Towards experimental validation of TEM turbulence simulations in the HSX stellarator

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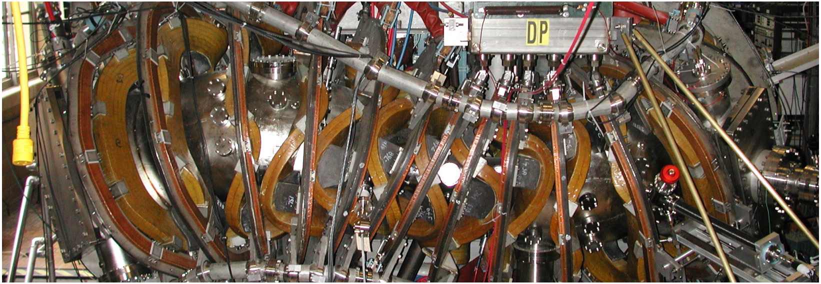
Outline

1. Neoclassical transport reduced in HSX — Next step: turbulence optimization
2. Gyrokinetic simulations: anomalous flux is smaller in a helically symmetric vs. broken symmetry configuration
3. Ongoing and proposed experimental diagnostics efforts

Many degrees of freedom in a stellarator → optimization

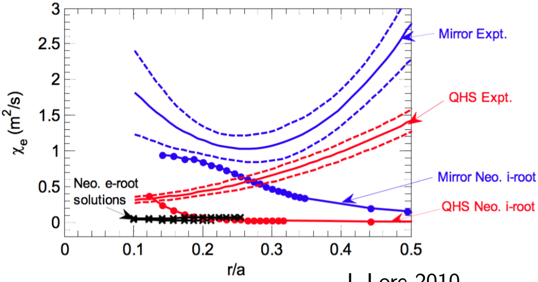


- HSX: flexible coilset, can validate geometry impact on simulations.
- HSX has demonstrated reduced neoclassical transport.
- Optimization for turbulence requires understanding relative importance of geometric parameters (H. Mynick 2006).

HSX is dominated by anomalous transport

QHS Quasi-Helical Symmetry, dominant [n,m] = [4,1] term.

Mirror Broken symmetry configuration: large [n,m] = [4,0] and [8,0] mirror terms.

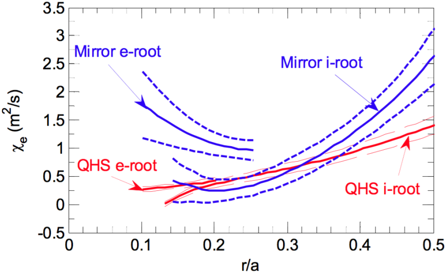


J. Lore 2010

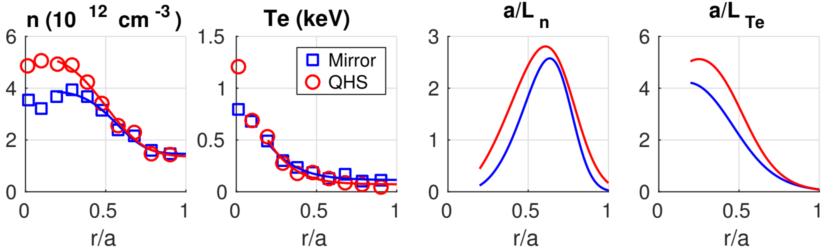
- HSX has demonstrated reduced neoclassical transport with quasi-helical symmetry for $r/a < 0.3$.
- Anomalous transport dominates neoclassical transport for $r/a > 0.3$.

Anomalous heat flux is larger in Mirror

- Matched QHS/Mirror profiles require 1.7× more input power in Mirror.
- Anomalous transport increased in configurations with broken symmetry.
- Current simulations target $a/L_n = 2$, $a/L_{T_e} = 0$.

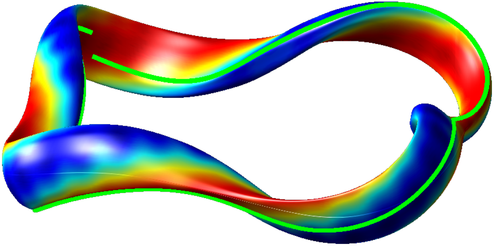


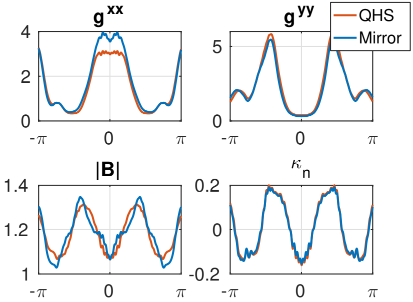
Anomalous heat flux (J. Lore 2010).

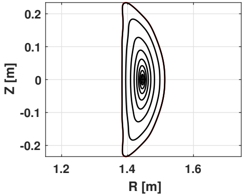


Configurations in simulation: QHS and Mirror

- Simulation domain: flux tube centered in bad curvature region.
- Studies use multiple flux tubes.

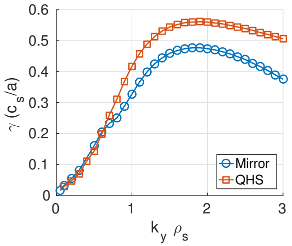




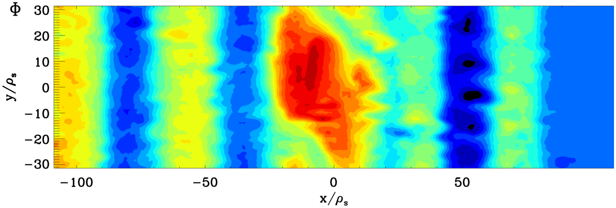


Nonlinear saturation depends on zonal flows, coherent structure

- GENE (www.genecode.org): ∇n TEM dominant in QHS, Mirror.
- Zonal flows essential in TEM saturation, transport regulation.
- *Note*: shearing rate paradigm fails ($\omega_s \approx \gamma$).
- A coherent structure at low-k_y can drive large variation in the saturated fluxes.



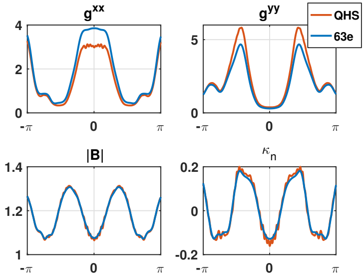
QHS, a/Ln = 4, a/LTe = 0



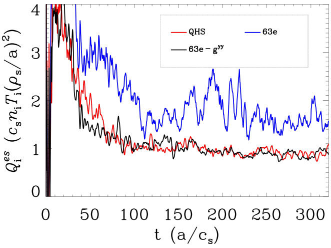
Saturation is sensitive to geometric parameters

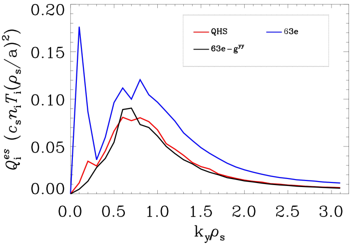
QHS – High mode number VMEC that reproduces field line following.

63e – Low mode number VMEC that does not reproduce coil ripple, LCFS shape.



- Large difference in heat flux resolved by substitution of g^{yy} (local shear) in 63e.
- Careful choice of VMEC is important !

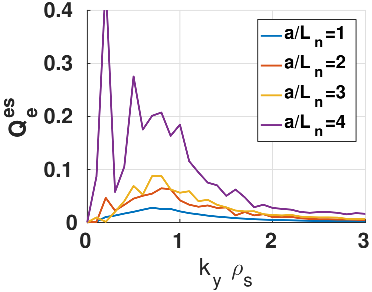


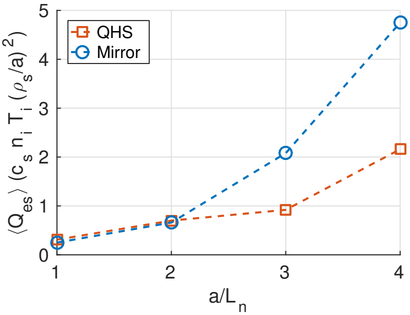


Mirror has larger flux than QHS in simulation

- Heat flux scales more strongly with density gradient in Mirror.
- Increase in heat flux related to onset of coherent structure.

QHS heat flux spectra

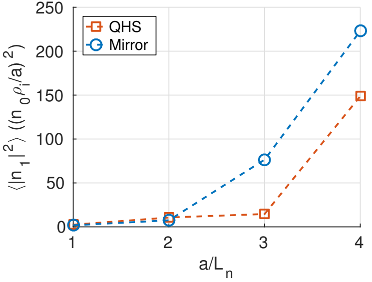


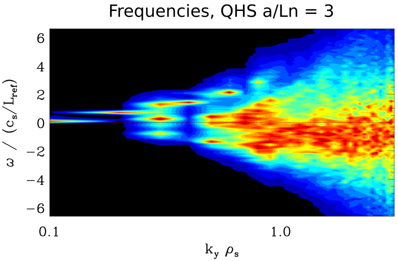


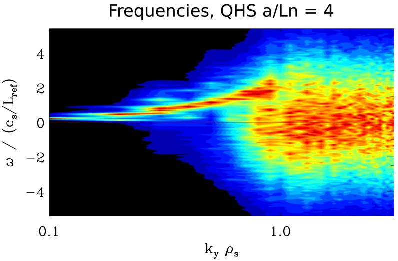
- Heat flux difference is on order of experimental difference.

Density fluctuations - accessible validation target

- Density fluctuations mirror Q_e^{es} trend with a/L_n.
- Cross-phase is constant — amplitude measurement.
- Appearance of strong ion frequency feature at large gradients.



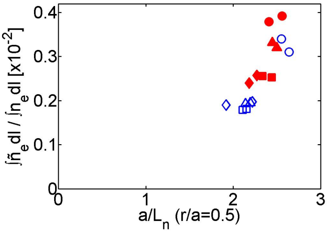




Turbulence diagnostics at HSX

- Reflectometer – $\tilde{n}$ amplitude for $0.2 \leq k_y \rho_s \leq 1$ (operational, K. Likin, HSX).
  - Synthetic diagnostic is immediate future work (J. Smoniewski).
- Microwave scattering – k resolved $\tilde{n}$ amplitude for $k_y \rho_s \leq 2$ (upgrade in progress - C. Deng, HSX).
- CECE – $\tilde{T}_e$ at $k_y \rho_s \geq 0.3$ (under construction - K. Likin, HSX).
- Measurement of zonal flows by Langmuir probes (S. Ohshima, Kyoto Univ.).
- Edge Langmuir probes – $\tilde{n}$, $\tilde{\phi}$ amplitude and phase (operational).
- BES – k resolved n fluctuations (under consideration - S.T.A. Kumar, HSX & S. Kobayashi, Kyoto Univ.).

$\tilde{n}$ from interferometry



From C. Deng

Towards validation of TEM turbulence simulations

- Surveying HSX configurations with gyrokinetics — predicting fluxes, fluctuation levels.
- TEM transport is sensitive to geometry, cannot accurately be described by linear physics.
- Density fluctuations, accessible by microwave scattering and reflectometry — validation candidate.
- Zonal flows prominent in turbulence — validation candidate.
- An initial survey of 729 HSX configurations was completed with a linear growth rate proxy by J. Proll, IPP.

Next steps:

- Implement a synthetic diagnostic for comparison to reflectometer measurements.
- Microwave scattering and CECE under construction.
- Identification of zonal flows with Langmuir probes.