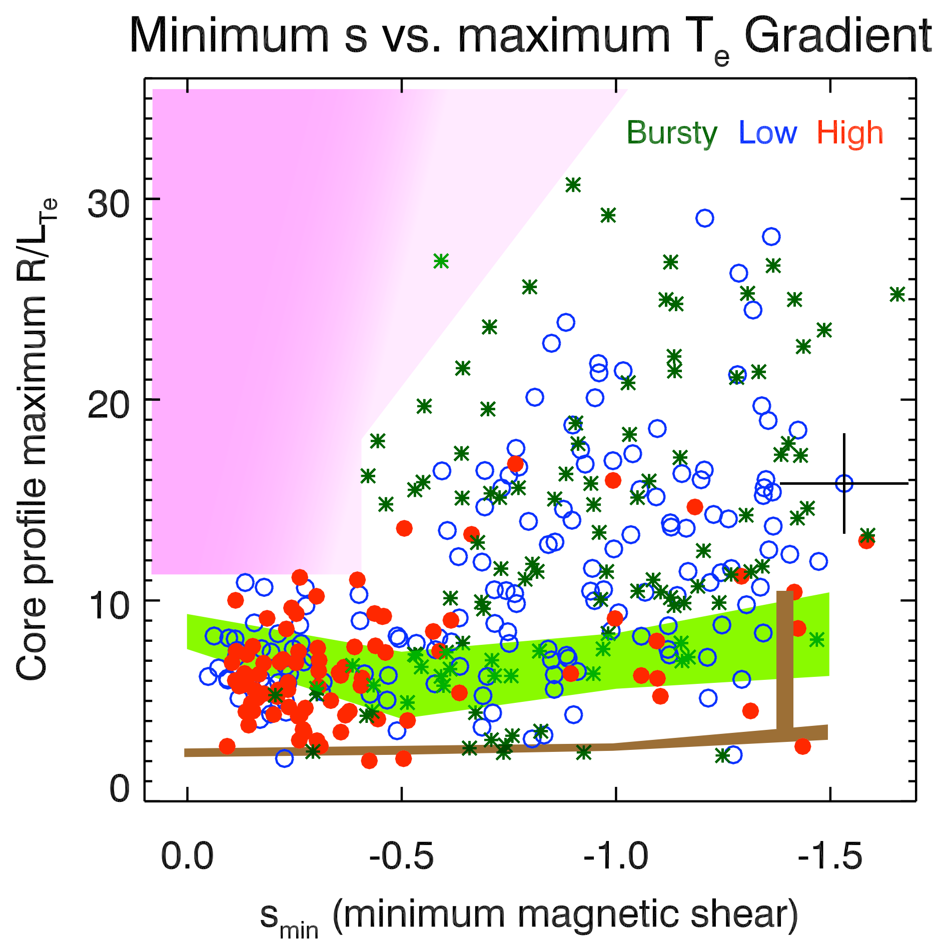
Summary

- Nonlinear gyrokinetic simulations of reversed shear NSTX e-ITB discharge show electron temperature gradient driven turbulence.
- Reversed magnetic shear suppresses this turbulence.
- We have discovered a stronger nonlinear up-shift of the critical gradient for transport at negative magnetic shear.
- Above this critical gradient, transport is dominated by off-midplane streamers, and may be linked to a unique linear mode.

Goal: Explore reversed shear NSTX results of electron temperature gradients well above linear ETG threshold.





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Simulating Strongly Reversed Magnetic Shear: NSTX Discharge #129534 @ 232 ms

- RF-Driven Electron Temperature Gradient
  - All linearly unstable $(R/L_{T_e})_{crit} \approx 4.5$
- Scan Electron Temperature Gradient
- 70 Nonlinear Flux Tube Simulations - GYRO
- 16 or 24 Modes, electron-scale resolutions
- Gyrokinetic electrons, gyrokinetic or adiabatic ions
- Electrostatic, No ExB Flow Shear
- ~2,000,000 total CPU hours @ ORNL XT5 (Jaguar)

$$R/L_{n_e} = 1.74$$

$$Z_{eff} = 3.39$$

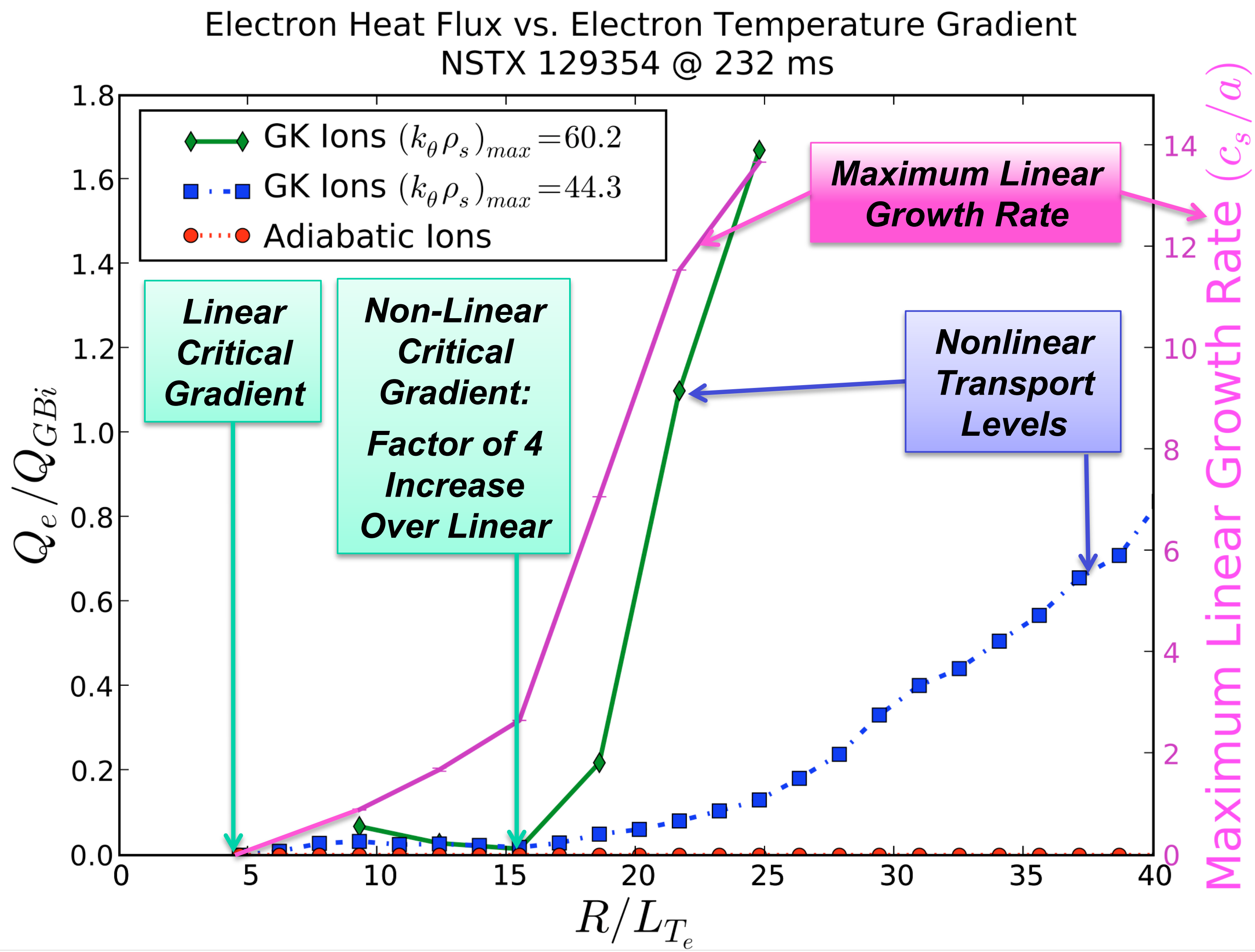
$$\mu_e = 60.0$$

$$\hat{s} = -2.4$$

$$q = 2.4$$

$$\nu_{ei} = 0.16\ (a/c_s)$$

The Nonlinear Up-shift of the Critical Gradient for Transport is Very Strong in Reversed Shear



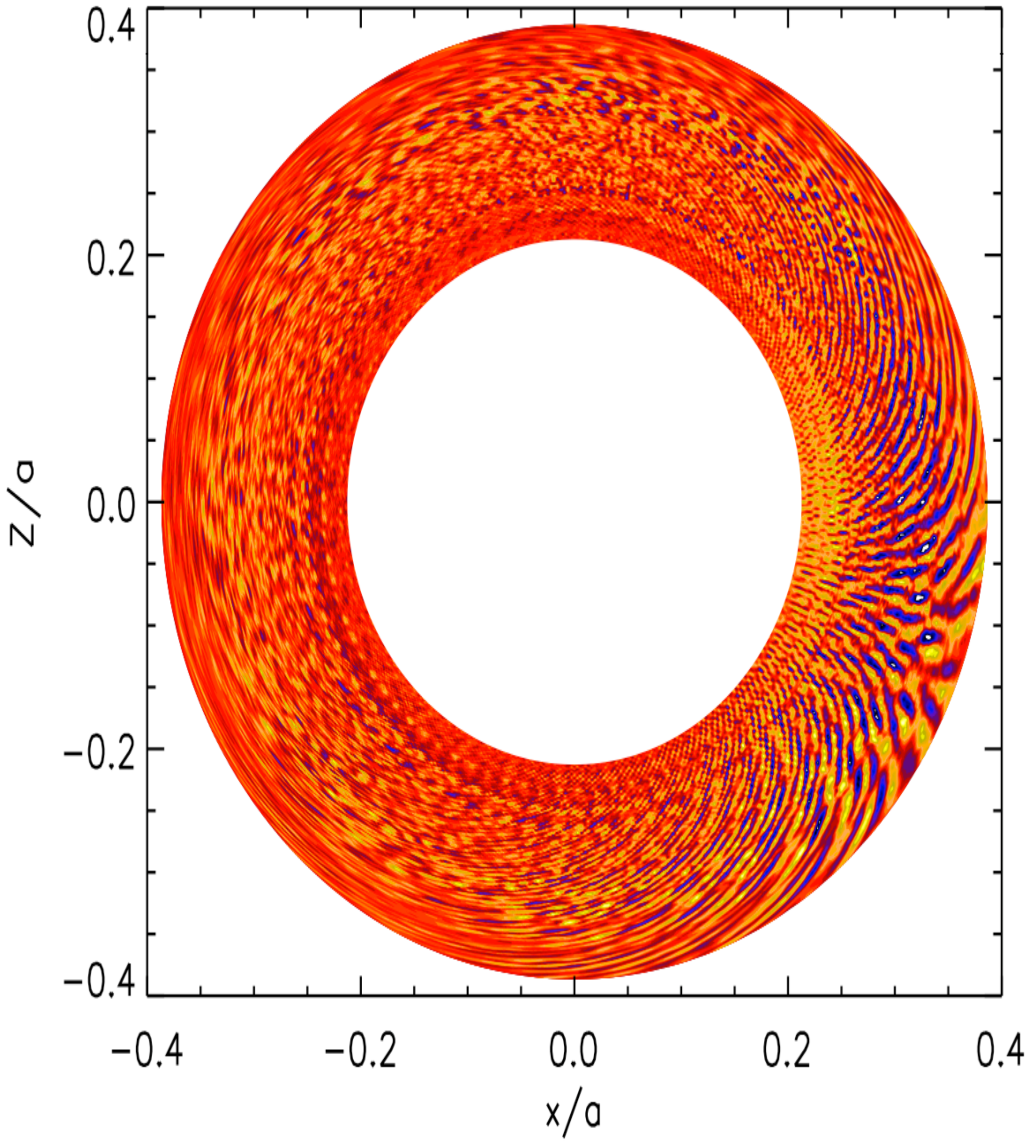
Below Nonlinear Critical Gradient Threshold: Streamers Sheared Apart, Low Transport

$$R/L_{T_e} \approx 12.5$$

$$Q_e/Q_{GB,i} = 0.028 \pm 0.01$$

Eddies Sheared, Saturate at Low Amplitude

Linearly Unstable, But Low Levels of Transport



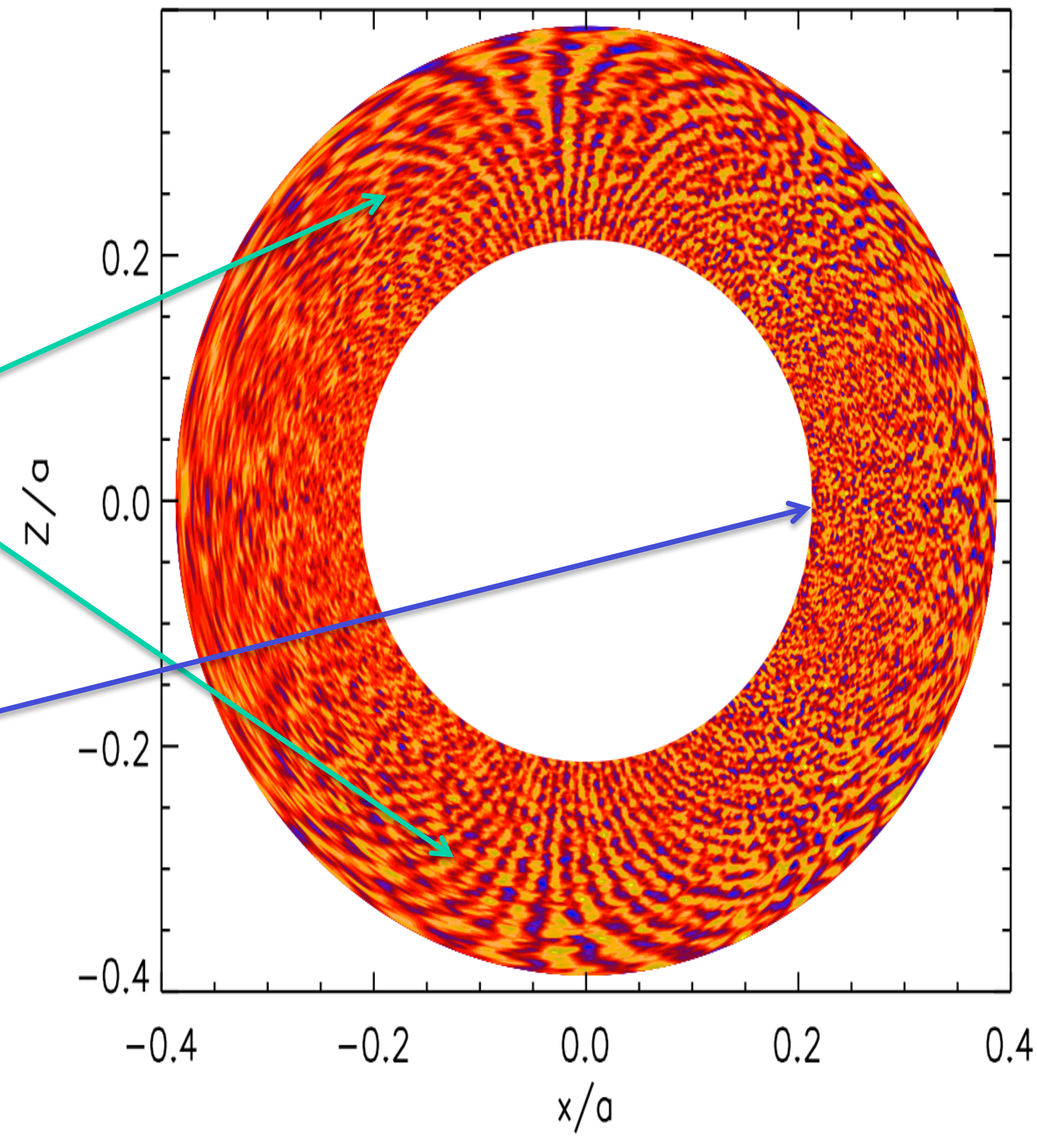
Above Nonlinear Critical Gradient Threshold: Streamers Not on Midplane, Large Transport

$$R/L_{T_e} \approx 22$$

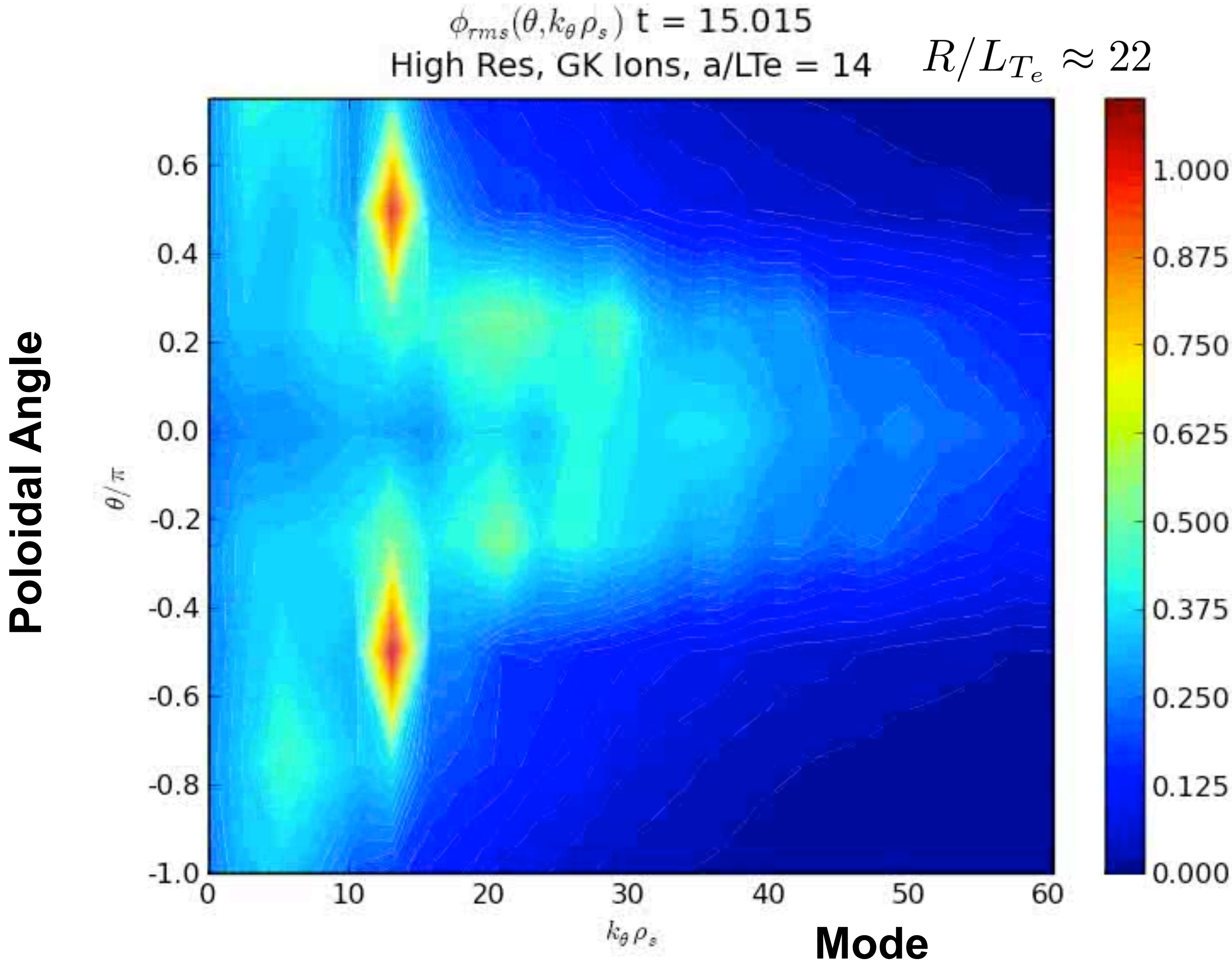
$$Q_e/Q_{GB,i} = 1.136 \pm 0.013$$

Radial Streamers out of Top and Bottom

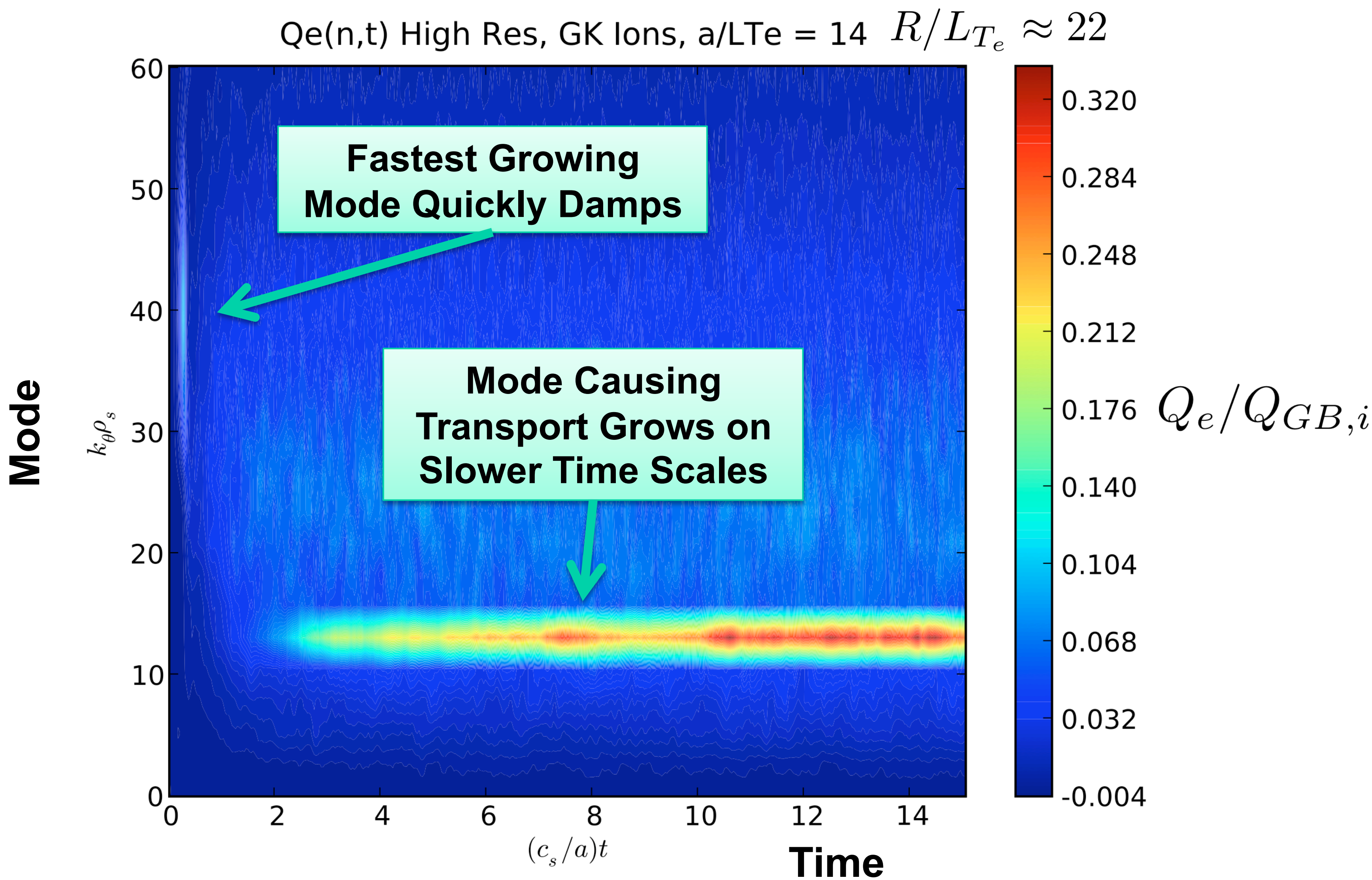
Midplane Eddies Sheared Apart, Even at High Driving Gradient



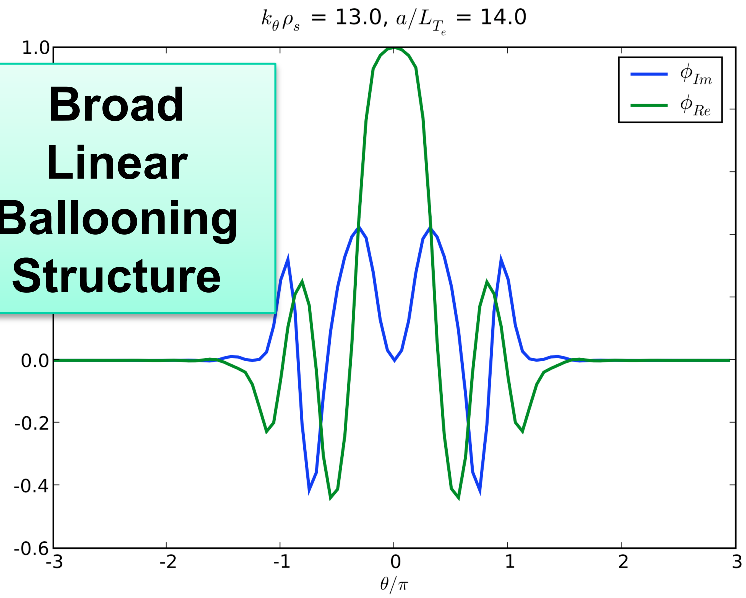
Fluctuations Peak Off Midplane in Single Mode



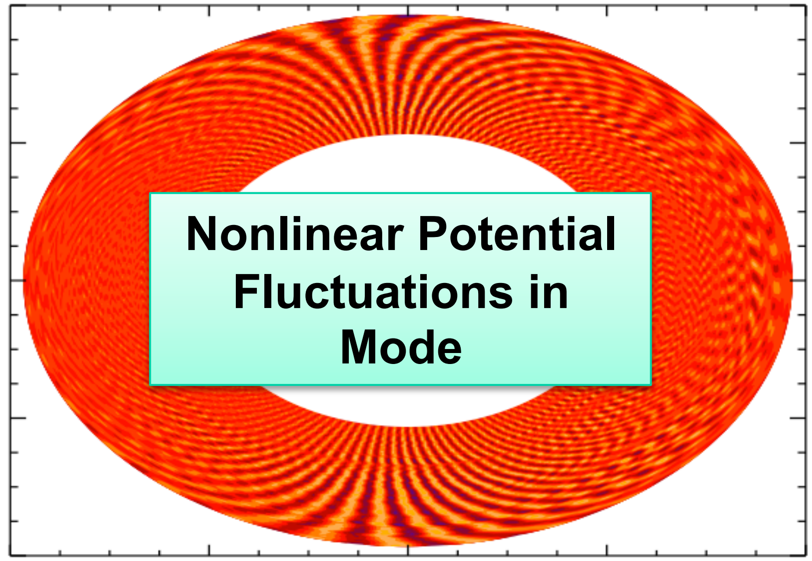
The Fastest Growing Mode Dies Away, Not Responsible for Transport



Transport Causing Mode Found With Both Linear Initial Value and Field Eigenmode Solvers



Broad Linear Ballooning Structure

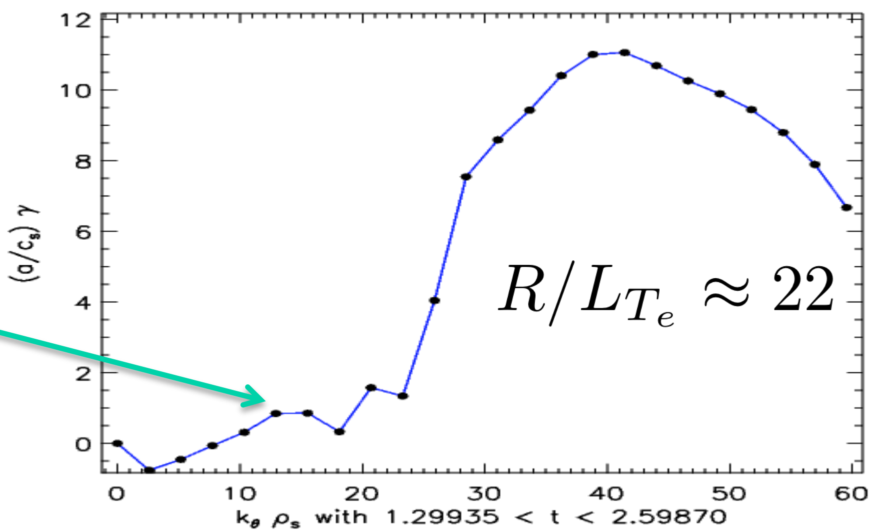


Nonlinear Potential Fluctuations in Mode

Sub-dominant Linear Growth Rate, Nonlinearly Saturates at Highest Amplitude

$$\omega = 25.19\ a/c_s$$

$$\gamma = 0.838\ a/c_s$$



Conclusions

- Reversed Shear temperature gradient scans find a second-instability threshold for electron transport.
  - ~ 4x the linear critical gradient, only seen with kinetic ion simulations
- Nonlinear critical gradient is consistent with observations of maximum attainable gradients in NSTX reversed shear discharges.
- Above threshold, a slow-growing mode saturates with highest amplitude, causes majority of transport.
  - Linearly sub-dominant, nonlinearly dominant
  - **Streamers out of top and bottom**: midplane streamers sheared

Some Testable (?) Speculations

- Reversed shear discharges can still have significant ETG turbulence off the midplane.
  - Move high-k, look for difference / stronger fluctuations away from midplane
- Performance of e-ITBs is limited by nonlinear critical gradient for transport.
  - Map out critical gradient as function of shear, compare with xp data
- Transport relies on interplay between ballooning ETG and broad mode
  - Energy transport diagnostics in simulation
  - Map out linear stability properties of both modes, compare w/ nonlin.
- "Bursty" turbulence is characteristic of turbulence near nonlinear critical gradient
  - Synthetic diagnostics

Acknowledgements

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Extra Slides

Future Work

- Thorough analysis of transport causing mode's linear properties
  – Goal: investigate second-instability threshold, top/bottom streamers
- Use gyrokinetic parameter scans around reversed shear discharge as benchmark for TGLF
  – Goal: more robust and accurate ST TGLF/TGYRO transport predictions
- Calculate synthetic high-k spectra based on these GK simulations
  – Goal: comparison with high-k experimental data
  – Goal: investigate "bursty" high-k signals in this regime
- Multi-scale nonlinear simulations
  – Goal: link ion and electron scales, especially if this intermediate-k transport causing mode is important.

Parameters For Nonlinear Reversed Shear Flux Tube Simulations

16 Modes

$$L_x \times L_y = 2.13 \times 2.13\rho_s$$
$$= 128 \times 128\rho_e$$
$$k_\theta \rho_s = [2.95, 44.25]$$
$$k_\theta \rho_e = [0.043, 0.738]$$

- Adiabatic Ions
- Kinetic Ions

$$R/L_{T_e} = [4.6, 52.6]$$

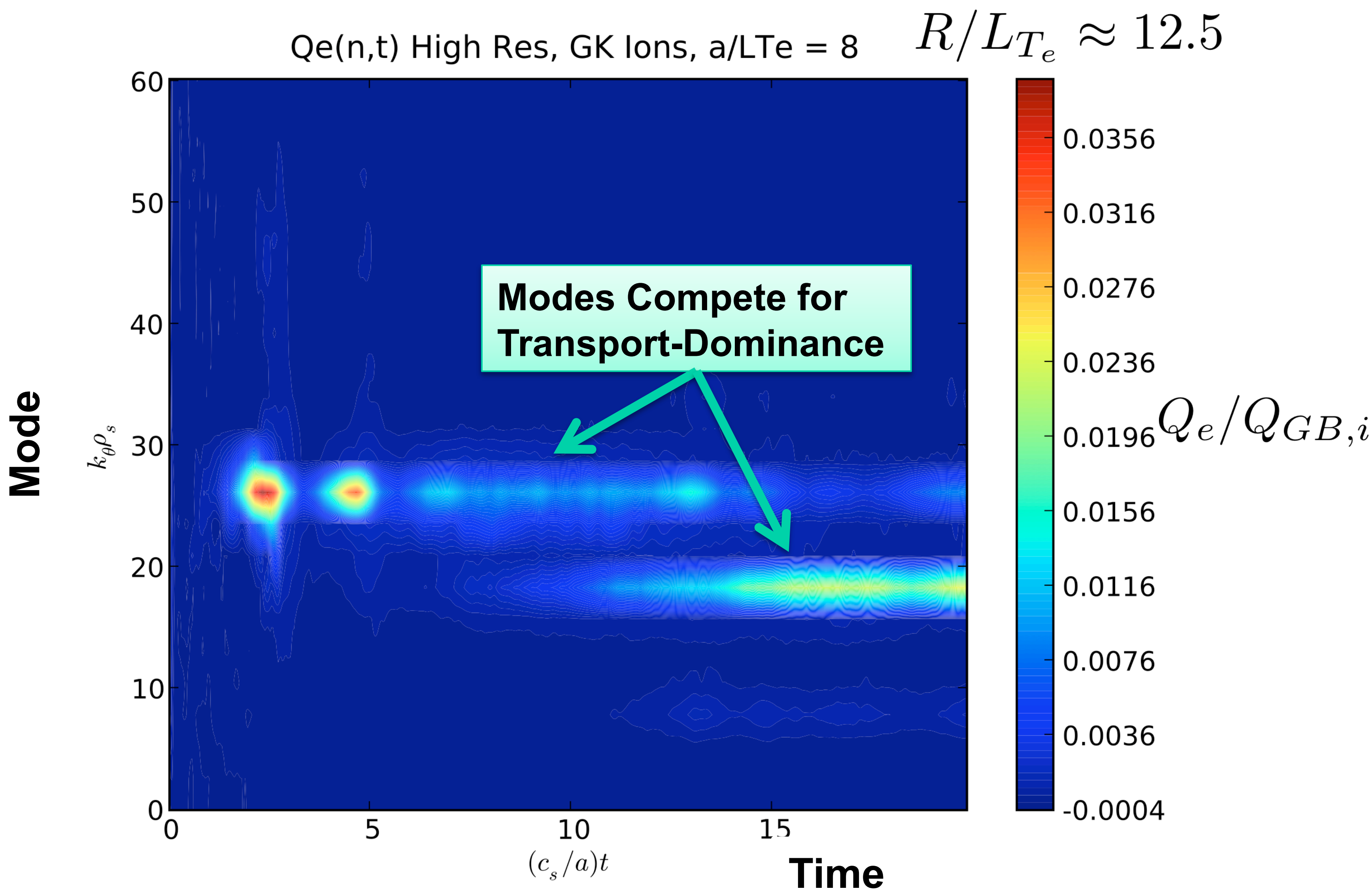
24 Modes

$$L_x \times L_y = 4.26 \times 2.4\rho_s$$
$$= 255 \times 144\rho_e$$
$$k_\theta \rho_s = [2.618, 60.21]$$
$$k_\theta \rho_e = [0.043, 1.004]$$

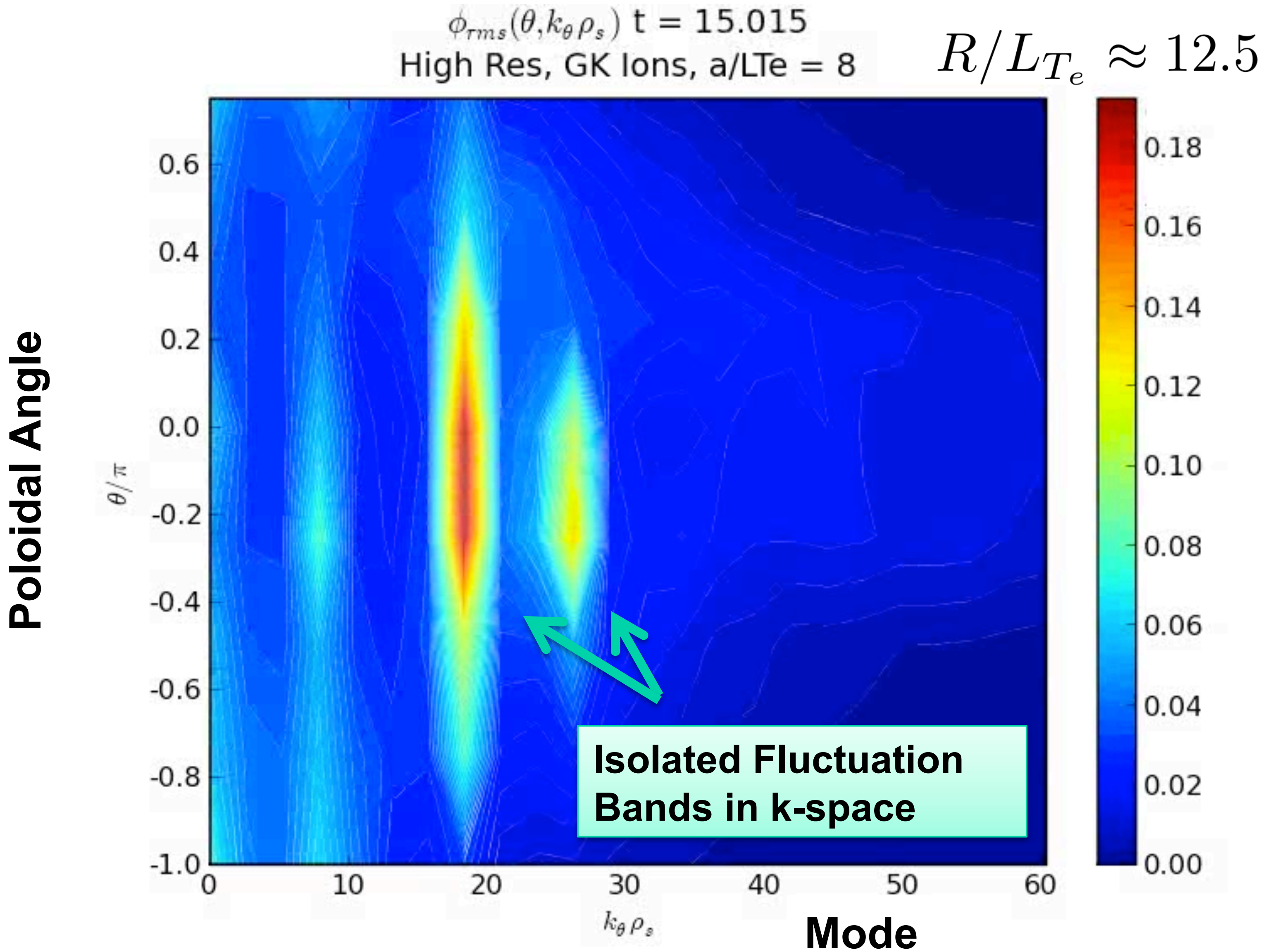
- Kinetic Ions

$$R/L_{T_e} = [9.28, 34.75]$$

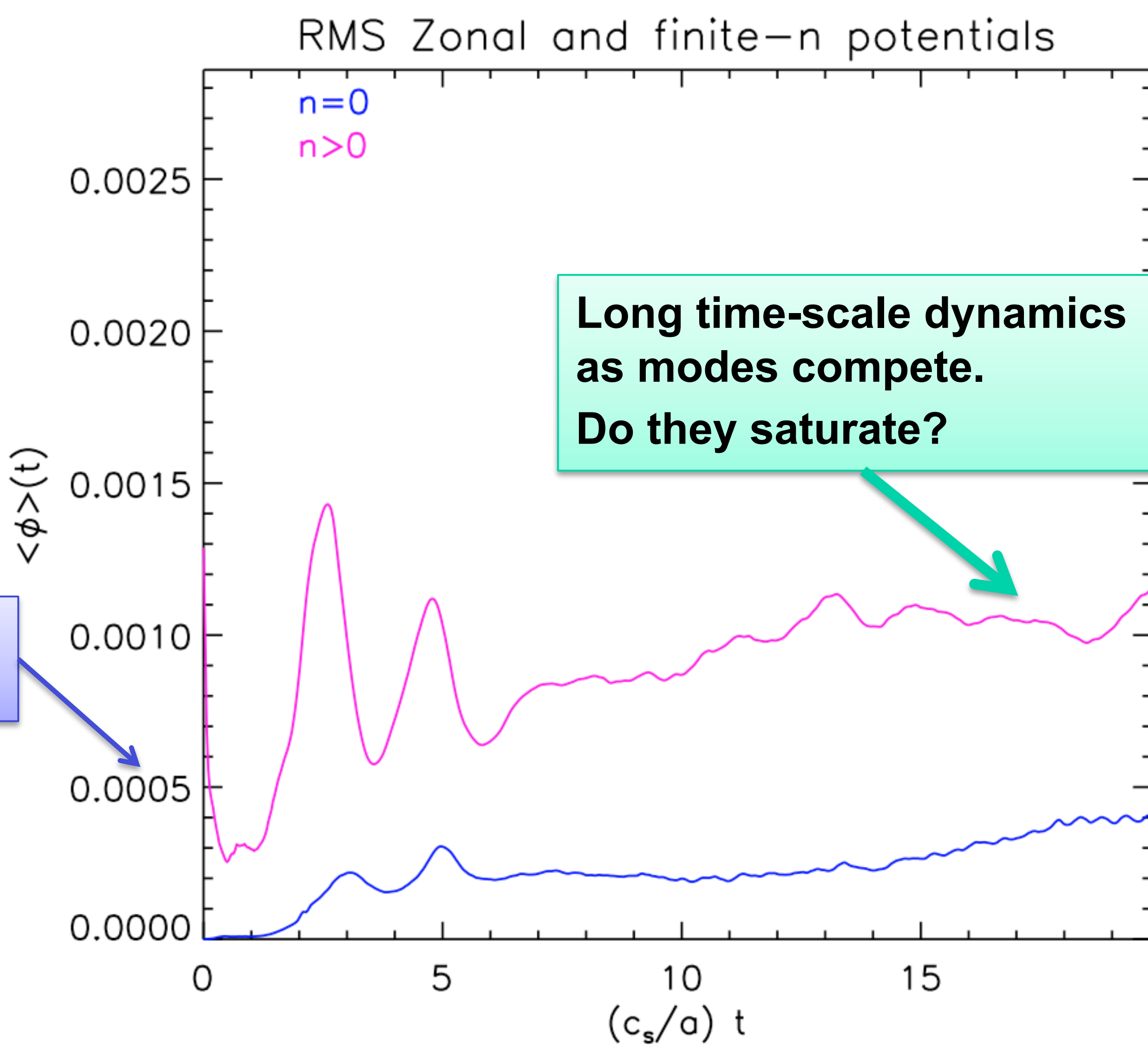
No Single Mode Dominates in Shear-Suppressed Regime



Low-transport modes centered on Midplane



Zonal Flows Appear Correlated with Finite-n Potential Fluctuations Below Critical Gradient

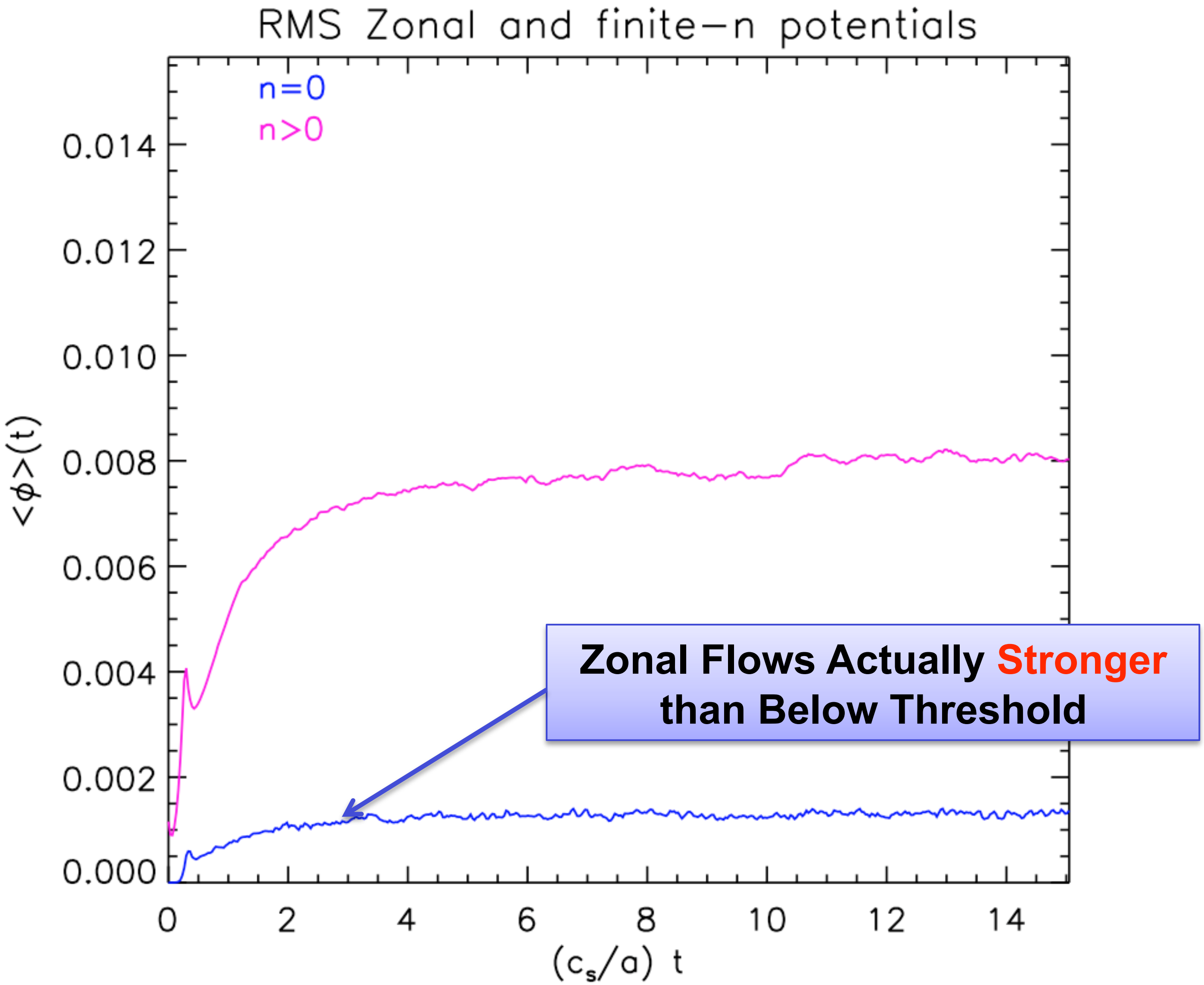


Long time-scale dynamics as modes compete.

Do they saturate?

Low-magnitude

Above Nonlinear Critical Gradient, Quicker Saturation



Potential Fluctuations Strongest on Outboard Side for Global Low-Shear Case.