Comparing Turbulent Transport in Quasi-Helically Symmetric and Quasi-Axisymmetric Stellarators

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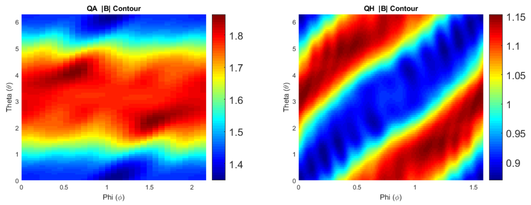
I. Overview

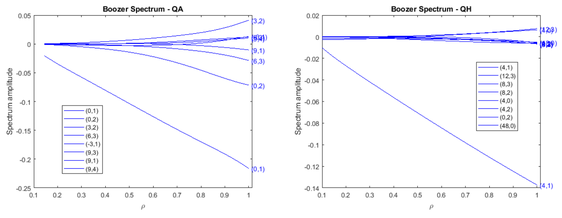
- ITG turbulence studied using GENE for two quasi-symmetric stellarators: quasi-helical symmetry (QH/HSX) and quasi-axisymmetry (QA/NCSX)
- Change of heat flux between configurations opposite of linear trends, $Q_{QH} < Q_{QA}$ while $\gamma_{QH} > \gamma_{QA}$
- Linear electromagnetic simulations suggest lower KBM β in quasi-helical symmetry

II. Quasi-Symmetry

- Variety of optimized stellarators: quasi-helical (HSX), quasi-omnigenous (W7X), and quasi-axi-symmetry (NCSX)
- Goal of quasi-symmetry: create symmetry in $|B|$ contours, whether that be helical or toroidal



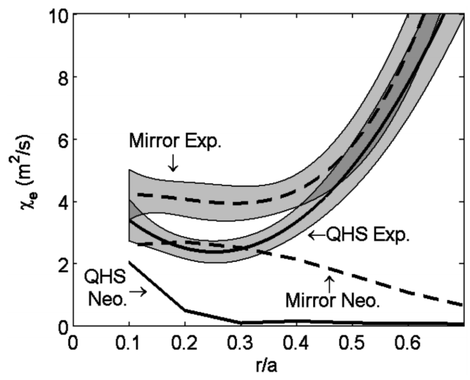
- Dominant term is (4,1) in this flavor of quasi-helical symmetry; (0,1) in quasi-axisymmetry
- Quasi-symmetry forces bounce-averaged particle excursion from flux surface during banana orbit to zero
- Magnetic (Boozer) spectra for quasi-axisymmetry (left) and quasi-helical symmetry (right) plot relative strength of magnetic modes



- Quasi-symmetric stellarators neoclassically optimized, dominant mechanism of heat and particle flux is turbulence

III. Experimental Motivation

- Disparity between electron neoclassical and anomalous transport at larger radii in quasi-helical symmetry shows turbulence dominates

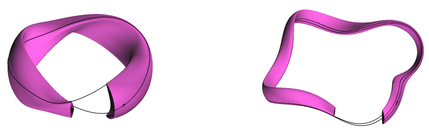


(Canik, 2007).

- Reduction of anomalous transport at center of ongoing optimization effort at UW-Madison

IV. Simulation Approach

- Gyrokinetics averages fast cyclotron motion, reduces phase space ⇒ large efficiency gain
- Gyrokinetic code GENE, (www.genecode.org), runs adiabatic or kinetic (electrostatic and electromagnetic) electrons
- Two flux tubes studied in QH (bean and triangle), one flux tube in QA



Courtesy of Pavlos Xanthopoulos.

- While GENE can do flux surface simulations, only local, flux tube domains used here

Acknowledgements

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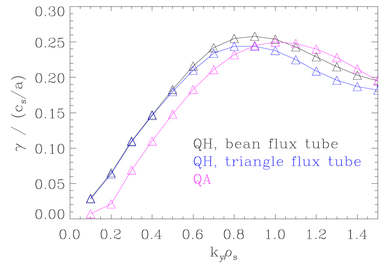
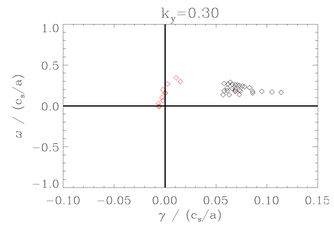
V. Stability Analysis

- Adiabatic electrons: normalized gradients of $a/L_{T_i} = 3$, $a/L_n = 0$ used to study ITG turbulence, motivated by anticipation of strong levels of ion heating in new stellarator

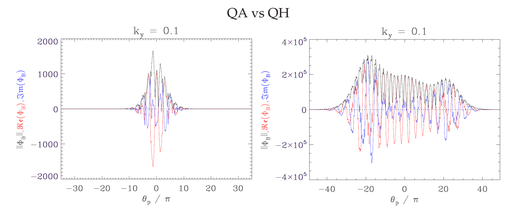


Adiabatic Electrons.

- Earlier work in (Rewoldt, 2005), consistent with our results, suggests QA more favorable then QH



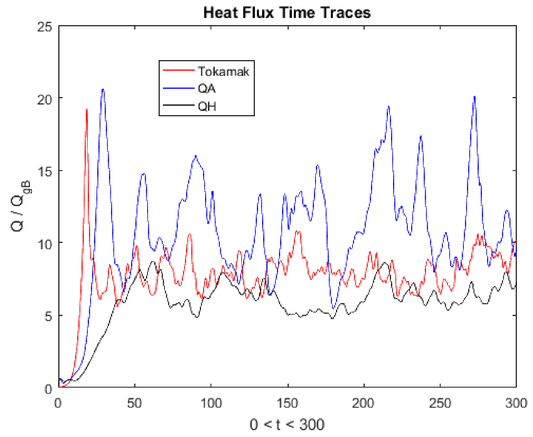
- QH (black) larger number of unstable modes, unlike QA (red)



- Eigenmodes highlight extended, slab-like nature of modes in quasi-helical symmetry versus more spatially localized, toroidal-like modes in quasi-axisymmetry

VI. Nonlinear Results

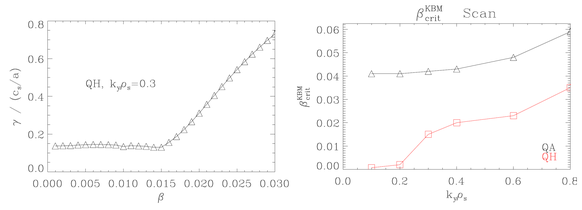
- A priori, unclear that linear results translate to nonlinear systems
- Adiabatic electrons: nonlinear shows $Q_{QH} < Q_{QA}$, but same order of magnitude



- Main takeaway of work is trends predicted by linear models are not seen nonlinearly ⇒ need nonlinear simulations or improve linear models for optimization

VII. Kinetic Ballooning

- Finite β linear runs suggest QH much lower $\beta_{\text{crit}}^{\text{KBM}}$ than QA



- Ongoing effort to compare low k_y results with MHD

VIII. Future Work

- Extending nonlinear studies to fully electromagnetic regime, expanding comparison between two symmetries
- Long time goal is design of turbulence optimized quasi-symmetric stellarator