Gyrokinetic Simulations and Measurements of Transport and Density Fluctuations in a JT-60U Plasma with Box-like ITB

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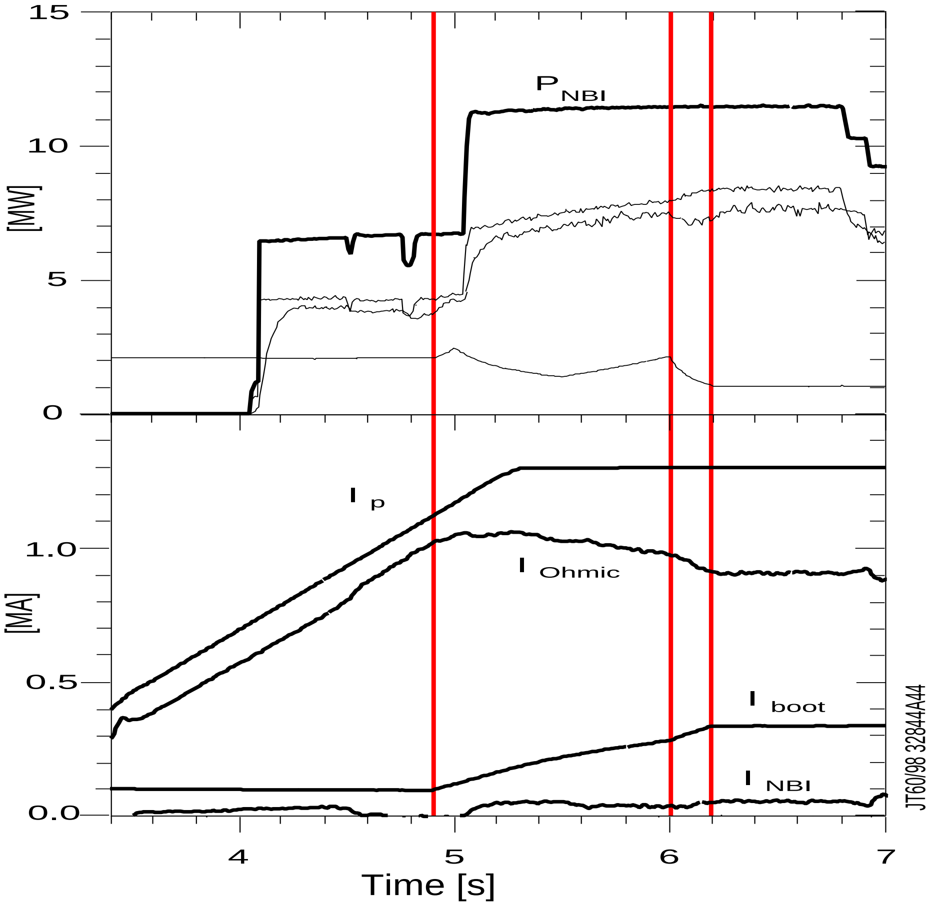
- Understanding transport is needed for practical Tokamak Reactors
- ITG / TEM turbulence is thought to cause most transport in present Tokamaks
- The GYRO Gyrokinetic code is thought to contain all the physics needed to understand ITG / TEM turbulence
- This poster tests the validity of GYRO by comparing simulations of transport and density fluctuations with measurements

Outline

- Description of the JT-60U plasma studied
- Transport analysis and GYRO simulations
- Comparisons of simulated and measured transport
  - GYRO energy transport high x2.5 or more (depending on ripple loss)
- Comparisons of simulated and measured $\tilde{n}_e$ radial correlation
  - GYRO λ_r during ITB $\simeq$ measurement
- Comparisons of simulated and measured $\tilde{n}_e/n_e$
  - GYRO rms($\tilde{n}_e/n_e$) high x(2-3)
- Conclusions

Description of JT60-U plasma with box-like ITB



GYRO simulation at 3 times

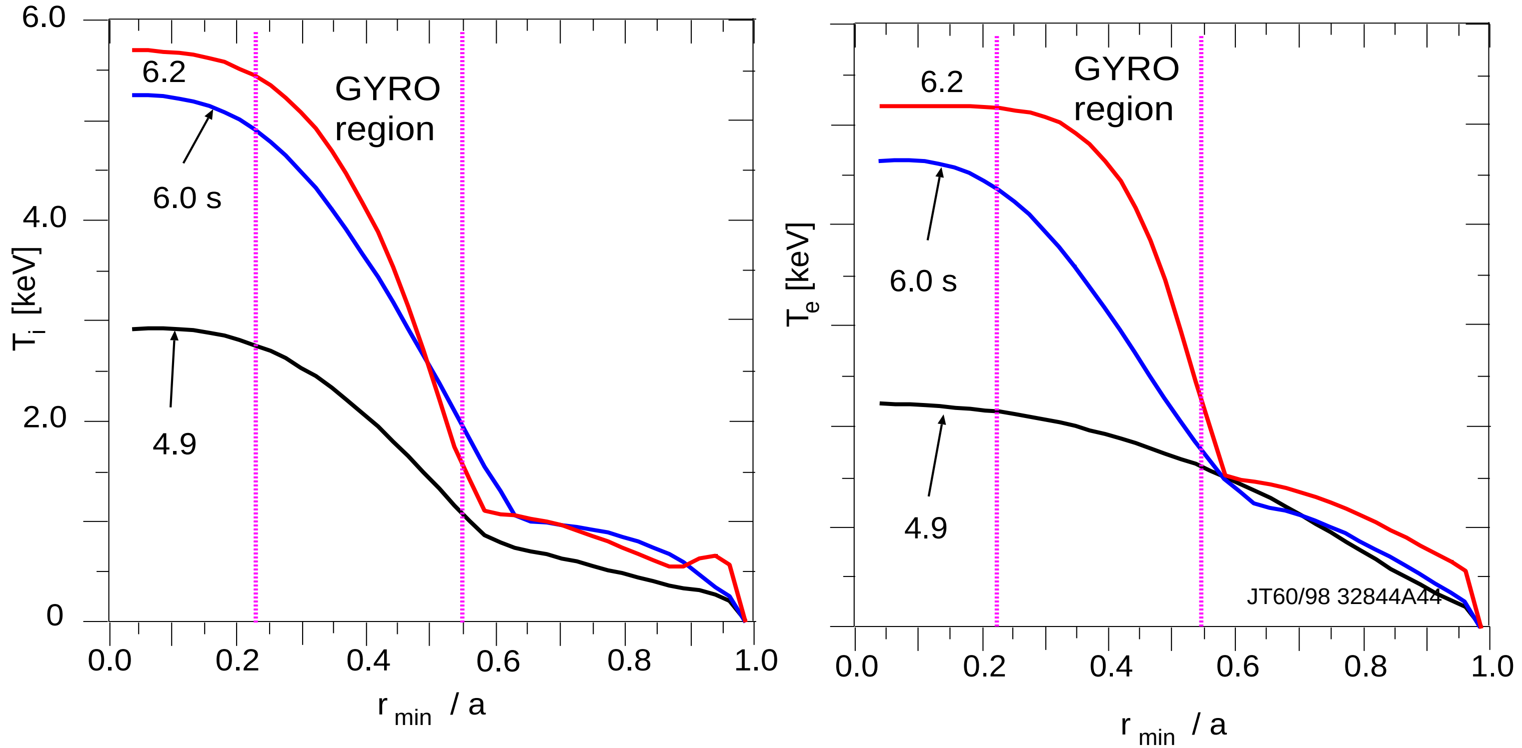
4.9 s: low power, pre-ITB

6.0 s: ITB's forms

6.2 s: Box-type T_e ITB

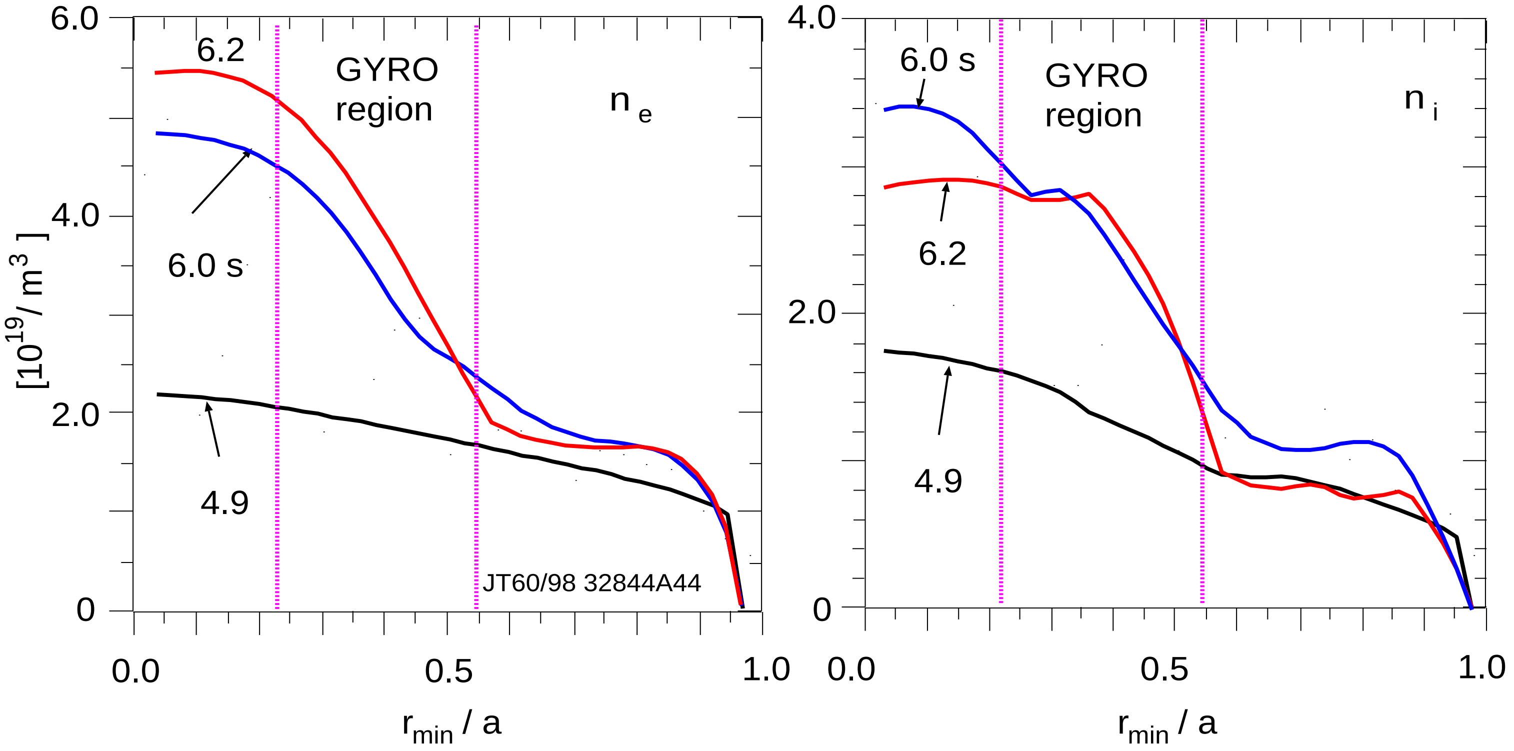
Temperature profiles develop ITB's

- early: slightly peaked T_i and broad T_e
- late: T_i ITB and box-like T_e ITB



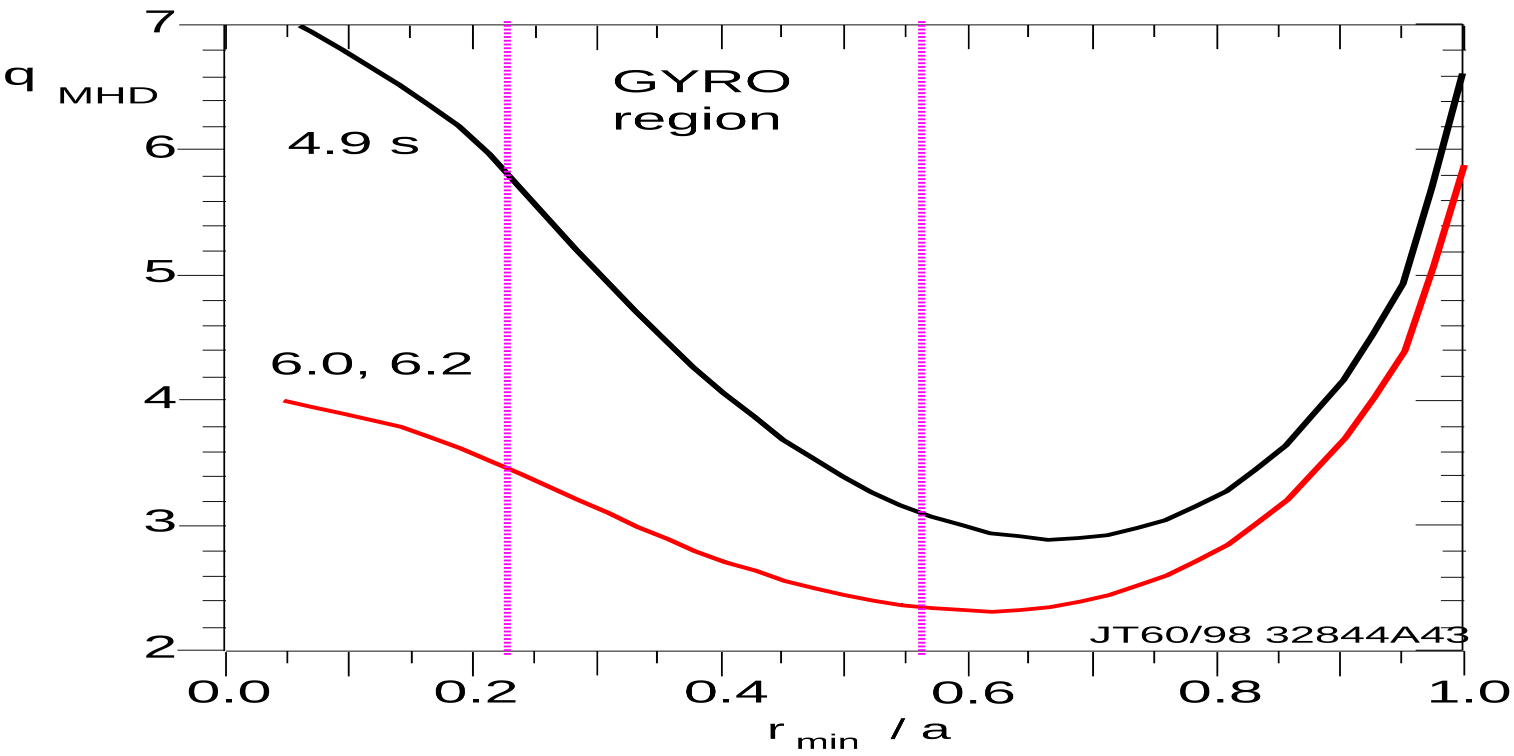
Density profiles become peaked

- n_e and n_i broad early, peaked later



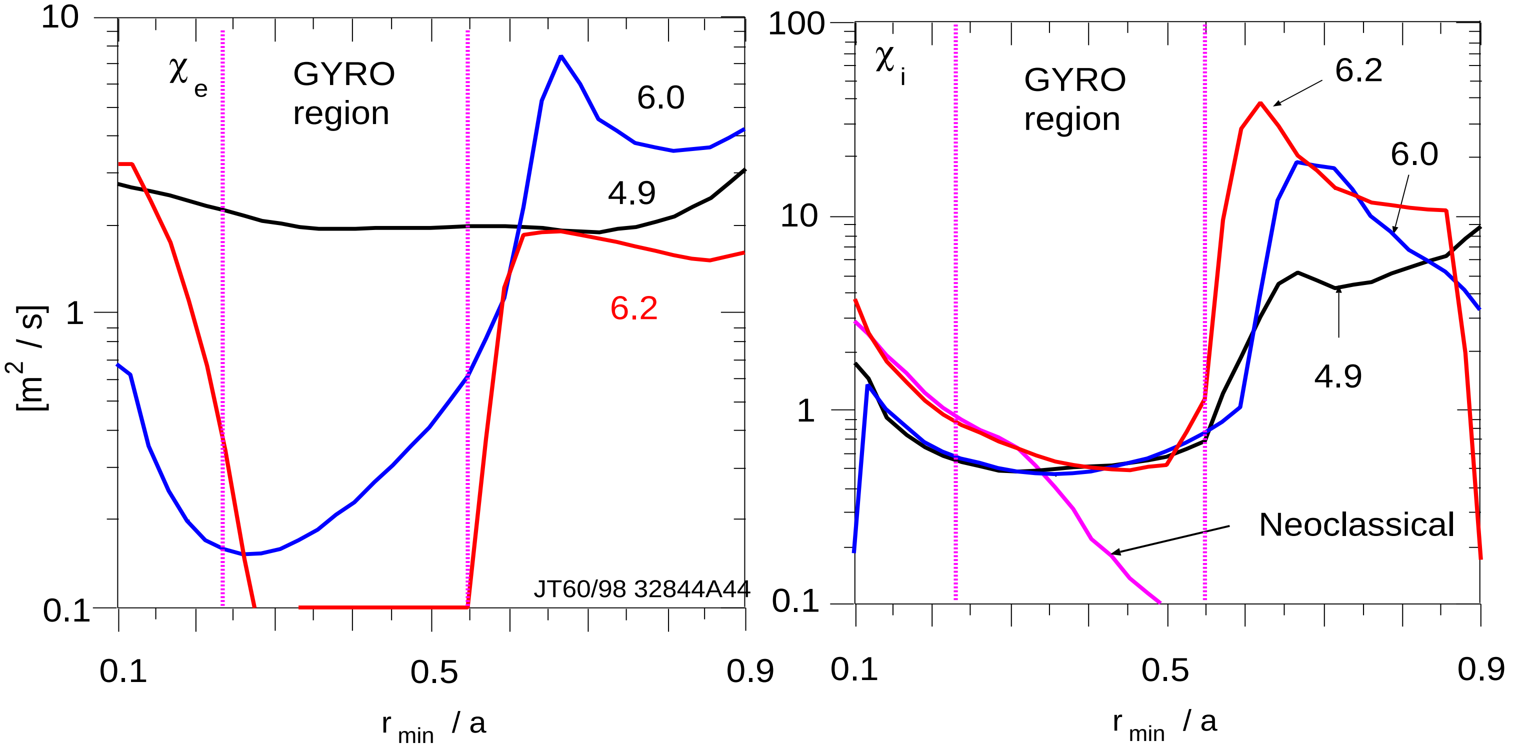
Reversed q_{MHD} profile

- GYRO simulations in region of strong gradients and reversed q_{MHD}



Low energy transport coefficients in core

- χ_e drops, χ_i remains low and near $\chi_{neoclassical}$
- Ignored ripple losses that would make χ_e and χ_i even lower



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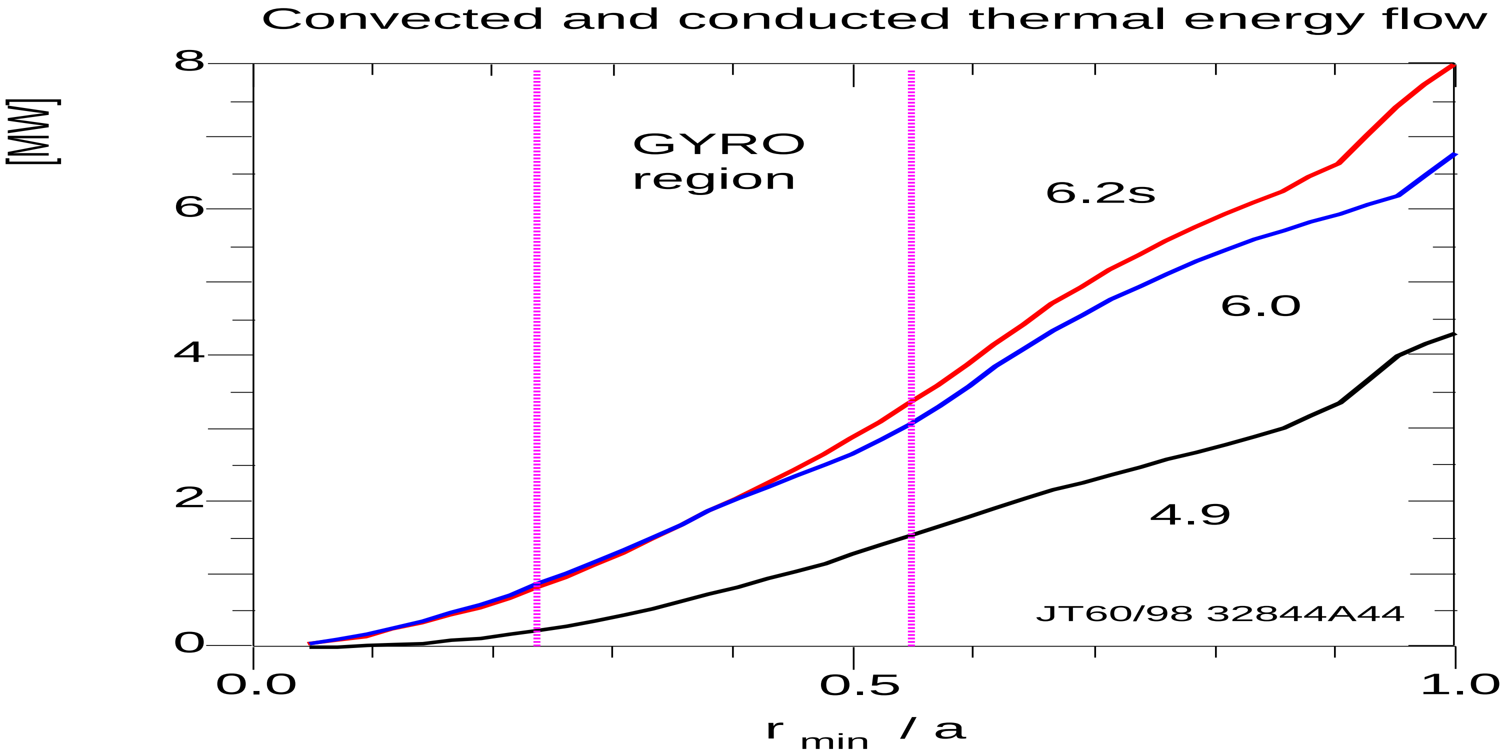
Profiles of energy flow from power-balance

- add conducted and convected energy flow via thermal plasma
- subtract P_{rad}, CX, beam-shine-through (large)
- ignore ripple loss (large?)

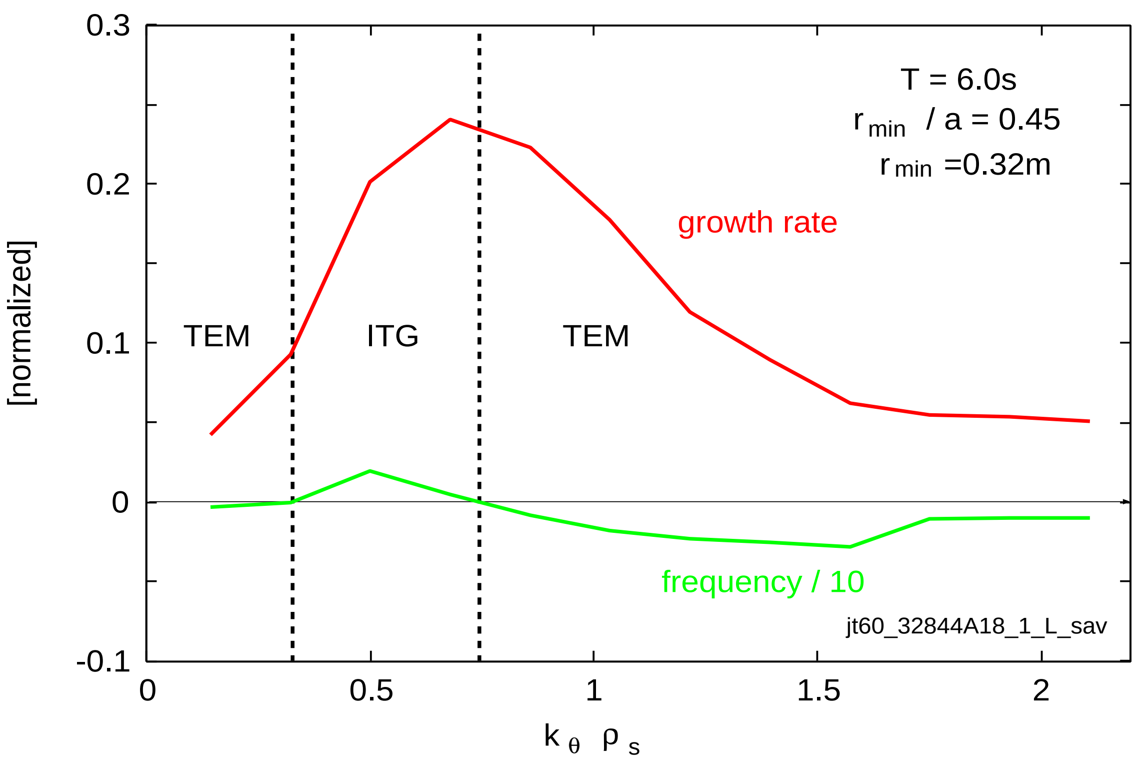


GYRO runs

- calculate time evolution of distribution fun'n of each species in 5D
- 2 ion species: 1) bulk hydrogenic, 2) lumped beam and impurity
- ITG/TEM with kinetic electrons ($k_\theta \rho_s < 1.0$)
- linear runs to study spectra in $k_\theta \rho_s$
- nonlinear runs to simulate transport and $\tilde{n}_e / n_e$
- include effects of E_r and Kelvin-Helmholtz ($v_{||}$) instability
- only electrostatic ($\beta_e = 0$) so far
- massive parallel processing (128-512 processors)

Example of scan in $k_\theta \rho_c$ from linear run

- Unusual to find TEM at low as well as high $k_\theta \rho_s$



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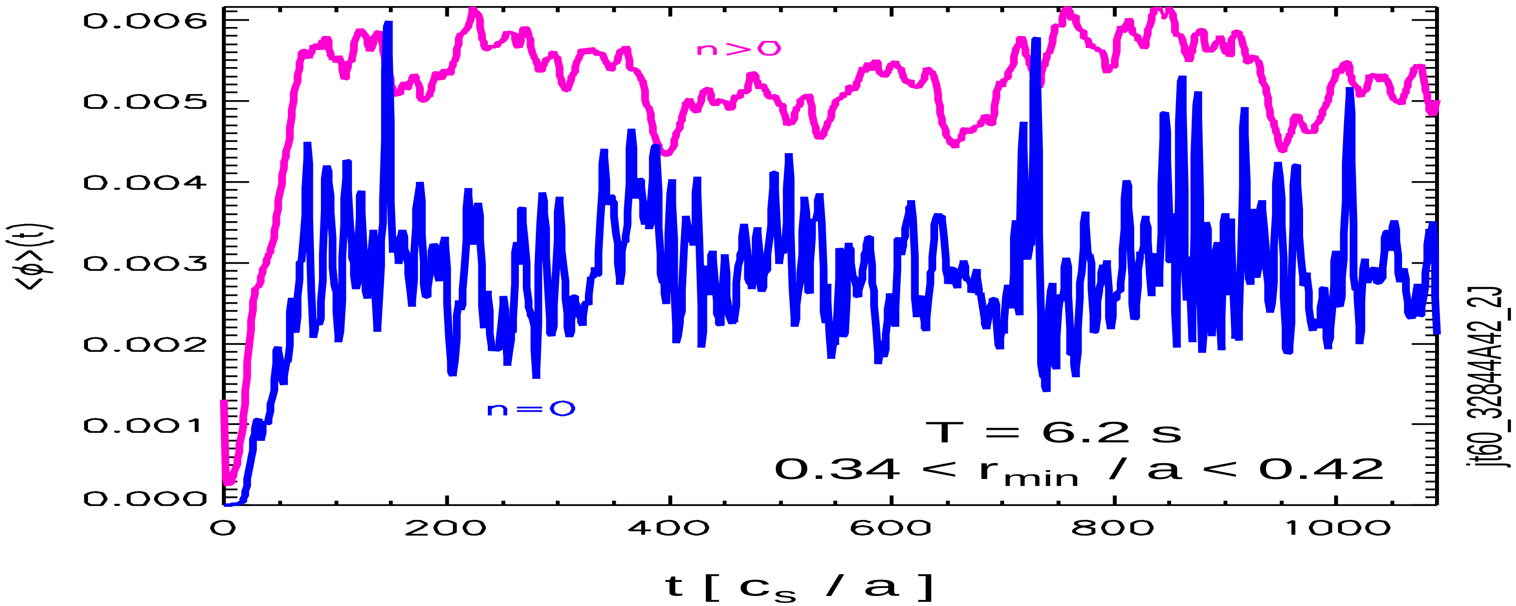
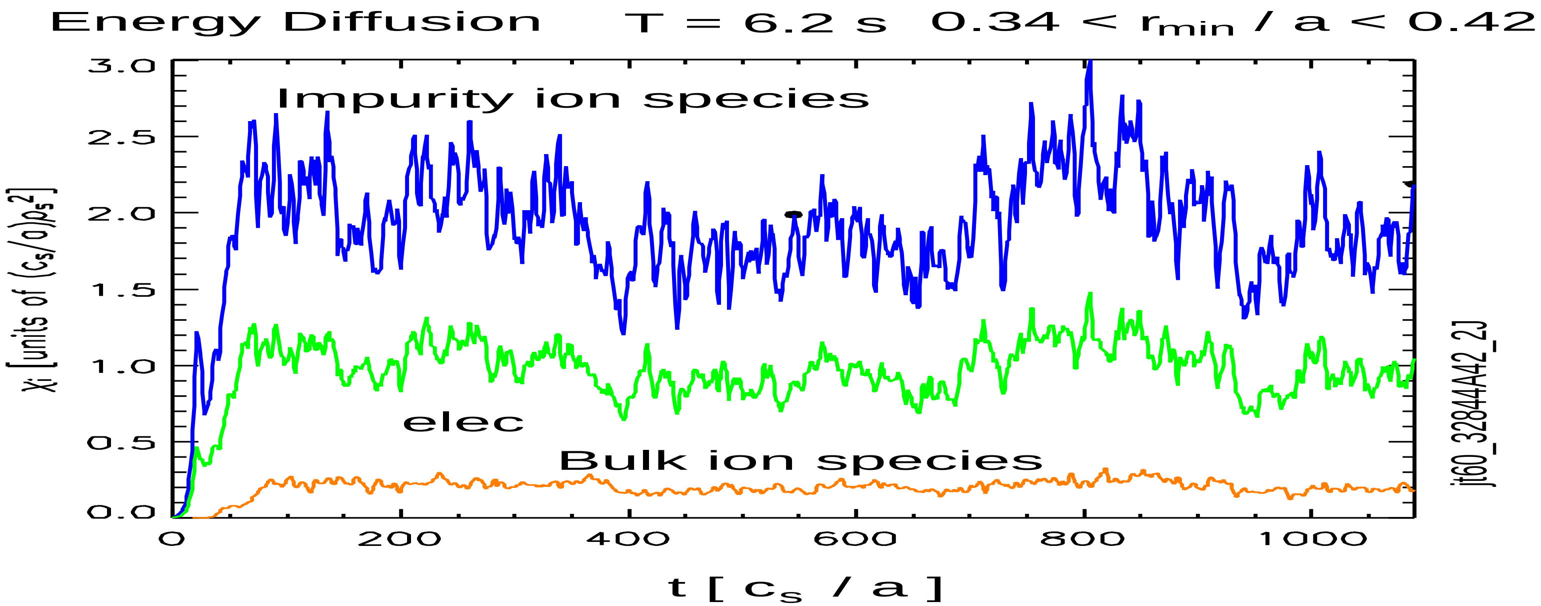
Saturation of Zonal Flow and higher $n_{toroidal}$ modes

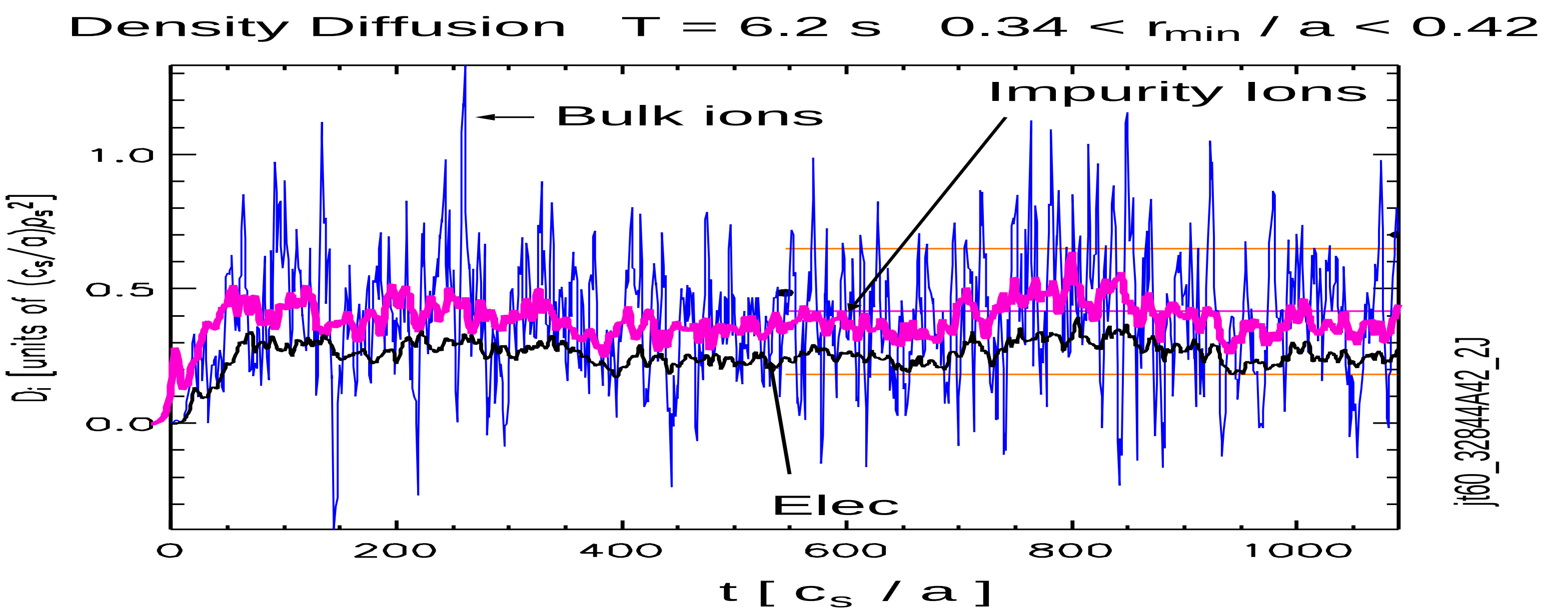
- $n_{toroidal}$ > 0 modes drive turbulence
- Zonal flows ($n_{toroidal}$ = 0) damp turbulence
- predator-prey interplay



Example of saturation of energy transport at T = 6.2 s



Species transport also computed



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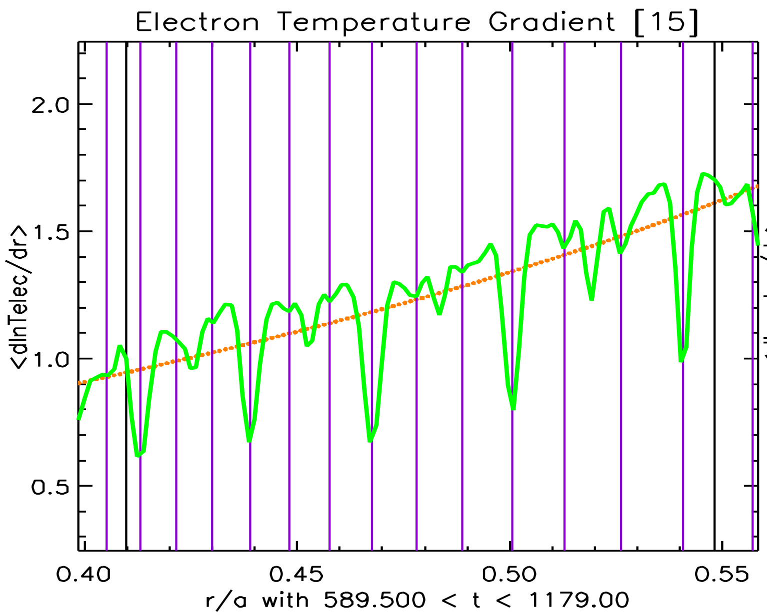
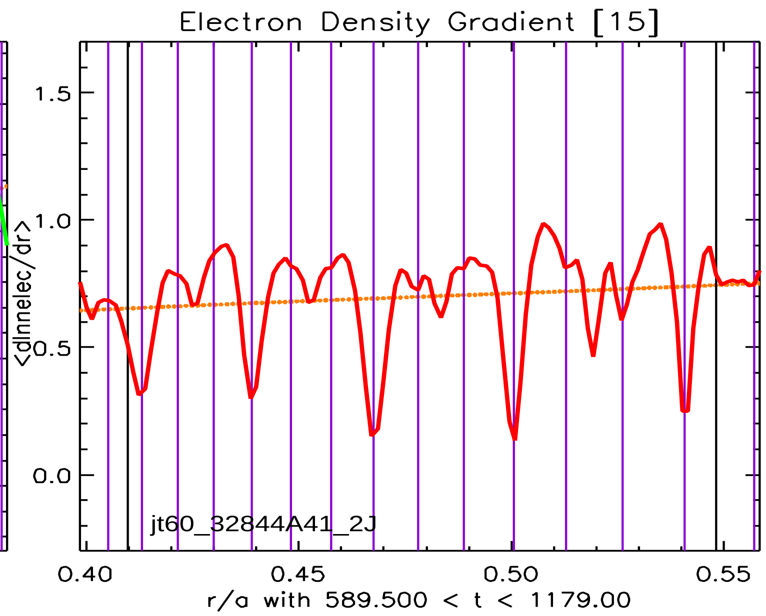
Corrugations in fluctuations at low-order rational surfaces

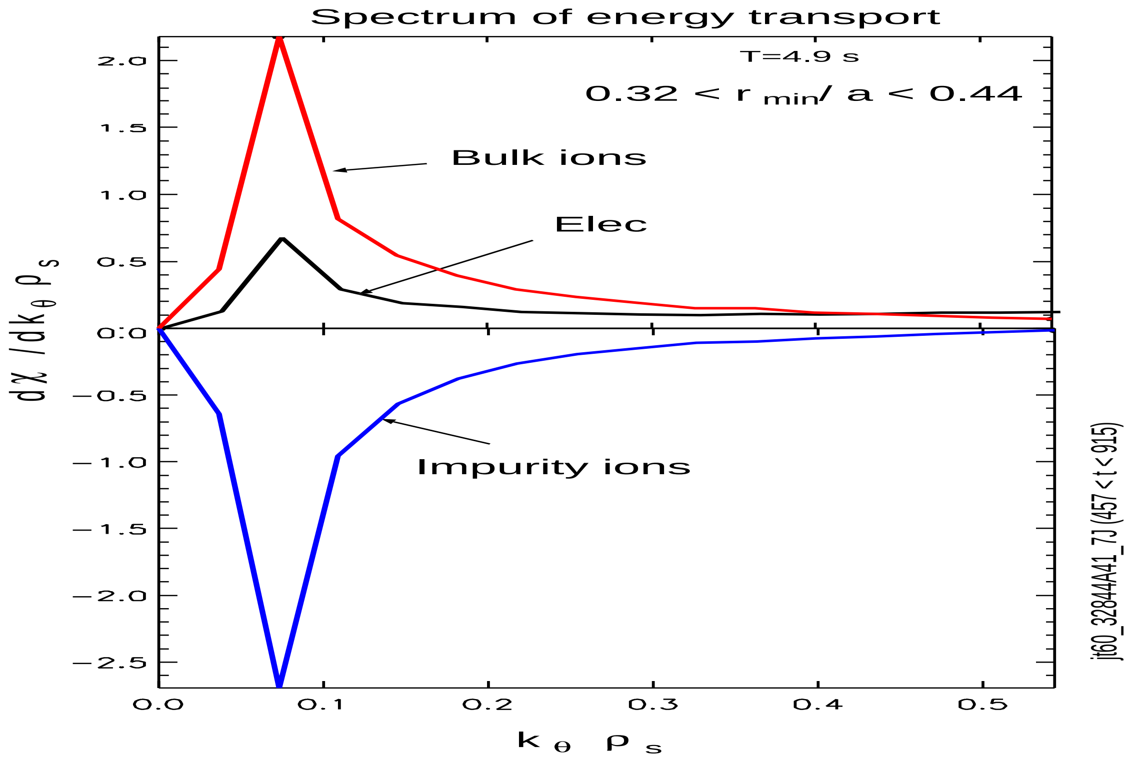
- Example at T=4.9s, $0.34 \leq r_{min}/a \leq 0.42$





Cumulative energy diffusivities at T = 4.9 s

- Early: dominate mode near $k_\theta \rho_s$ = 0.08
- Impurity energy flow inward



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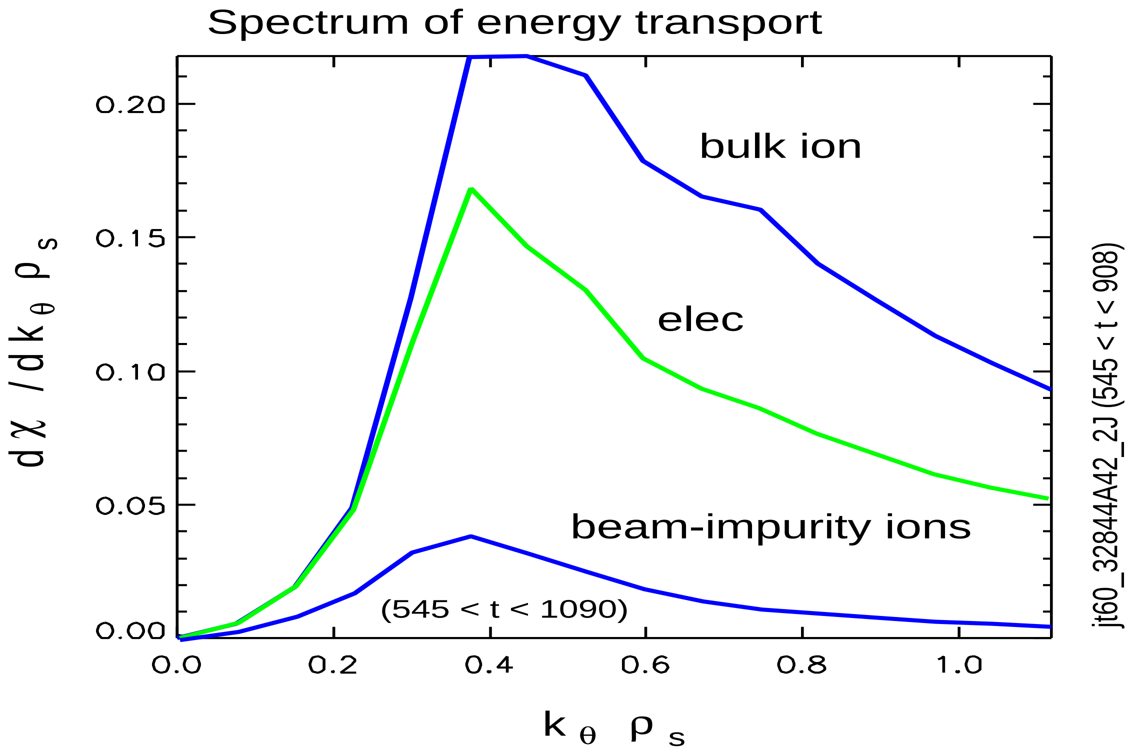
Cumulative energy diffusivities at T = 6.2 s

- $0.34 \leq r_{min}/a \leq 0.42$: dominate mode near $k_\theta \rho_s$ = 0.4



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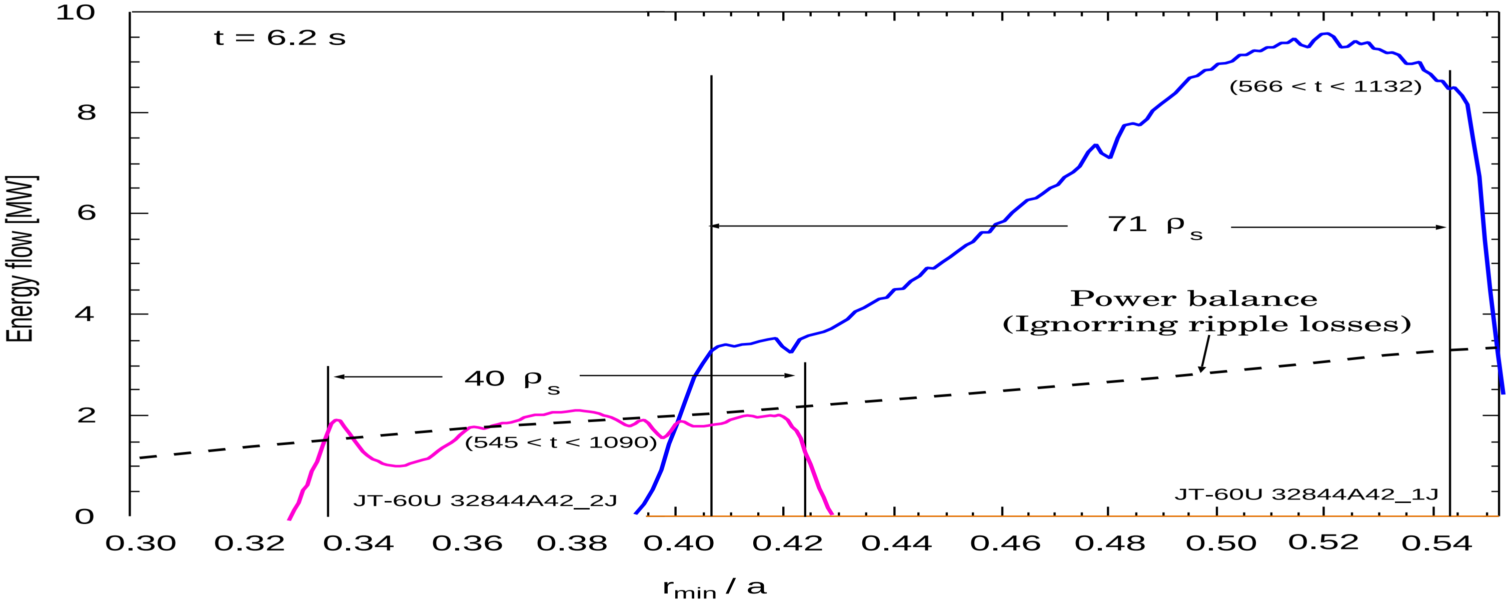
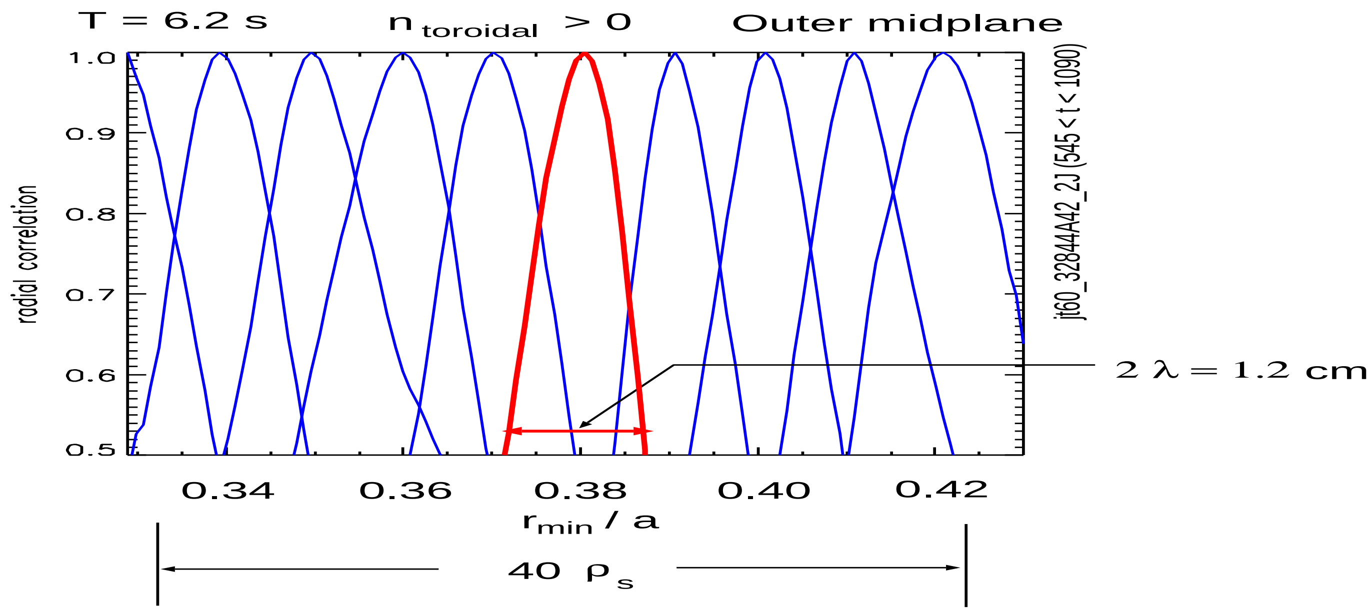
Energy flow profiles at 6.2 s

- GYRO simulated $q_i + q_e \simeq$ 2-9 MW, depends sensitively on $\nabla(T_i)$
- Offset near r_{min}/a = 0.4 due to turbulence spreading?



- TRANSP power balance $\simeq$ 1.2-3.5 MW

Small radial correlation length for potential fluctuations



- $\boldsymbol{\lambda_r(\phi) \neq \lambda_r(n_e)}$

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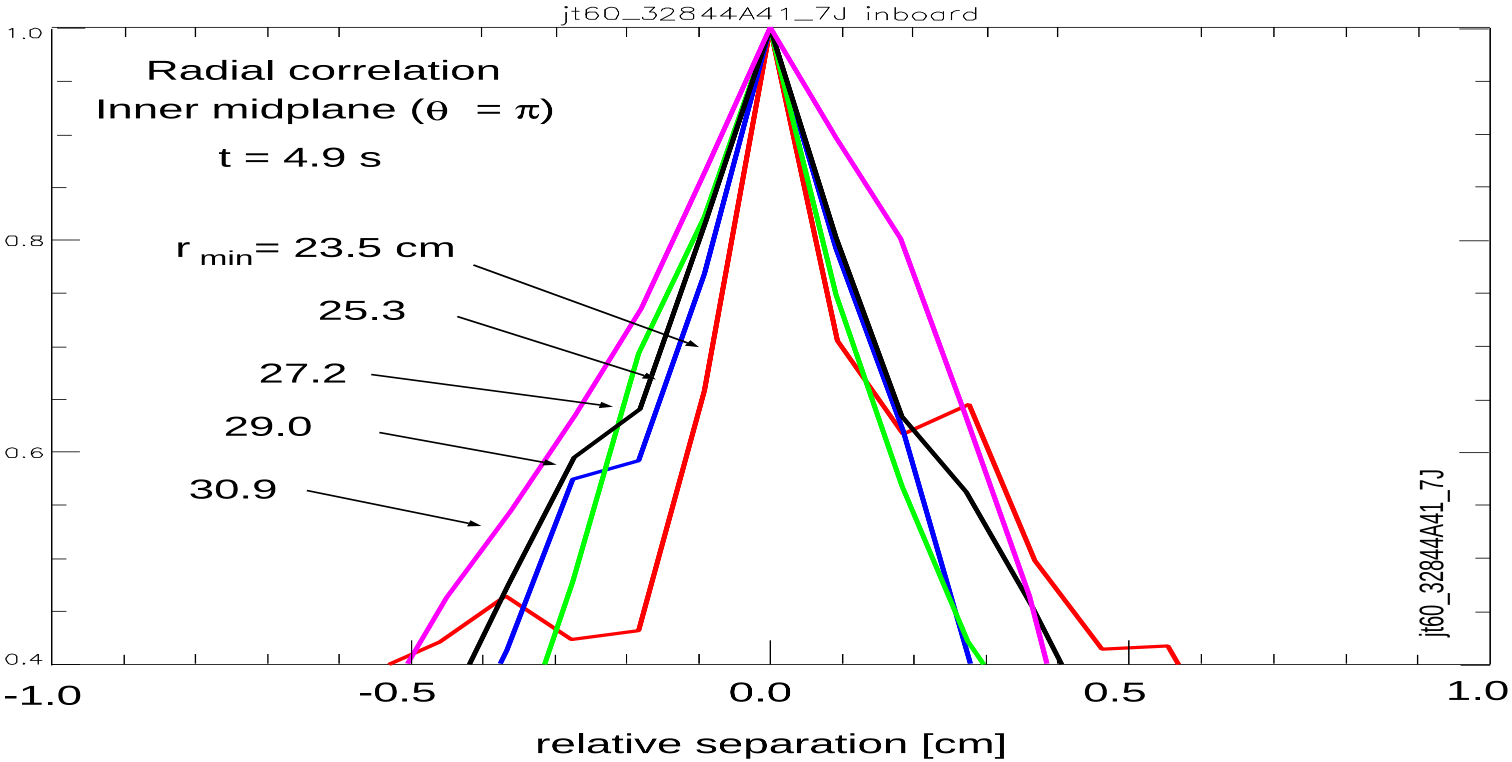
Short n_e radial correlation length early, T=4.9s

- GYRO on high-field side: $\lambda_r \simeq$ 0.3 cm, shorter than LFS x2



- Reflectometry on high-field side, $r_{min} \leq$ 10 cm: $\lambda_r \simeq$ 20 cm

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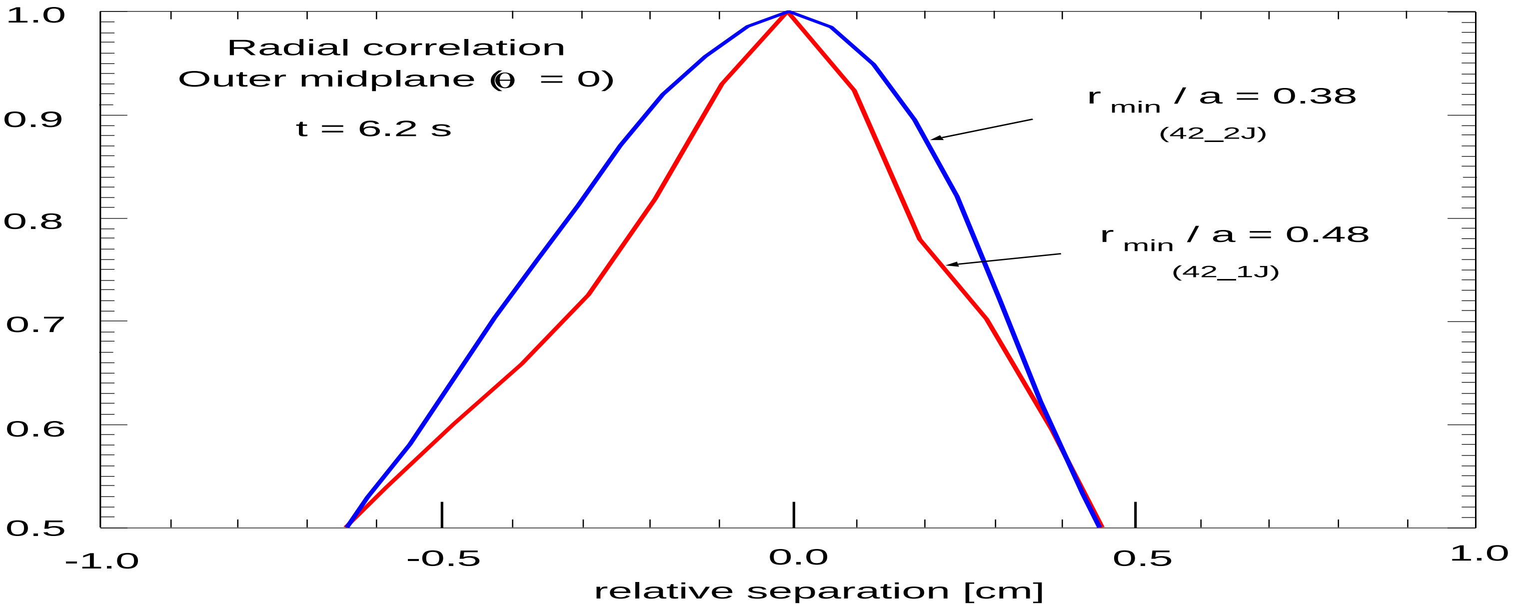
larger n_e radial correlation length at late times

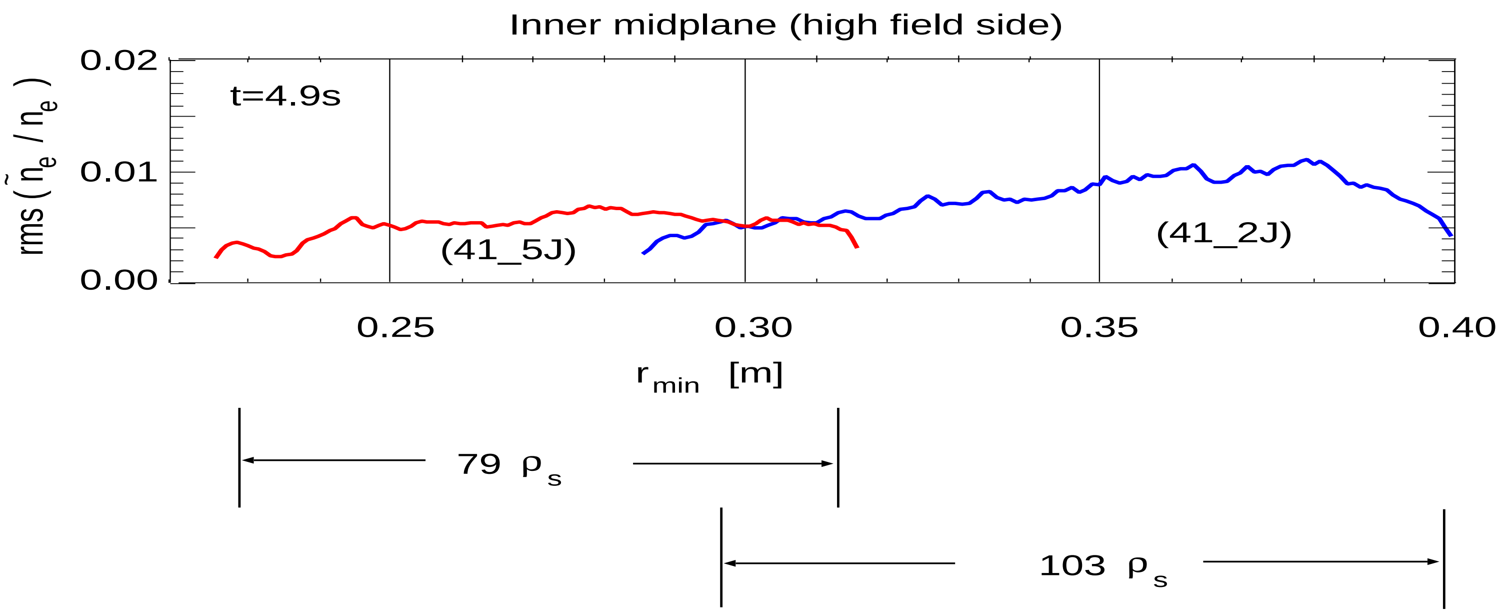
- GYRO: $\lambda_r \simeq 0.5$ cm



- Reflectometry at late times: $\lambda_r \simeq 0.4$ cm

Small root-mean-square ($\tilde{n}_e/n_e$) early, T=4.9s

- GYRO: rms $\simeq$ (0.5-1.0)%



- Reflectometry: high fi eld side rms = (0.2-0.3)%

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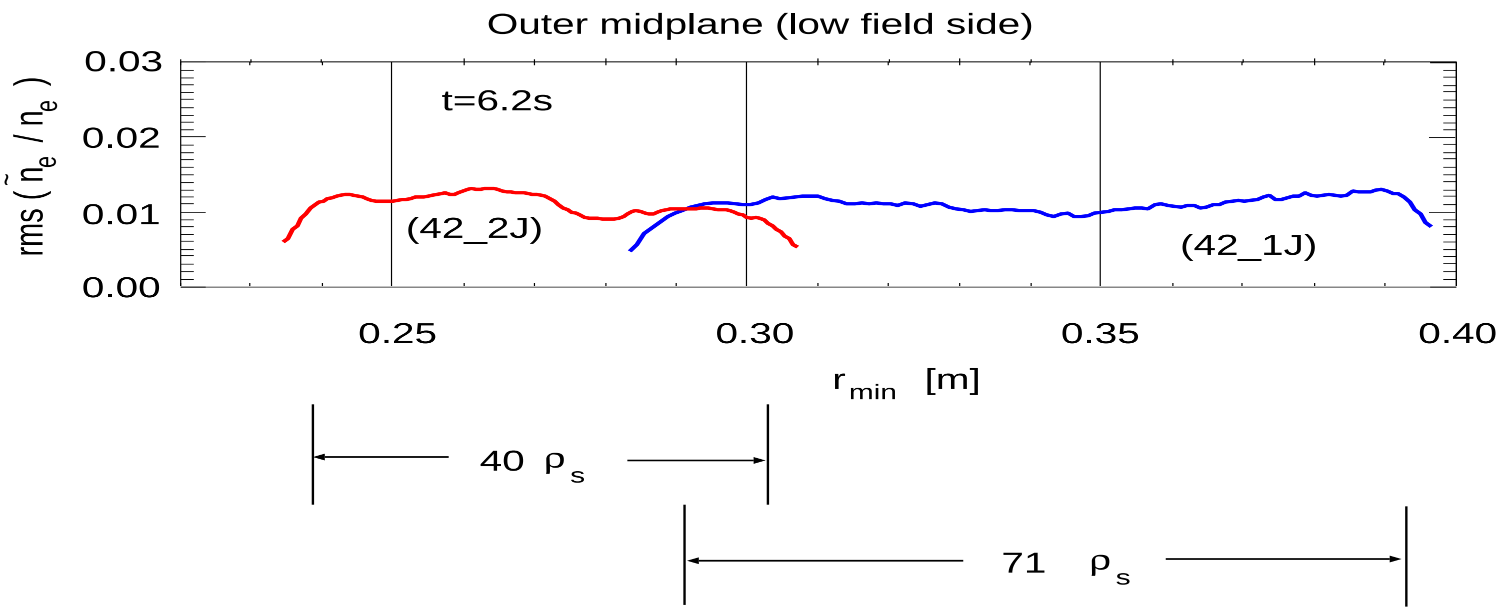
Larger root-mean-square ($\tilde{n}_e/n_e$) at late time

- GYRO at late time: rms relatively constant (1.0-1.5)%



- Reflectometry: rms relatively constant (0.3-0.4)%

Additional findings not discussed here

- Part of ongoing nonlinear GYRO simulations of DIII-D, JET, TFTR, and ITER
  1. energy, particle, and momentum transport and flows are predicted
  2. electron species flow in or out depending on conditions
  3. strong sensitivity to drive terms such as $\nabla(T_i)$
  4. strong sensitivity to E_r
- see 2005 EPS paper on momentum confinement in DIII-D and JET ELMy H-mode plasmas

Summary

- Results for JT60-U plasma in steep gradient region:
  1. Peak $k_\theta \rho_s$ near 0.08 at early time, 0.4-0.6 later times
  2. GYRO simulated energy flow (q$_i$ + q$_e$) higher by x2.5 or more than TRANSP power balance
  3. Gyro simulated n_e radial $\lambda \simeq$ measured reflectometry
  4. GYRO simulated rms($\tilde{n}_e/n_e$) higher x2-3 than reflectometry
  5. Being higher on flows consistent with being higher on $\tilde{n}_e/n_e$

- More work needed

1. Longer runs and alternative grids to test convergence
2. Variations of drive terms to study sensitivity and critical gradients
3. Alter GYRO to input separate v_{tor}^{bulk} and v_{tor}^{imp} for increased accuracy of angular momentum transport
4. Vary E_r and/or Kelvin-Helmholtz ($v_{||}$) drive for comparison
5. Study variation of density fluctuations as $\nabla(n_e)$ varies
6. Increase β_e above zero for EM runs