



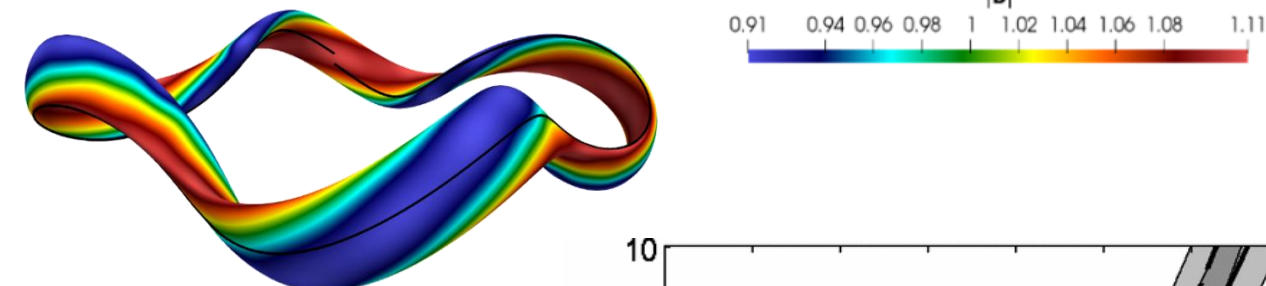
# Using Non-Linear Global Gyrokinetic Simulations to Investigate the Effects of Profile Shaping on Turbulence in the Helically Symmetric eXperiment (HSX)

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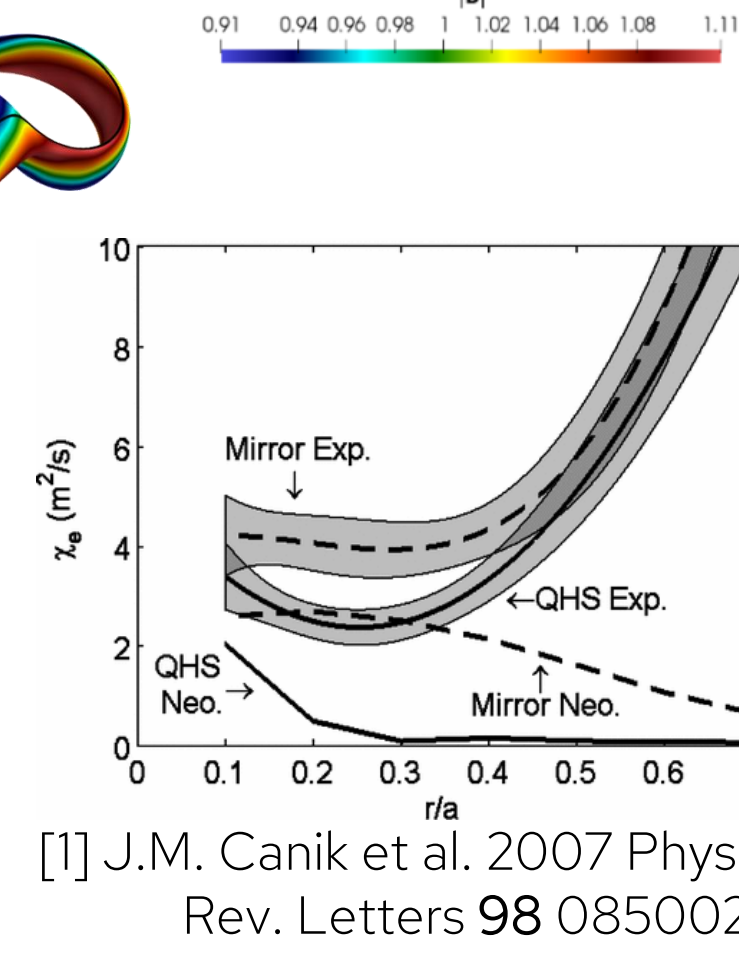
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## The HSX Stellarator Has Low Neoclassical Transport in QHS



- Major radius: 1.2 m
- Minor radius: 12 cm
- 48 main field coils
- 48 planar auxiliary coils
- Quasi-Helically Symmetric (QHS)
- QHS configurations have been shown to have reduced neoclassical heat and particle transport [1], as a result, anomalous transport can be studied in this configuration



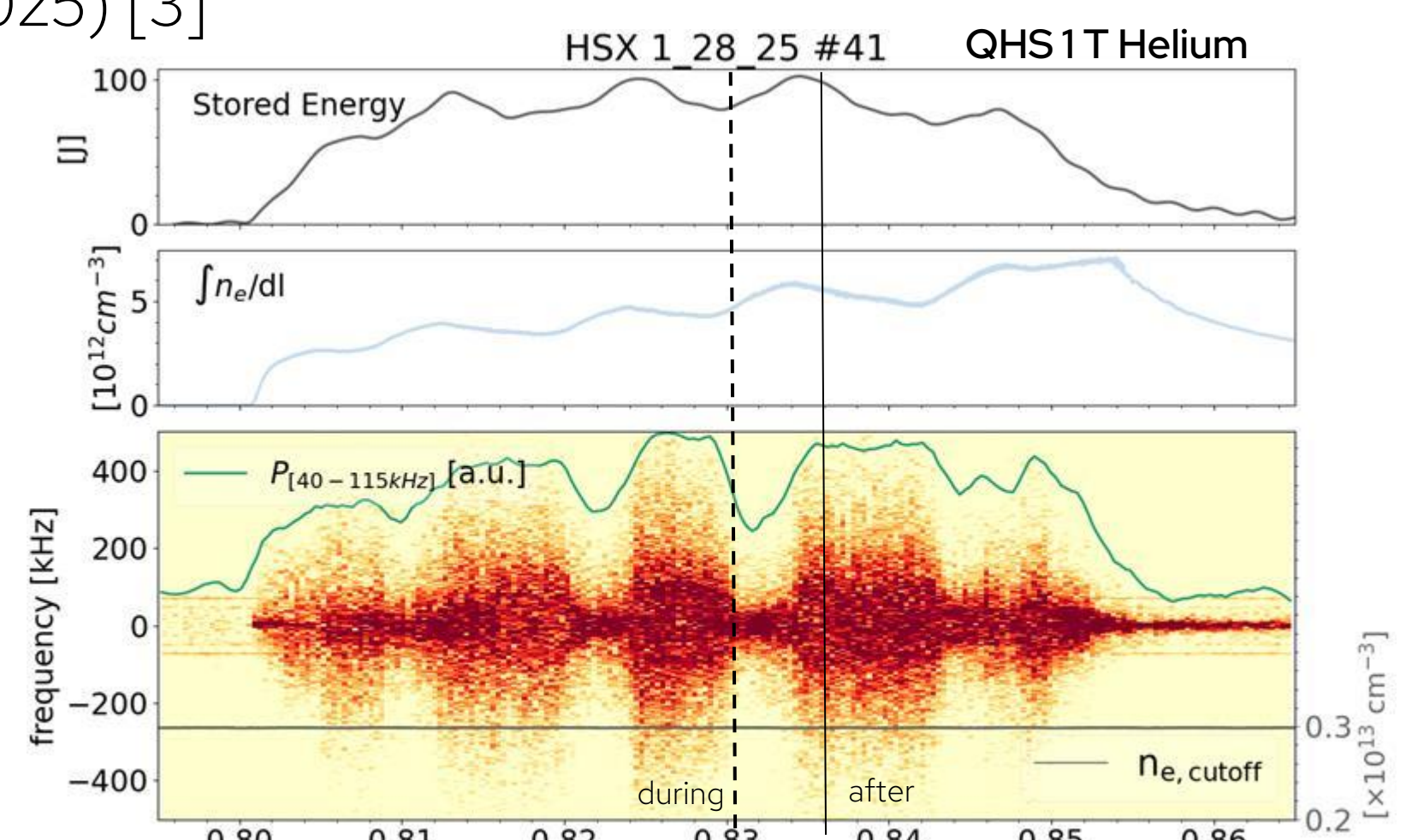
[1] J.M. Canik et al. 2007 Phys. Rev. Letters 98 085002

- Previously, HSX has been shown to be dominated by density-gradient driven trapped electron mode (TEM) [2]

[2] B. J. Faber et al Phys. Plasmas 22, 072305 (2015)

## These Simulations Are Motivated by Recent Experimental Results on HSX

- Recent density ramping experiments in QHS showed increased plasma stored energy (top) during density ramping (center)
- Reflectometry also showed narrowing of the density fluctuations (bottom) with increasing stored energy
- Similar experimental results were reported in X Han et al (2025) [3]



[3] X Han et al Plasma Phys. Control. Fusion 67 (2025) 045011

## The Global Gyrokinetics Code GENE3D Is Used to Simulate 3D Fluctuations

- GENE3D solves the non-linear gyrokinetic-Vlasov equation using a delta-F approach

### The Gyrokinetic Vlasov Equation

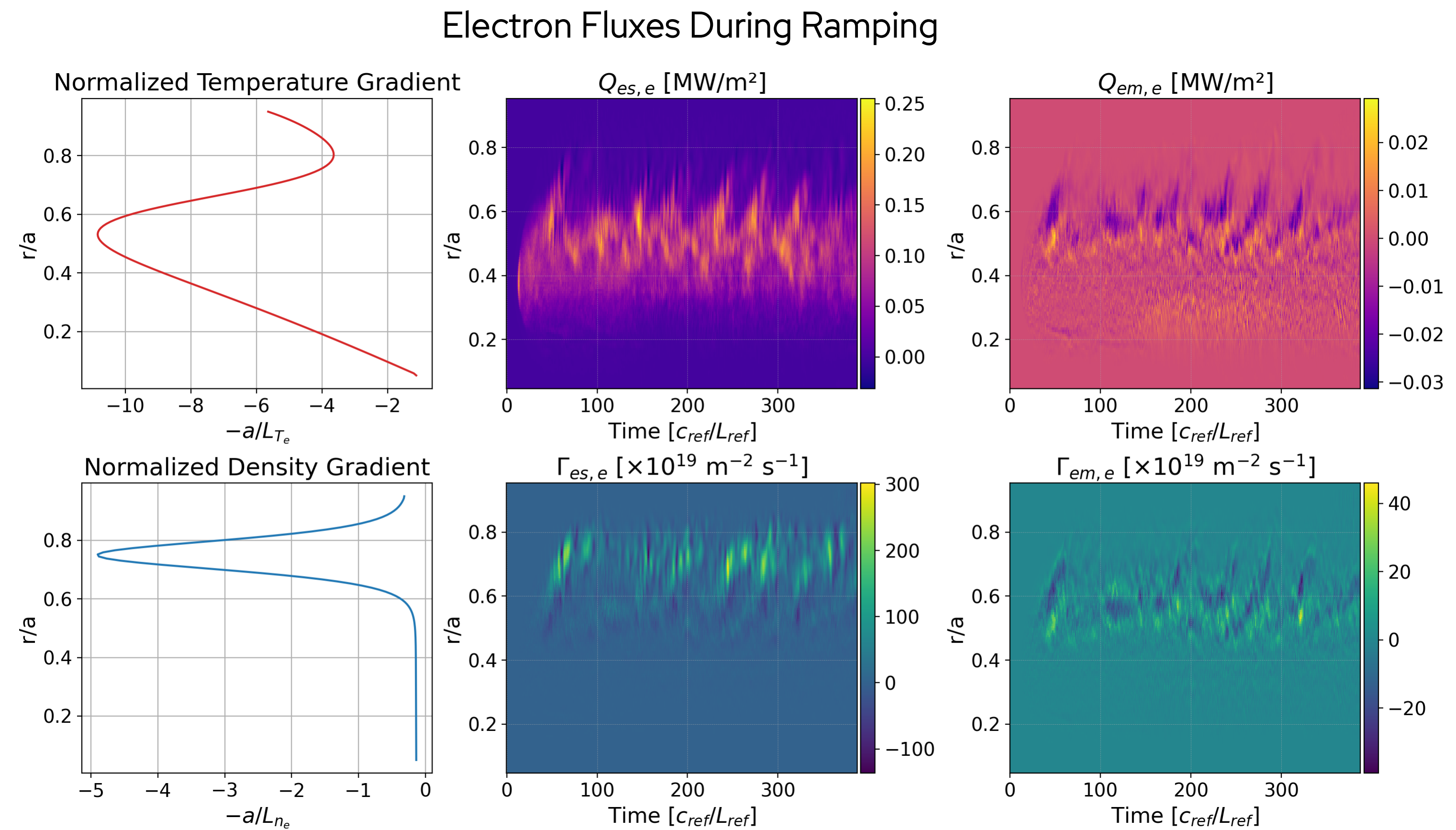
$$\frac{\partial F_{1\sigma}}{\partial t} + v_{\parallel} \hat{\mathbf{b}}_0 \cdot \nabla_{\sigma} F_{1\sigma} - \hat{\mathbf{b}}_0 \cdot \frac{\mu}{m_{\sigma}} \nabla B_0 \frac{\partial F_{1\sigma}}{\partial v_{\parallel}} + (\mathbf{v}_{\nabla B_0} + \mathbf{v}_c) \cdot \nabla_{\sigma} F_{1\sigma} + (\mathbf{v}_{E_0} + \mathbf{v}_{E_1}) \cdot \nabla F_{1\sigma} + \mathbf{v}_{E_1} \cdot \left[ \nabla F_{0\sigma} + \mu \nabla B_0 \frac{F_{0\sigma}}{T_{0\sigma}} \right] + (\mathbf{v}_{\nabla B} + \mathbf{v}_c) \cdot \nabla F_{0\sigma} = 0,$$

- Solved on computational coordinates, based on a field-aligned system where:

- o x represents the radial direction  $x = a \rho_{\text{tor}}$ ,
- o y represents the binormal direction  $y = \sigma B_p C_y (q\theta^* - \phi)$ ,
- o z represents the parallel direction  $z = \sigma B_p \theta^*$ .

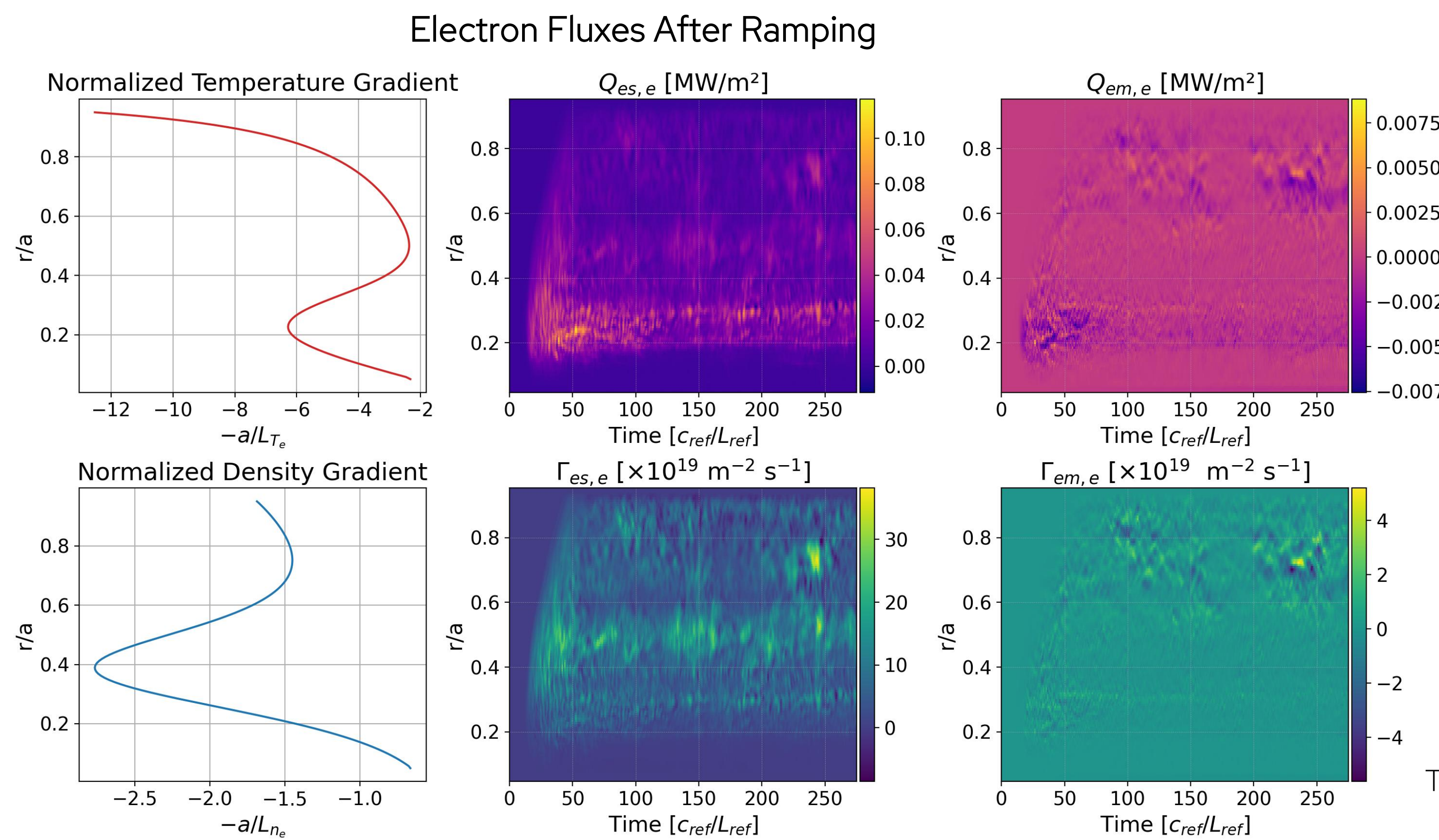
[4] M. Maurer et al. / Journal of Computational Physics 420 (2020) 109694

## Simulation Results Indicate That Different Transport Regimes Are Present

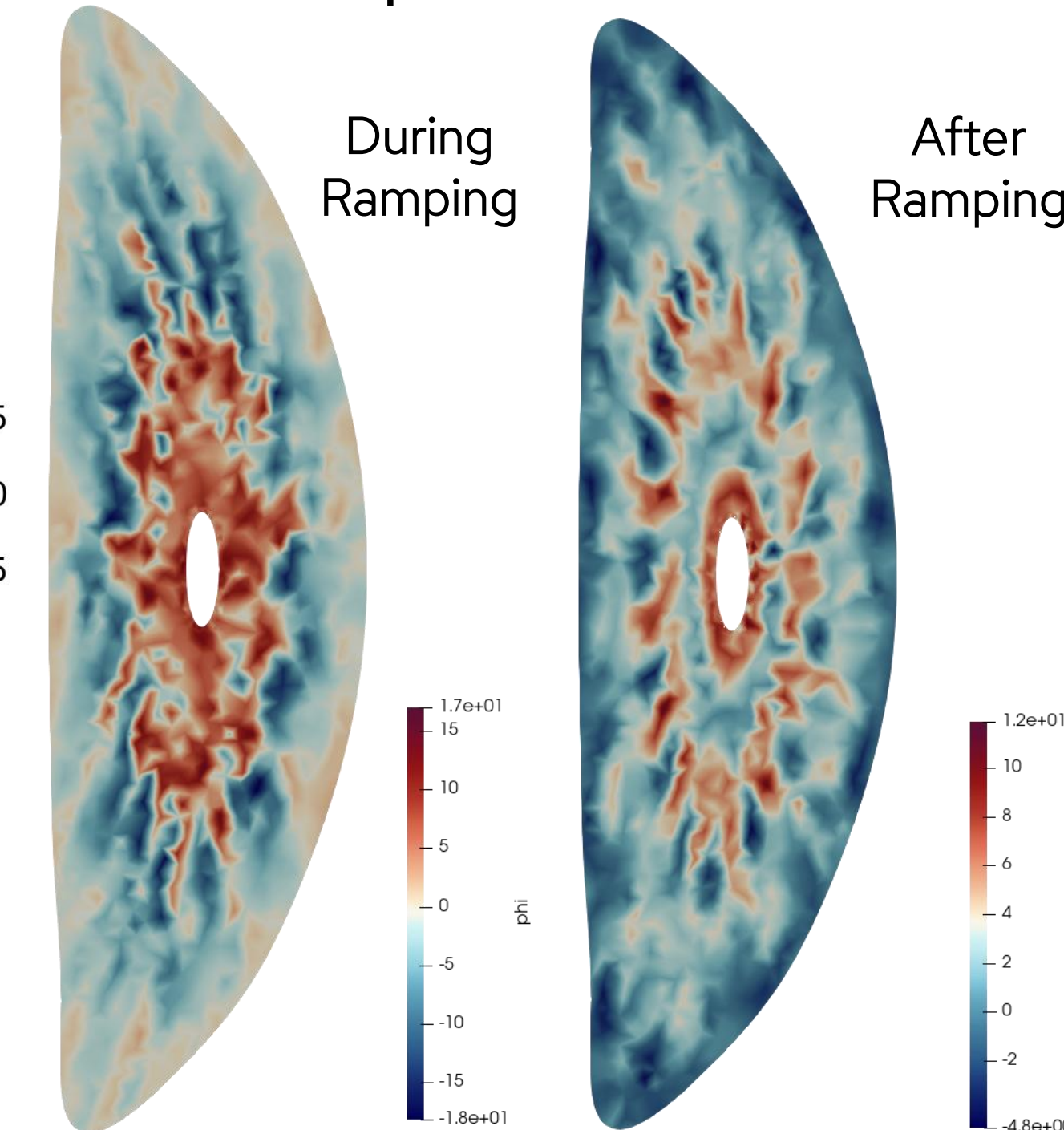


- Electron heat (Q) and particle (Γ) fluxes are calculated with electrostatic (es) and electromagnetic (em) components
- Fluxes are consistent with normalized gradients in both cases
- This suggests that temperature-gradient driven trapped electron modes may be responsible for transport, particularly during ramping
- Stronger, more localized heat/particle flux is seen during ramping, compared to broader heat/particle flux after ramping

$$\frac{a}{L_{\kappa}} = \frac{a}{\frac{1}{\kappa} \frac{dk}{dx}}$$

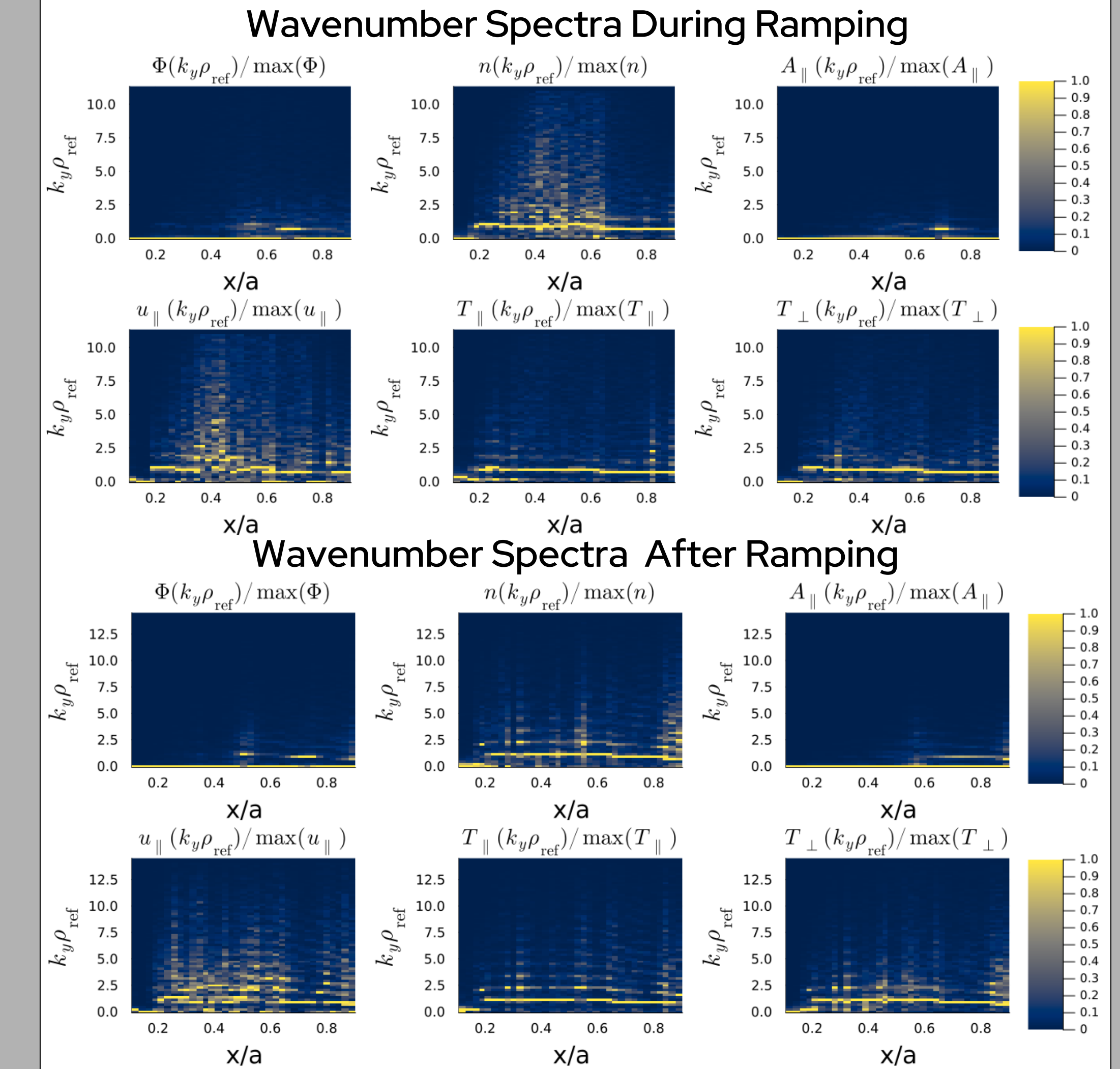


### Poloidal slices of the electrostatic potential



The structures that form within the simulation have different characteristics

## k<sub>y</sub> Spectra of Fluctuating Quantities Show Difference in Structures Between Simulations



- Spectra are averaged over z and binned along x/a
- $\phi$ ,  $A_{\parallel}$ , and  $T_{\parallel/\perp}$  spectra show similar characteristics between simulations
- During ramping  $u_{\parallel}$  fluctuations shows a narrower radial extent (near x/a=0.4) of fluctuations than after
- Density fluctuations during ramping show a wider radial extent than after ramping

## Conclusions and Future Work

This work aims to characterize turbulent transport seen in experimental results on the HSX stellarator by using the global gyrokinetic code GENE3D

- Two cases are modeled: during and after density ramping
- The heat and particle fluxes from these simulations indicate that these cases are two different transport regimes in HSX
- Spectra of fluctuation quantities show further differences in the structures forming
- Additional convergence studies of the simulation parameters will be done for non-linear simulations
- Future analysis will be done, such as:
  - o Comparison to flux-tube gyrokinetic simulations
  - o More thorough comparison to experimental results
  - o Calculation of coherence, cross phase and other statistical quantities
  - o Development of different analysis tools such as frequency spectra and poloidal/toroidal spectra

## Simulations Are Initialized with Experimental Profiles and QHS Magnetic Equilibrium

- These simulations represent some of the first global gyrokinetic simulations of HSX
- Electrons are assumed to be adiabatic, i.e.  $m_e/m_i \rightarrow 0$ , and  $v_{Te}/v_{Ti} \rightarrow \infty$
- Fluctuations are assumed to be small for delta-F formulation to be valid
- Initialized simulations using experimental Thomson profiles for density and temperature: (1) During ramping and (2) after ramping
- Simulated from x/a of 0.1 to 0.9, and over one field period (1/4 of the plasma volume)
- The magnetic equilibrium is set up using a VMEC equilibrium for the QHS configuration solved in vacuum
- Simulations are run until they reach a quasi-stationary state, when volume-averaged values plateau

### Profiles Used to Initialize Simulations

