Gyrokinetic study of electron transport in NSTX using XGC

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59th Annual Meeting of the APS Division of Plasma Physics, October 23 - October 27, 2017, Milwaukee, Wisconsin

PPPL PRINCETON PLASMA PHYSICS LABORATORY

EPSI Edge Physics Simulation

Funding Source: SciDAC
Computational Resource: NERSC

Electron Temperature Gradient Modes in NSTX and NSTX-U

- Electron heat transport in NSTX has been a puzzle. Prediction for NSTX-U is unclear.
- Electron temperature gradient (ETG) modes are high k_y, electron scale instabilities driven by the temperature gradient of electrons [Horton *et al.*, Phys. Fluids (1988)]
- ETG may produce large electron heat transport relevant to experimental level [Jenko *et al.*, Phys. Rev. Letts (2002)].
- ETG modes can be responsible for profile stiffness observed in T_e [Idomura *et al.*, Nucl. Fusion (2005)]
- Nonlinear toroidal coupling can regulate the ETG turbulence level [Lin *et al.*, JPCS (2005)]
- Kinetic ion physics and ion scale zonal flow modes are required for nonlinear saturation [Waltz *et al.*, Phys. Plasmas (2007)]
- How do ETG modes interact with global ion-scale turbulence, including the edge turbulence?
- Here we present linear results as initial steps.

Introduction of XGC1 code

- XGC1 is a PIC based full-f gyrokinetic code
- Can simulate the whole volume from magnetic axis including X point and scrape off layer
- Uses EFFIT experimental geometry, Grad-Shafranov circular geometry, or analytic toroidal geometry
- It is 3d in configuration space and 2d in velocity space
- Calculates turbulent as well as neoclassical field together
- Includes source and sink, neutral particle physics
- Fully nonlinear collision operator

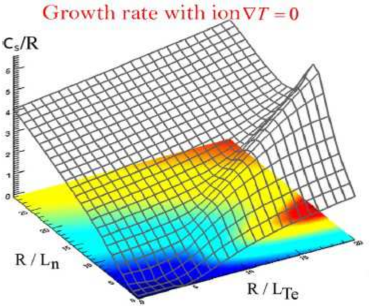
Benchmark studies with GENE and GYRO:

Ions are adiabatic and electrons are gyrokinetic. Electrostatic and no collisions. Circular, concentric flux surfaces. Following parameters are used

Minor radius $a = 0.3995\text{m}$; Major radius $R_0 = 1.7\text{m}$;
Magnetic field $B = 1.14T$
the location of simulation $r_0 = 0.5a$;
safety factor, $q(r_0) = 1.4$;
shear $\hat{s}(r_0) = 0.78$
Electron temperature $T_e = 5.0 \times 10^3$ eV
Ion temperature $T_i = 5.0 \times 10^3\text{eV}$;
Real Electron to Ion mass ratio. Electron temperature gradient $R/L_{Te} = 6.9$,
Density gradient $R/L_n = 2.2$,
Aspect ratio $a/R = 0.235$

Trapped Electron Modes are absent in the chosen parameter space

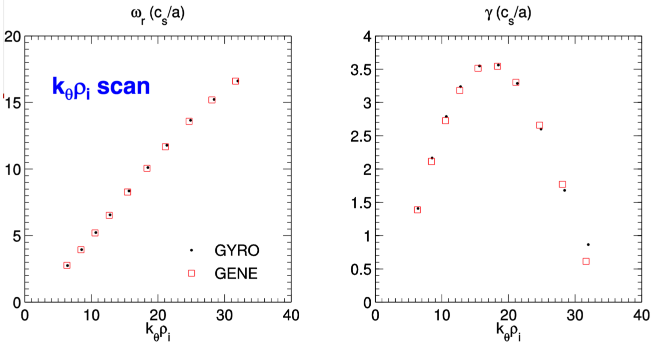
The TEM should be stable. We found that the mode is insensitive to density gradient. It has high k_y. Following stability diagram for TEM corroborates the observation.



Ernst *et al.*, Phys. Plasmas (2009)

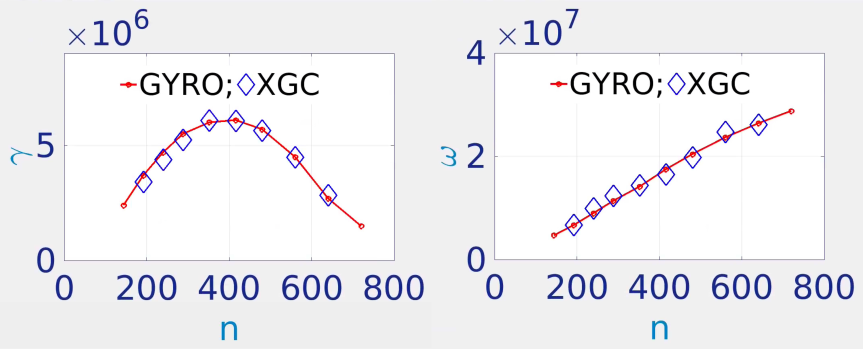
GENE-GYRO comparison

GENE and GYRO calculations match very well. (Taken from W. Guttenfelder slides)



GENE simulations are by D Mikkelsen, GYRO simulations are by W Guttenfelder

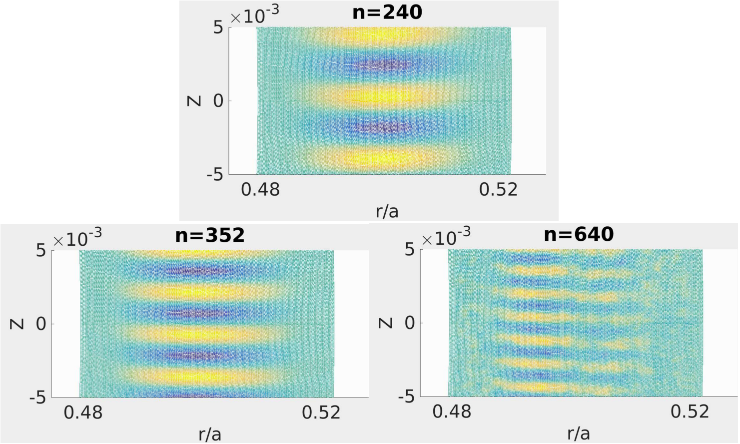
XGC1 agrees very well with GYRO/GENE



Growth rates and real frequencies for XGC1 and GYRO simulations

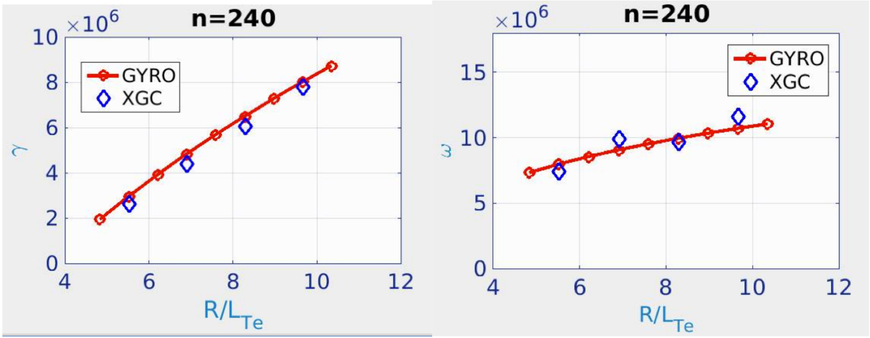
$r_{in} = 0.48a$, $r_{out} = 0.52a$, $\Psi_{in} = 0.363$, $\Psi_{out} = 0.410$
$\#$ of flux surfaces $= 109$; $\#$ of elements $\simeq 3.4e6$; $\triangle r = \rho_e$,
$\triangle l_\theta = \frac{\rho_e}{2}$, particle/cell=50, real electron to ion mass ratio.

Mode Structure of the ETG mode



Mode structures of ETG for different n. The mode structure becomes finer as the mode number increases. Demand higher resolutions and are computationally very expensive.

XGC1 agrees well with GYRO/GENE simulations: R/L_{Te} scan



Growth rates and real frequencies or XGC1 and GYRO simulations

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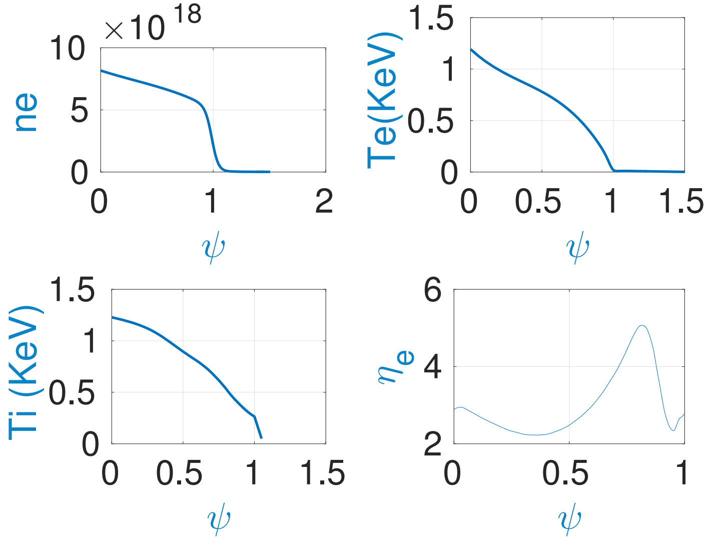
$\triangle l_\theta = \frac{\rho_e}{2}$, particle/cell=50, real electron to ion mass ratio.

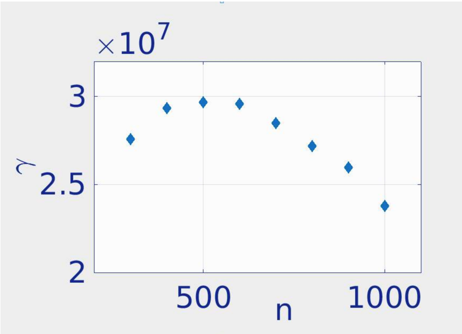
Study of ETG mode in the NSTX

The profiles for the shot number 139047 are depicted below.



Study of ETG mode in the NSTX: core simulations

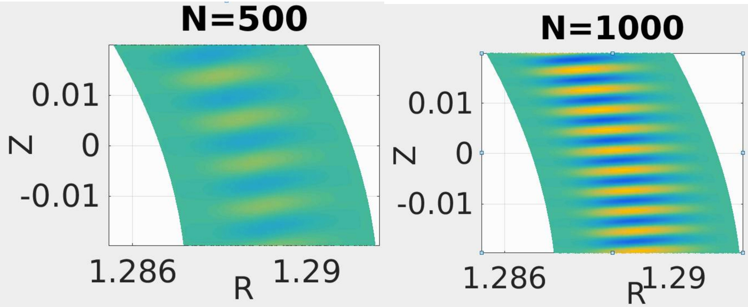
Here, $r/a = 0.5$, $r/R \sim 0.3$, $q \sim 2.0$, $shear \sim 0.7$, $Te/Ti = 0.85$.
We consider $Z_{eff} = 1.0$, and no collisions. Ions are adiabatic.



We use following simulation parameters
$r_{in}/a = 0.495$, $r_{out}/a = 0.505$, $\Psi_{in} = 0.32267$, $\Psi_{out} = 0.33365$
flux surfaces=41, # of elements$\simeq$ 3.0e6, $\triangle_r = \rho_e$, $\triangle l_\theta = \frac{\rho_e}{2}$,
of particles/cell=100. Real electron to ion mass ratio.

Study of ETG mode in the NSTX: core simulations

Mode structure for different toroidal mode numbers in the core



Mode structures of ETG for different n. The mode structure becomes finer as the mode number increases. Computationally very expensive.

Summary and future directions

- We used actual electron to ion mass ratio and carried linear stability studies for the ETG mode.
- The linear growth rates and real frequencies calculated with XGC1 agree very well with GYRO and GENE over a wide range of toroidal mode numbers and electron temperature gradient values.
- We are studying the role of the ETG mode in the electron transport in NSTX using experimental profiles and parameters.
- We calculated the linear growth rates of the ETG mode for different toroidal mode numbers in the core.
- Presence of the ETG mode for edge parameters is under investigation.
- ETG interaction with global ion kinetic physics will be included in the next phase.