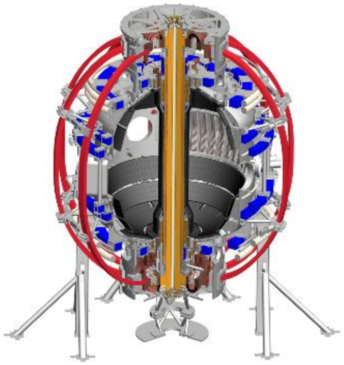
TGLF-GYRO comparisons for NSTX L-mode

T&T TSG group meeting

December 7, 2017



Overview

From 2013:

- Initial linear TGLF-GYRO comparisons based on NSTX L-mode 141716 (Ren NF 2013)
- Definition of "STL-STD" parameters
- Initial nonlinear TGLF-GYRO comparisons

2017:

- Beginning of aspect ratio comparison to test NL saturation & ZF dynamics

NSTX test cases

- In NSTX H-mode discharges, any and all of the following micro-instabilities can be unstable at different regions, simultaneously: ITG, TEM, ETG, KBM, microtearing
  $\rightarrow$ challenges any reduced model

- **To start, focus on cases expected to be dominated mostly by one instability**
  [Ref. 1] L-mode discharge (ITG) – NSTX 141761
  I_p=0.9 MA, B_T=0.55 T, P_{NBI}=2 MW
  [Ref. 2] "Low" beta H-mode discharge (ETG) – NSTX 141031/141040
  I_p=, B_T= , P_{NBI}=3 MW
  [Ref. 3] "High" beta H-mode discharge (microtearing) – NSTX 120968/138564
  I_p=0.7 MA, B_T=0.35 T , P_{NBI}=4 MW
  [Ref. 4] NSTX-U scenario – 142301 (?)
  I_p=, B_T= , P_{NBI}=6 MW

[1] Y. Ren et al., IAEA (2012), Nucl. Fusion (2013)
[2] Y. Ren et al., Phys. Plasmas (2012)
[3] W. Guttenfelder et al., Phys. Rev. Lett. (2011)
[4] S.P. Gerhardt et al., Nucl. Fusion (2012)

NSTX L-mode at relatively low beta

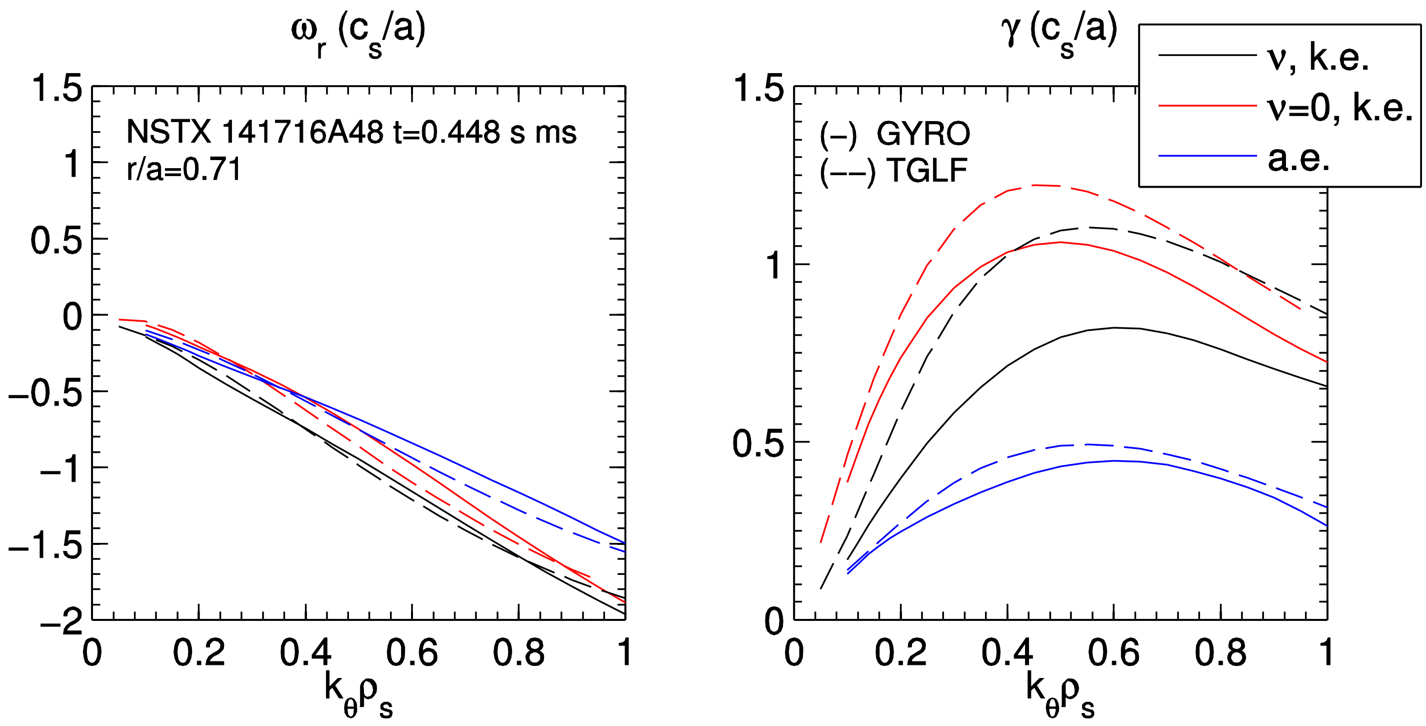
- **Shaping not very extreme (local surface shape κ=1.5, δ=0.1)**
- **Biggest difference to DIII-D is aspect ratio (R/a<1.5) and higher $\nu_{ei} \cdot a/c_s$~0.4-2.9**

r/a	q	s	T_e/T_i	a/L_{Ti}	a/L_{Te}	a/L_{ne}	Z_{eff}	ν_{ei}	β_e (%)	γ_E	γ_p	Ma	α_{MHD}
0.6	1.39	0.89	0.89	4.68	5.17	3.47	1.19	**0.39**	**0.586**	0.77	2.57	0.47	0.46
0.66	1.55	1.45	0.90	6.82	5.98	3.03	1.19	**0.61**	**0.312**	0.59	2.00	0.40	0.31
0.71	1.77	2.30	0.94	6.83	6.35	1.60	1.15	**0.99**	**0.184**	0.35	1.22	0.37	0.20
0.76	2.15	3.49	0.95	7.00	6.94	1.63	1.15	**1.75**	**0.104**	0.24	0.95	0.38	0.16
0.8	2.64	4.65	0.96	8.46	7.94	2.55	1.15	**2.86**	**0.060**	0.25	1.16	0.39	0.15

r/a	**R/a**	Z/a	κ	δ	ζ	dR/dr	dZ/dr	s_κ	s_δ	s_ζ
0.6	**1.449**	0.008	1.542	0.090	-0.013	-0.267	-0.001	-0.023	0.036	-0.027
0.66	**1.432**	0.008	1.540	0.094	-0.015	-0.286	-0.001	0.002	0.049	-0.029
0.71	**1.417**	0.008	1.542	0.099	-0.017	-0.312	-0.002	0.029	0.078	-0.025
0.76	**1.401**	0.008	1.547	0.106	-0.019	-0.351	-0.002	0.073	0.140	-0.017
0.8	**1.386**	0.008	1.555	0.115	-0.019	-0.392	-0.003	0.129	0.229	-0.002

Using identical model choices with collisions (ν_{ei}=0.99 c_s/a) TGLF predicts growth rates ~35% larger than GYRO

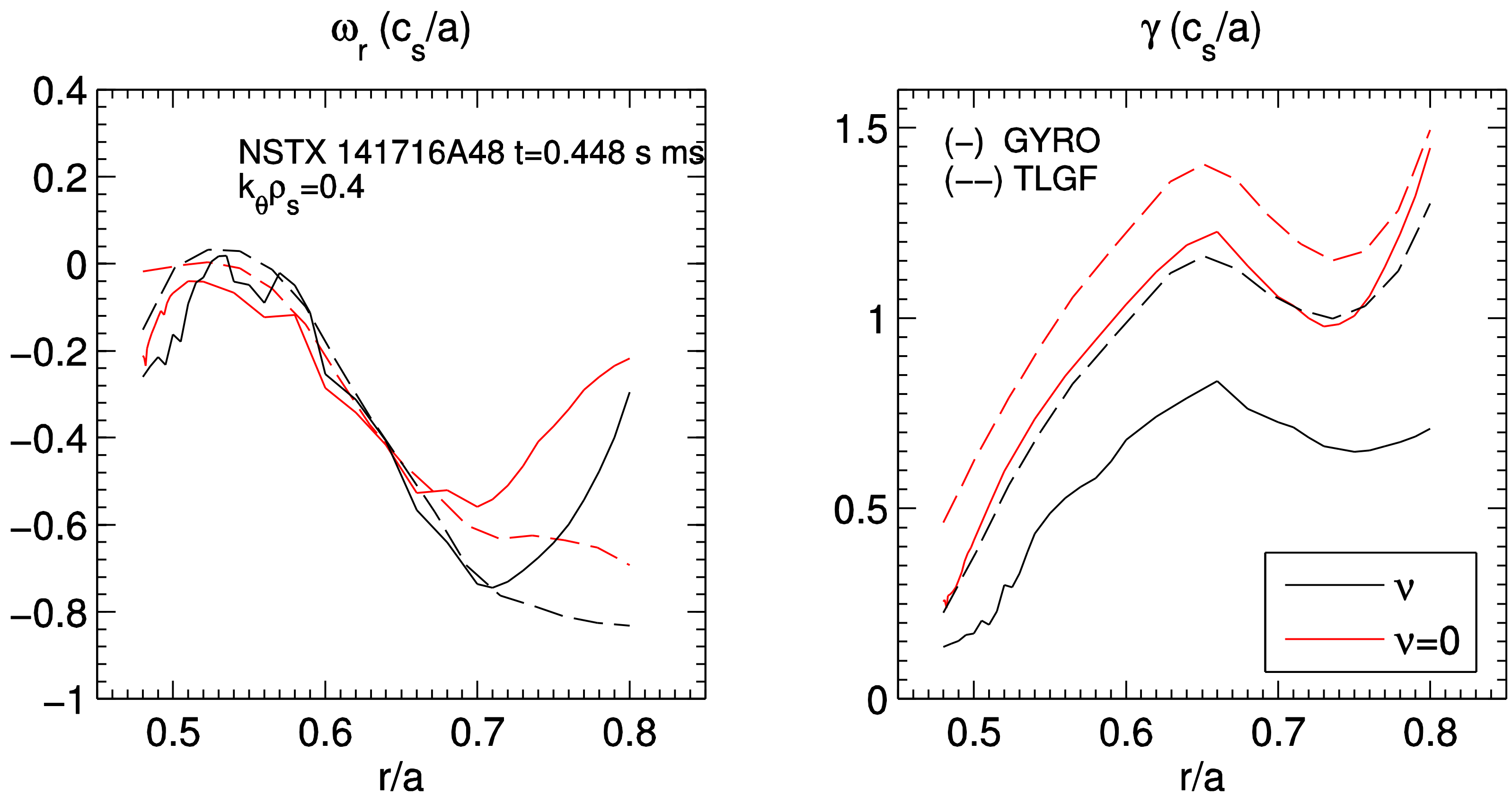
- Miller geometry, ES (EM effects negligible in this case), MHD approx. ($\nabla B/B=\kappa$)
- Real frequencies very close
- Discrepancy is reduced to ~15% in the collisionless limit, or with adiabatic electrons



- Using GYRO eigenvalue solver [Belli]
- Have verified numerical convergence for GYRO with energy grid (8→12), radial grid (4→8), parallel grid (14→22), radial basis function order (3→5)

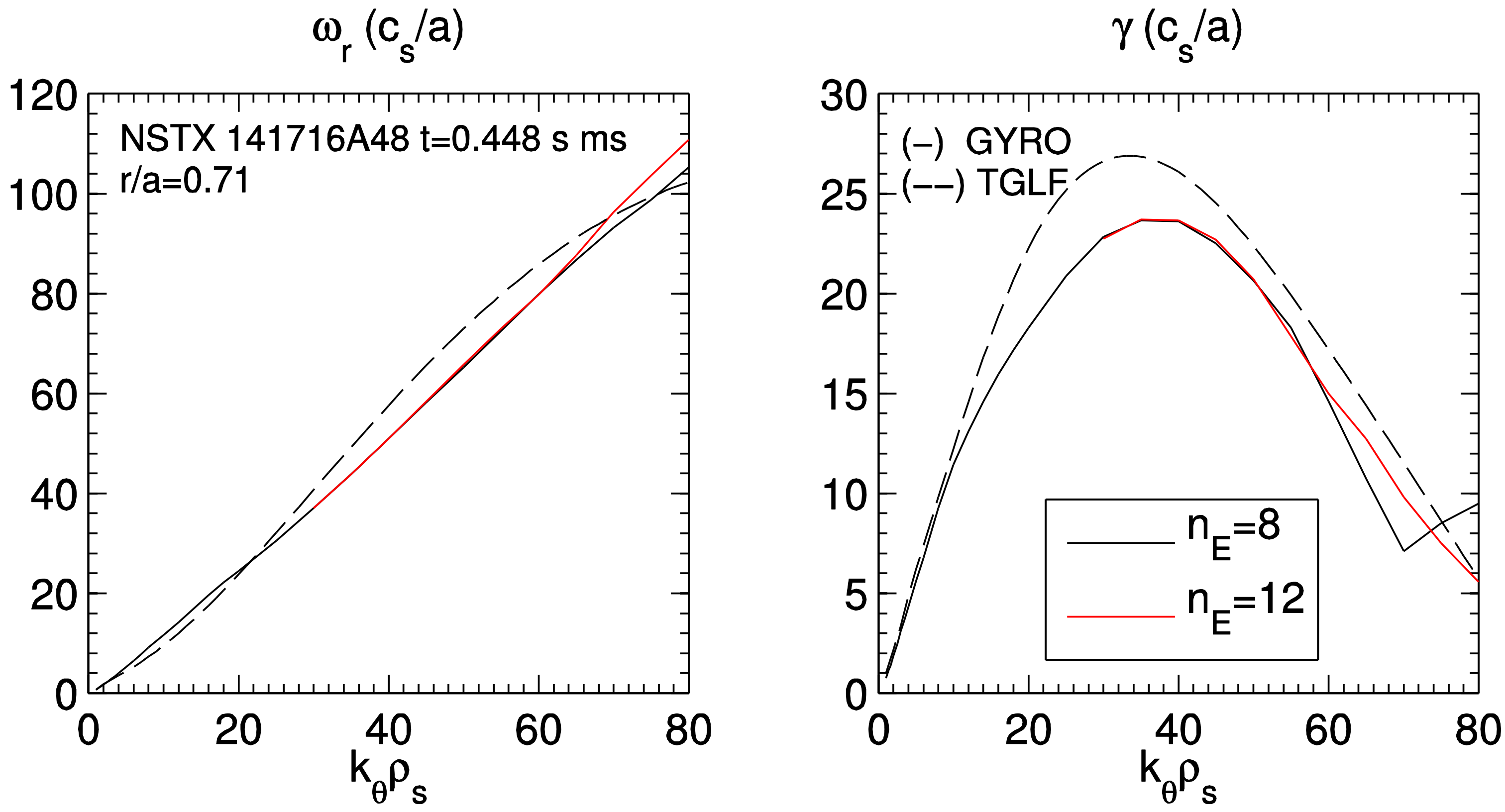
Similar agreement/discrepancy found across r/a=0.5-0.8

- Testing both with and without collisions ($k_\theta\rho_s$=0.4)



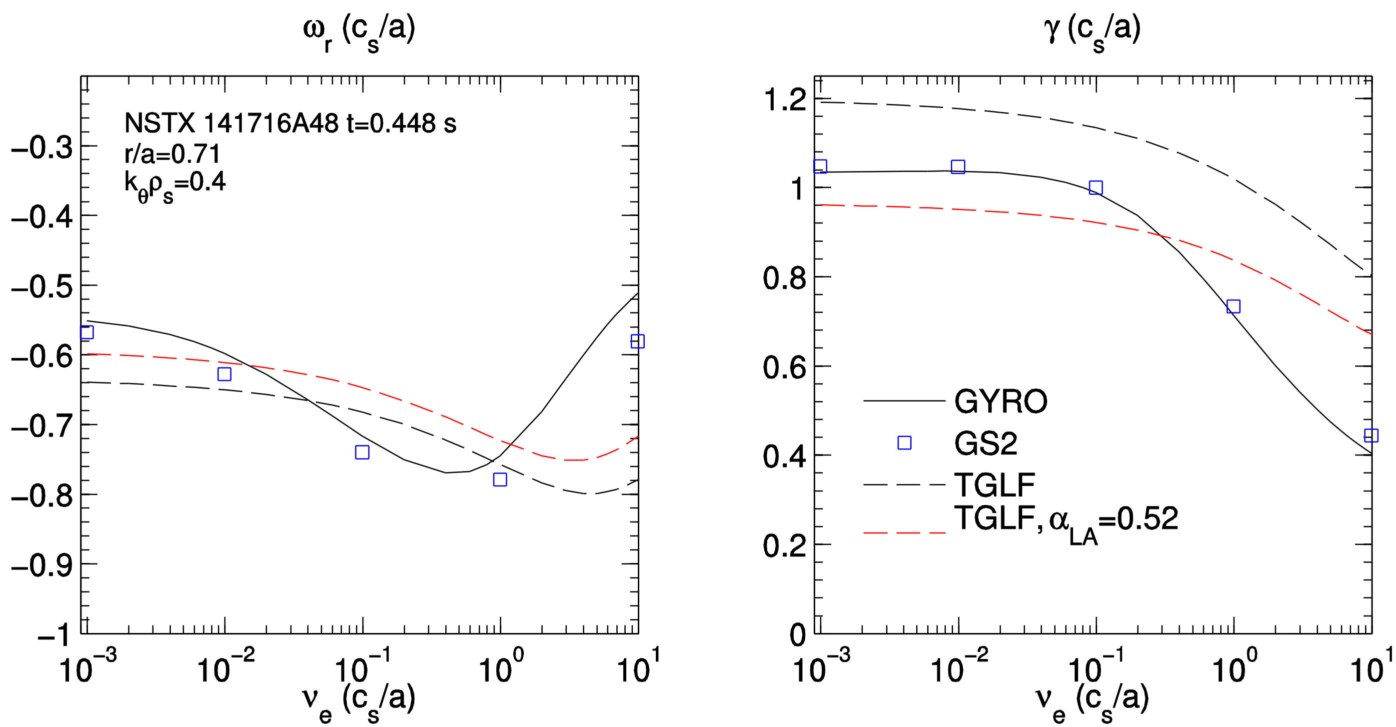
Comparable agreement for ETG growth rates

- This is collisionless, collisions make little difference
- High $k_\theta \rho_s$ GYRO simulations require more energy grid points (8→12)



Testing sensitivity to collisionality

- GS2 agrees pretty well with GYRO (GS2 not using ∇B/B=κ, but ~negligible effect here)
- Reducing THETA_TRAPPED (α_{LA} in the paper) from 0.7→0.52 improves agreement
- TGLF predicts a weaker tearing parity (ES) mode present over entire range



Many other scans were done (gradients, beta, geometry) with ~comparable results (see 2013 slides)

“STL-STD” base case established to ultimately include linear & nonlinear results in TGLF calibration

STL-STD base case established based on NSTX L-mode 141716, r/a=0.75 (from July, 2013)

For the STL-STD base case, we decided to also start with:

- Electrostatic
- Deuterium + electrons only
- $\nabla B/B=\kappa$ (at finite P'_{eq})

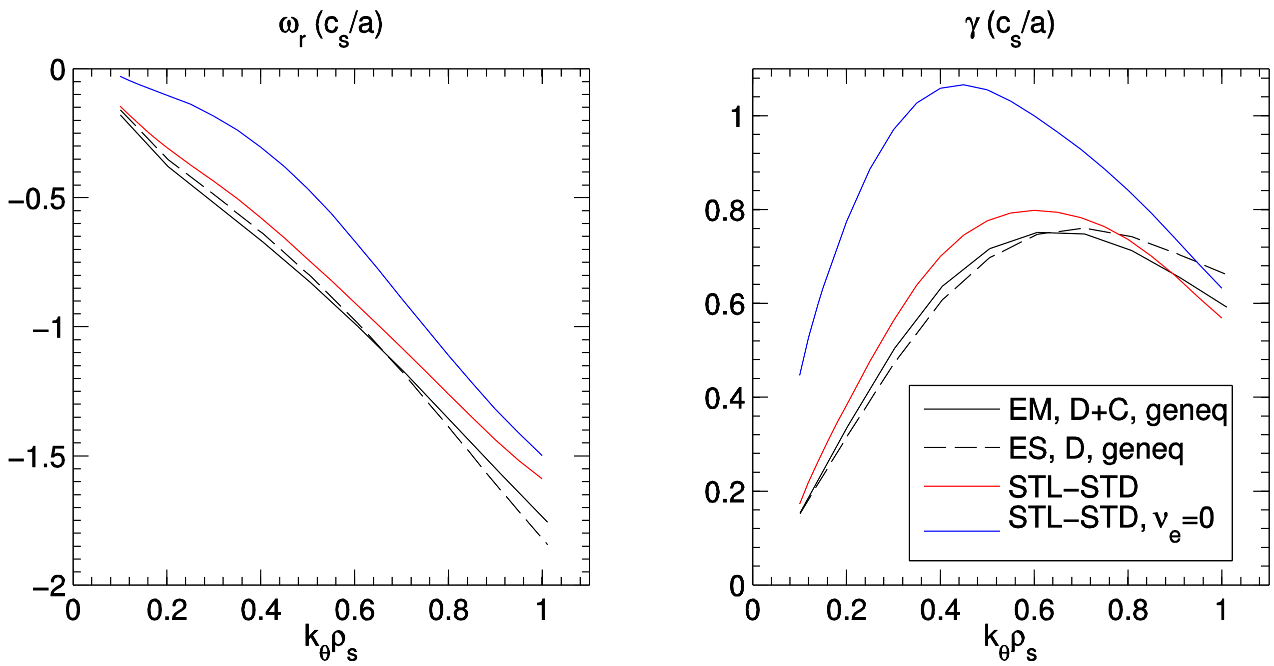
	r/a	q	s	T_e/T_i	a/L_{Ti}	a/L_{Te}	a/L_n	Z_{eff}	ν_{ei}	β_e (%)	γ_E	γ_p	Ma	ρ_*
exp.	0.75	2.06	3.23	0.95	6.84	6.79	1.53	1.15	1.56	0.12	0.25	-0.95	-0.38	0.0031
STL	**0.75**	**2**	**3**	**1**	**6**	**6**	**2**	**1**	**1.0**	**0.1**	**0**	**0**	**0**	**$\rightarrow$0**

	r/a	R/a	Z/a	κ	δ	ζ	dR/dr	dZ/dr	s_κ	s_δ	s_ζ
exp.	0.75	1.404	0.008	1.546	0.104	-0.019	-0.34	-0.002	0.063	0.124	-0.019
STL	**0.75**	**1.4**	**0**	**1.5**	**0.1**	**0**	**-0.3**	**0**	**0.1**	**0.1**	**0**

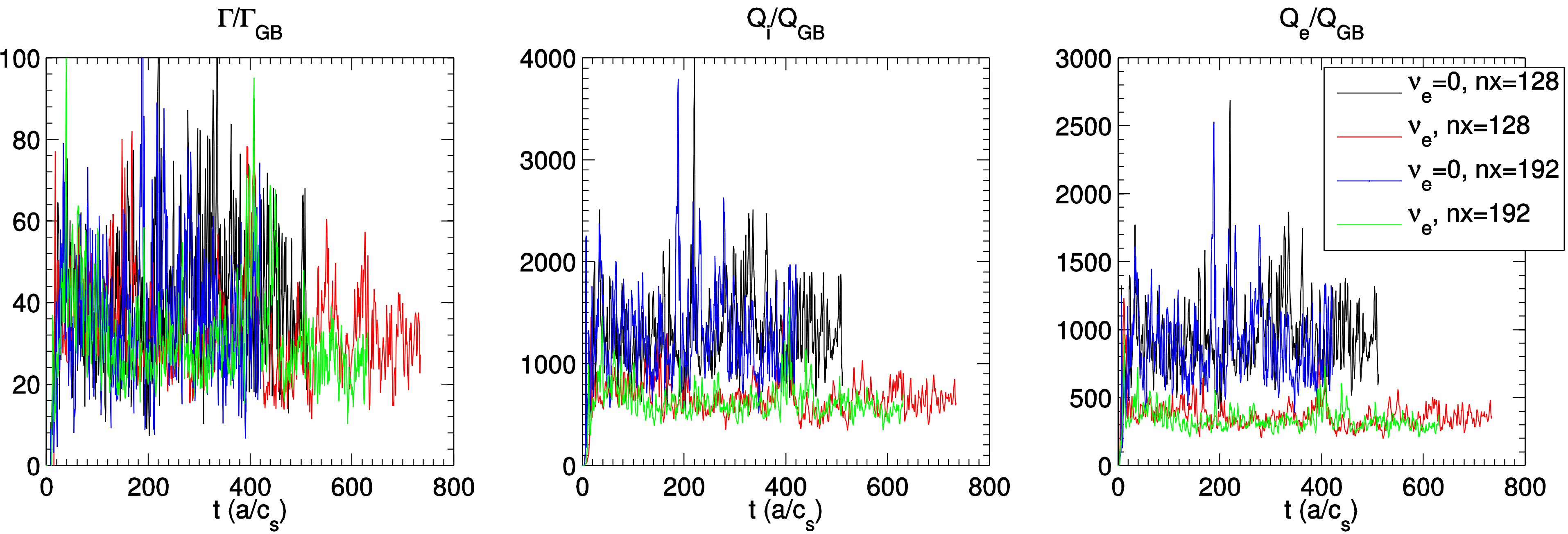
Small change stability using STL-STD (rounded parameters) compared to actual experimental values

- (black solid) experimental parameters with general numerical equilibrium, fully EM and carbon
- (black dashed) electrostatic and deuterium only – small change
- (red) STL-STD parameters - pretty close to experimental case
- (blue) STL-STD but with no collisions

Linear spectra



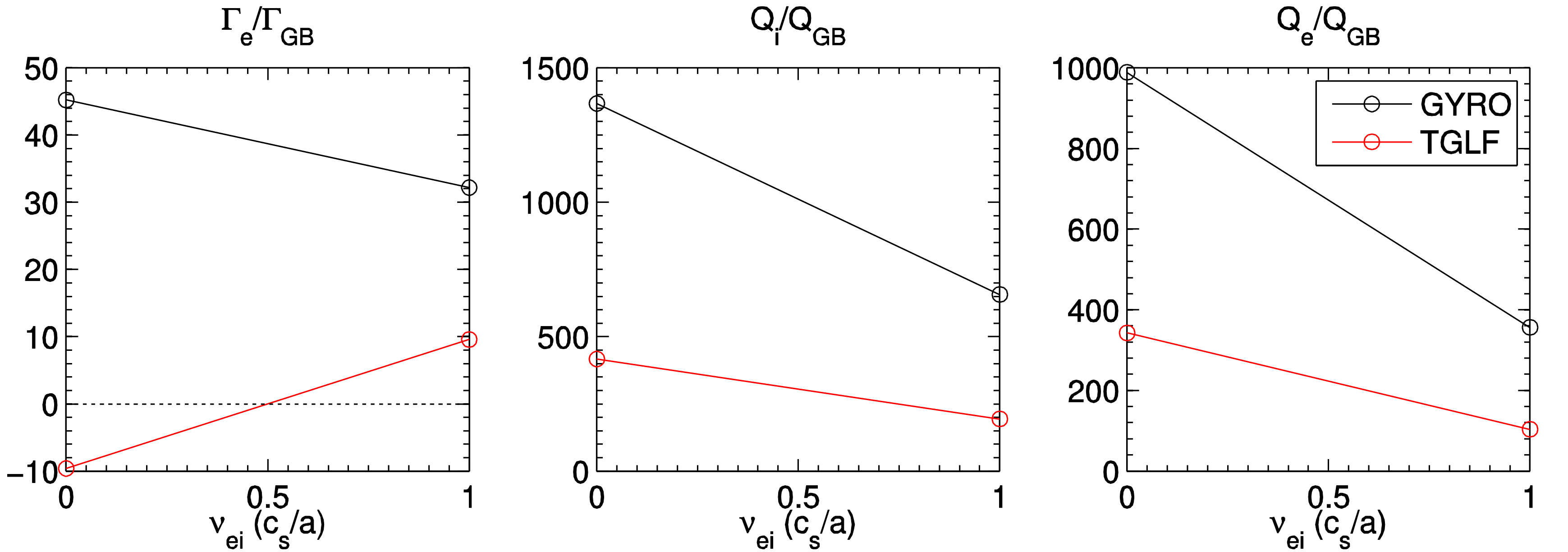
Nonlinear GYRO simulations run both with & without collisions (without E×B shear) – very large transport in GB units



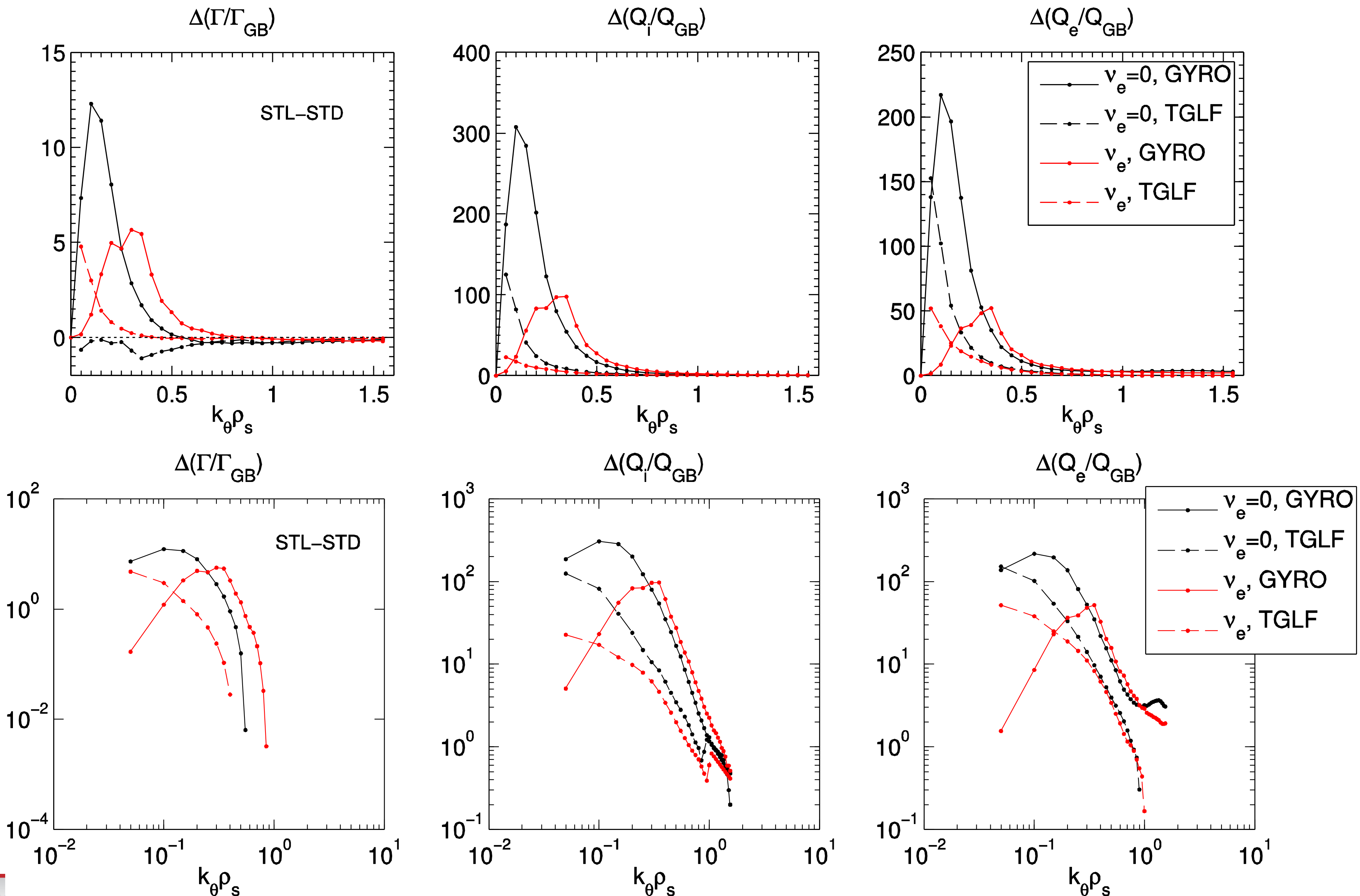
ν_{ei}	L_x (ρ_s)	L_y (ρ_s)	nx	ny	Δt (c_s/a)	t_{max} (c_s/a)	**Q_i** (Q_{GB})	**Q_e** (Q_{GB})	Q_e (k_y>1) %	k_y peak
0	126	126	128	32	0.002	~700	**1367**	**989**	4	0.1
0	126	126	192	32	0.002	~420	**1295**	**893**	3	0.1
1	126	126	128	32	0.005	~750	**657**	**356**	2	0.35
1	126	126	192	32	0.003	~630	**623**	**330**	6	0.2

TGLF heat fluxes ~3× lower than GYRO

- Sign of particle flux opposite for ν_e=0



Comparison with TGLF flux spectra

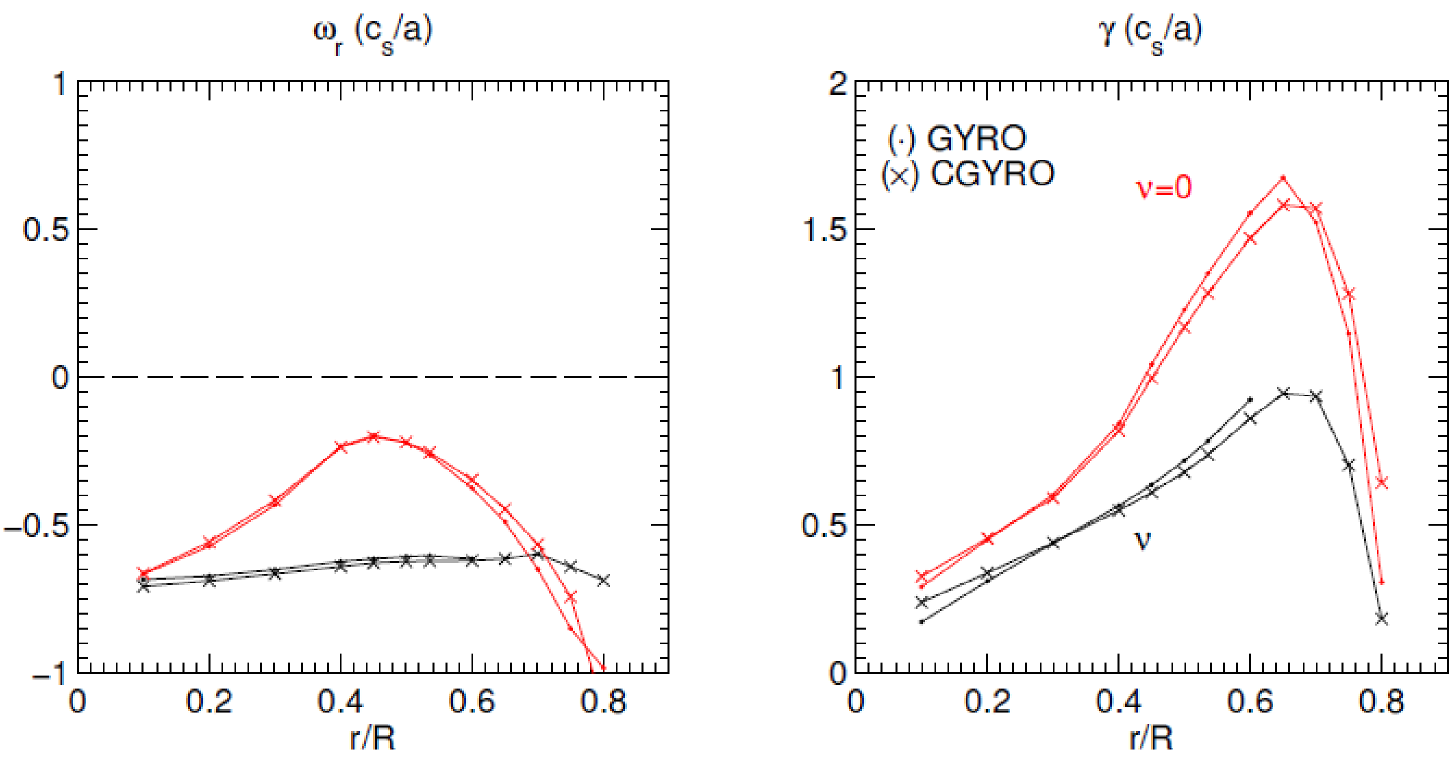


Want to continue with linear & nonlinear scans using "STL-STD" parameters

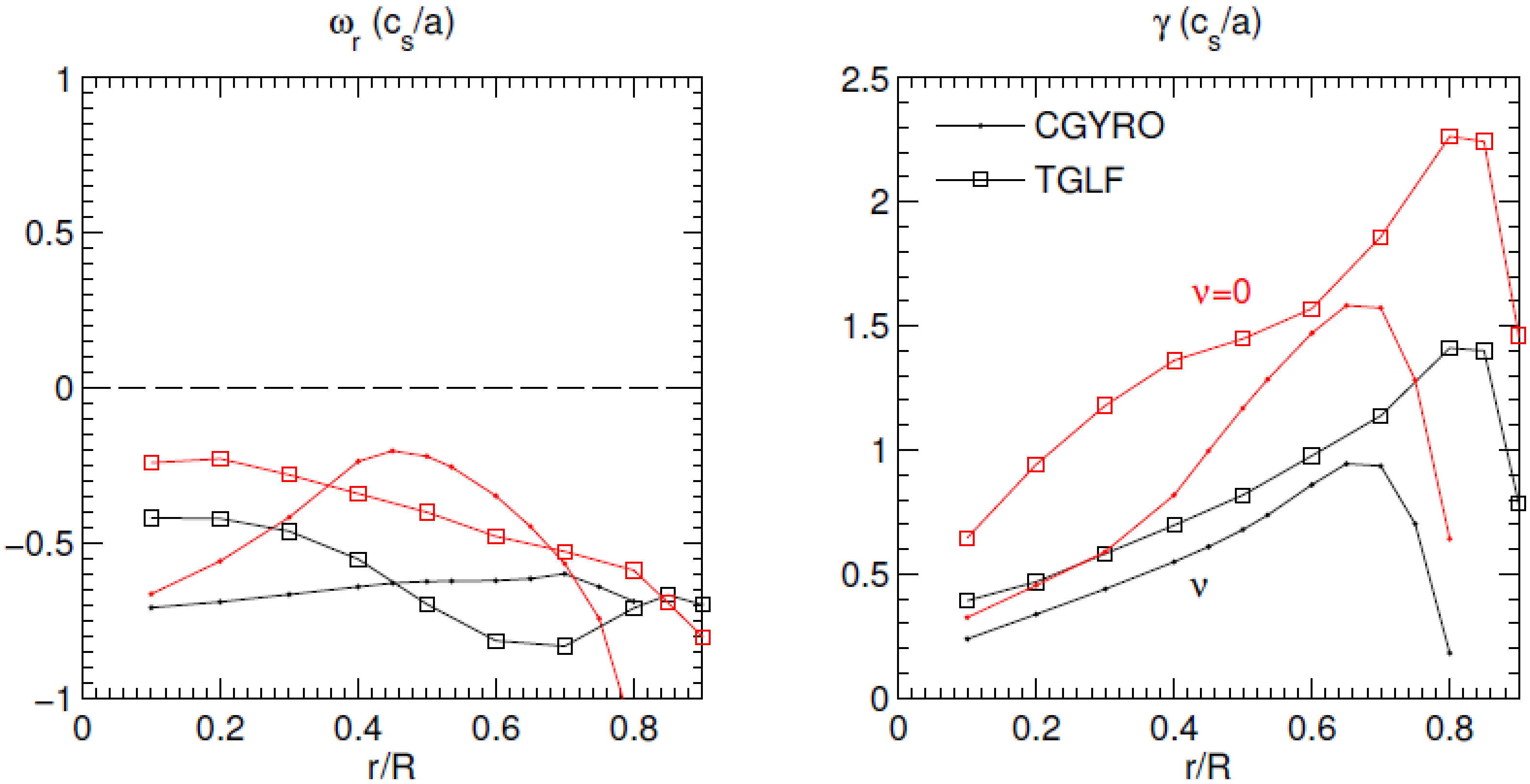
One obvious scan is testing linear stability & NL saturation with aspect ratio…

Aspect ratio scan by varying r/a using 'R' normalization (both collisional and collisionless)

- Growth rates become stabilized at high enough r/R using Miller geometry
- Hit a numerical resolution problem in GYRO with the collisional case at increasing r/R
- Repeated scans with CGYRO (generally good agreement but have not done any careful resolution tests)



TGLF captures gross trends and features

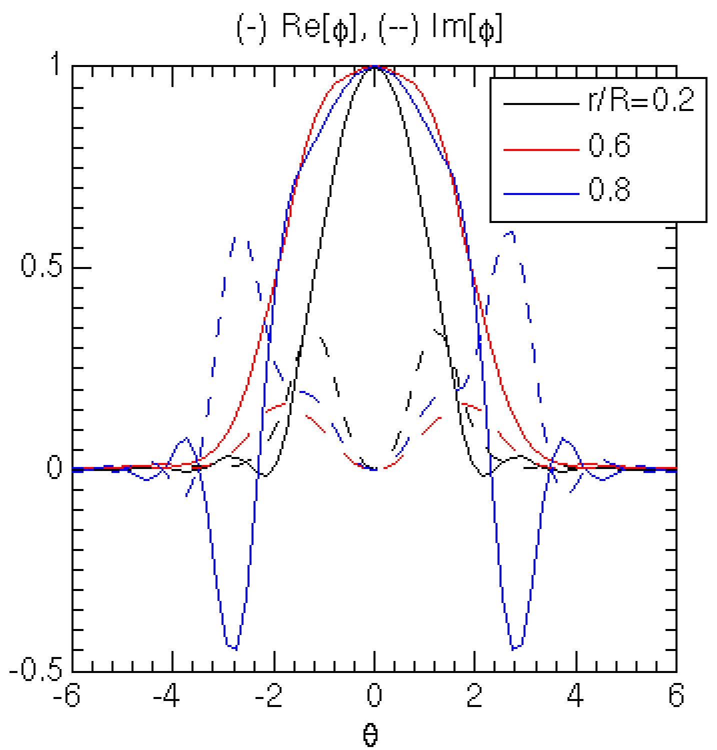


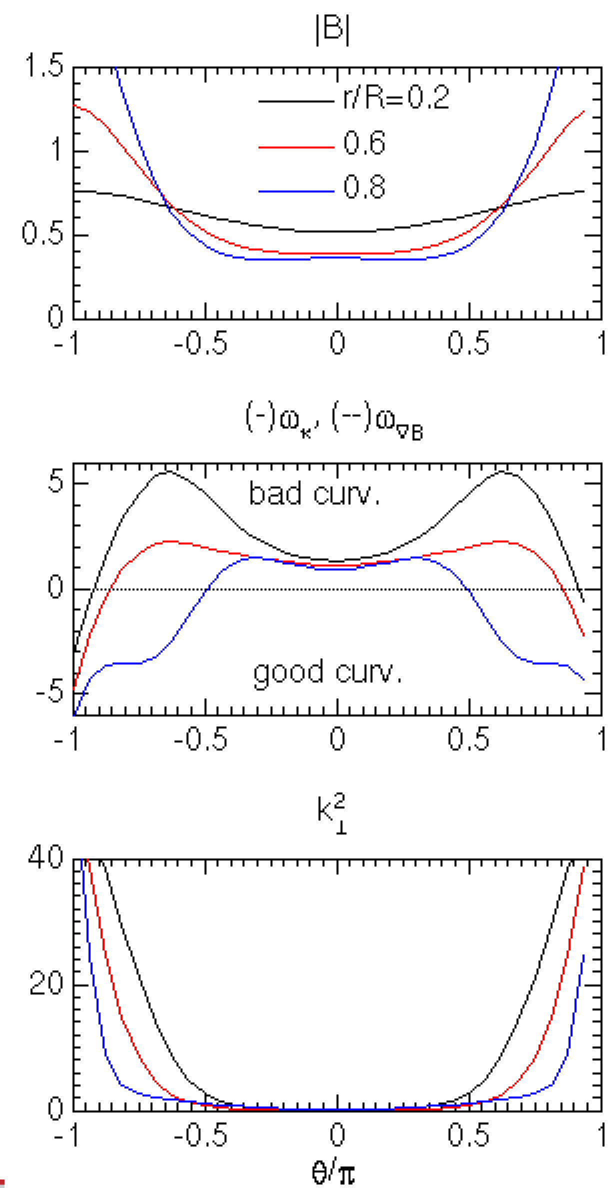
Considerations & future work

- TGYRO & TRANSP predictions of Te, Ti for this case
  - I tried using OMFIT, TGYRO_GACODE module -- hit some snags
- TGLF-GYRO linear ky scan at different r/R
- Overlay TGLF-GYRO eigenfunctions, changes with geometry metrics
- Q: Can we optimize TGLF linear model choices to obtain better agreement
- GYRO nonlinear scan with r/R

Eigenfunctions (ν=0) broaden with increasing r/R

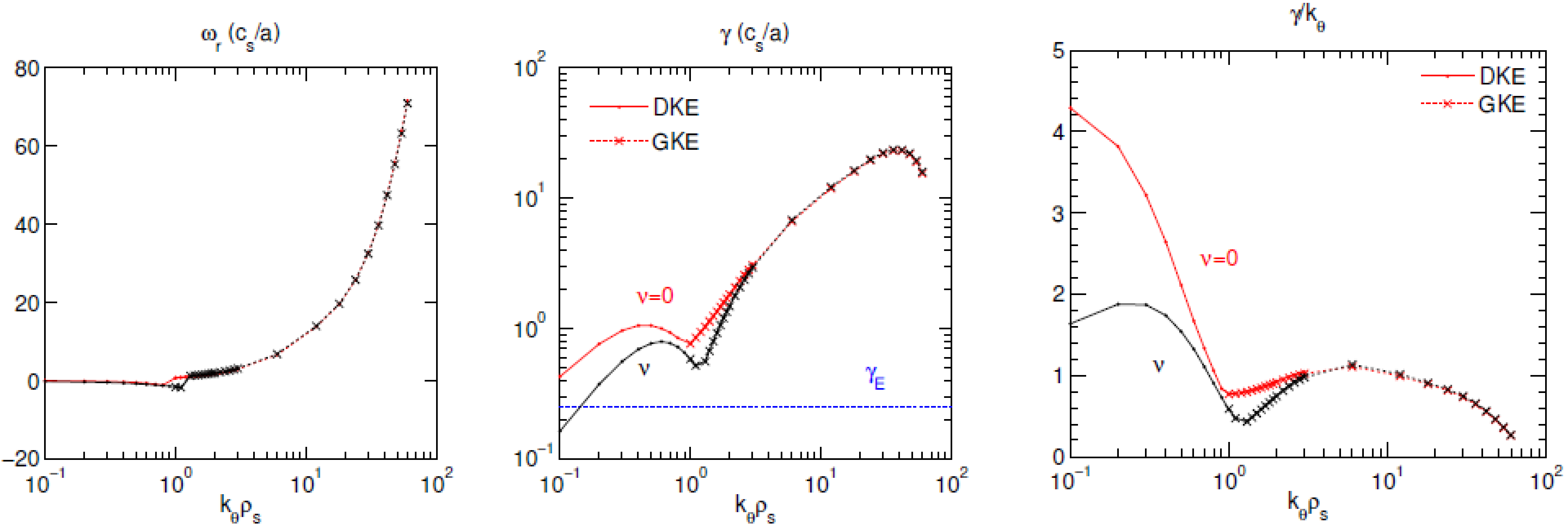
- θ-width of bad-curvature drive stays broad up to r/R=0.6, then shrinks
- Low $k_\perp^2$ ($\sim k_x^2$) region widens in θ with increasing r/R
- Note double-valued |B| at increased r/R





Broad spectrum of ETG modes are also unstable

- Ion scale growth rates are larger than local E×B shearing rate for collisional and collisionless cases
- $(\gamma/k_\theta)_{\text{low-k}} > (\gamma/k_\theta)_{\text{high-k}}$ for both ν, ν=0 cases



Generate broad spectrum stability plot (γ/k_θ) for multiple radii

Transforming from ‘a’ normalization to ‘R’ normalization for STL-STD parameters

- $k_\theta\rho_s$=0.3 (ES; D+e; $\nabla B/B=\kappa$: GEO_GRADBCURV_FLAG=1)

<u>a norm</u>

- R/a=1.4
- r/a=0.75
- a/LT=6
- a/Ln=2
- $\nu_{ei}a/c_s$=1
- (ω,γ) = (-0.433,0.559) c_s/a
- **(ω,γ) = (-0.606,0.783) c_s/R**

<u>R norm</u>

- R/a=1
- r/a=0.5357
- a/LT=8.4
- a/Ln=2.8
- $\nu_{ei}a/c_s$=1.4
- (ω,γ) = (-0.605,0.784) c_s/a
- **(ω,γ) = (-0.605,0.784) c_s/R**

- Collisional cases above

Older work from June 2017

GA-STD (reg02) case with s-α geometry

GA-STD (reg02) case

- Started with GYRO 'reg02' regression test (kinetic electrons)
- $q=2$, $s=1$, $\kappa=1$, $\delta=0$

a norm

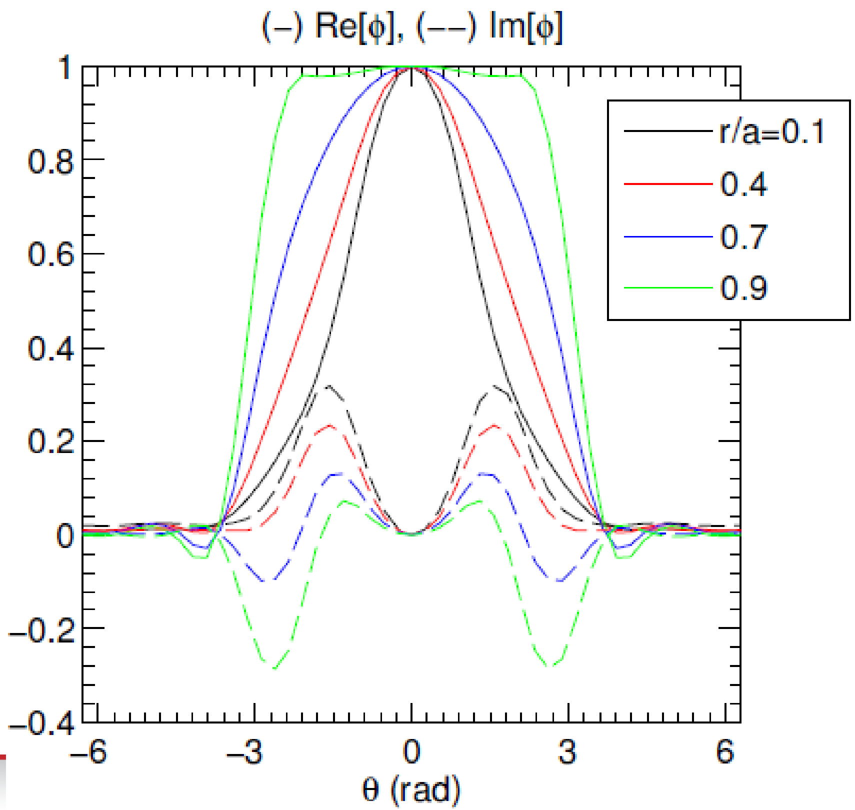
- R/a=3
- r/a=0.5
- a/LT=3
- a/Ln=1
- (ω,γ) = (-0.317,0.240) c_s/a
- **(ω,γ) = (-0.951,0.720) c_s/R**

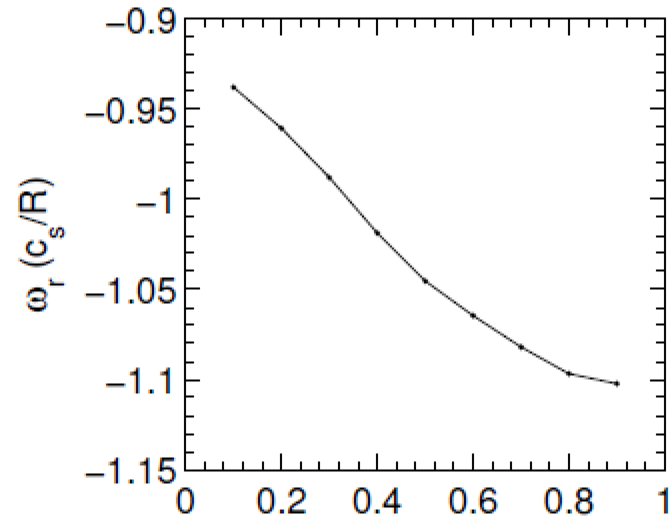
R norm

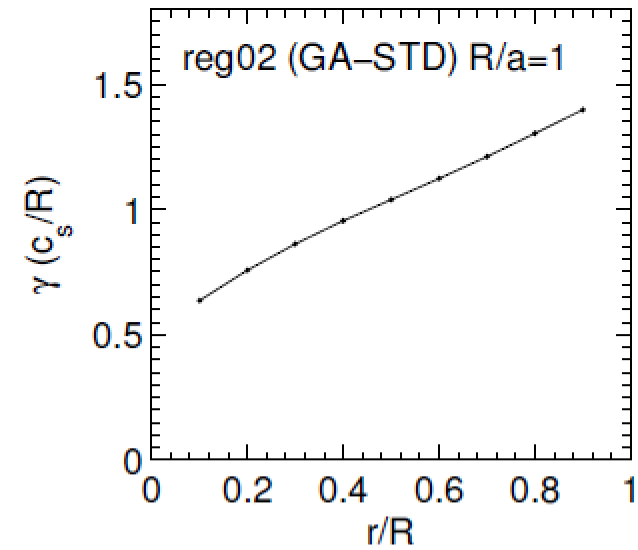
- R/a=1
- r/a=0.1667
- a/LT=9
- a/Ln=3
- (ω,γ) = (-0.952,0.720) c_s/a
- **(ω,γ) = (-0.952,0.720) c_s/R**

r/R scan using reg02 (GA-STD), R=a

- Was inspecting eigenfunctions, which looked pretty peculiar/broad at high r/R
- Also inspected geometry metrics, which weren't changing like I expected them to → **this was using s-α geometry (RADIAL_PROFILE_METHOD=1)**







GA-STD (reg02) case with Miller geometry

GA-STD-M case, reg02 with Miller geometry (RADIAL_PROFILE_METHOD=5)

- Started with GYRO 'reg02' regression test (kinetic electrons)
- Now actually using Miller geometry
- q=2, s=1, κ=1, δ=0

a norm

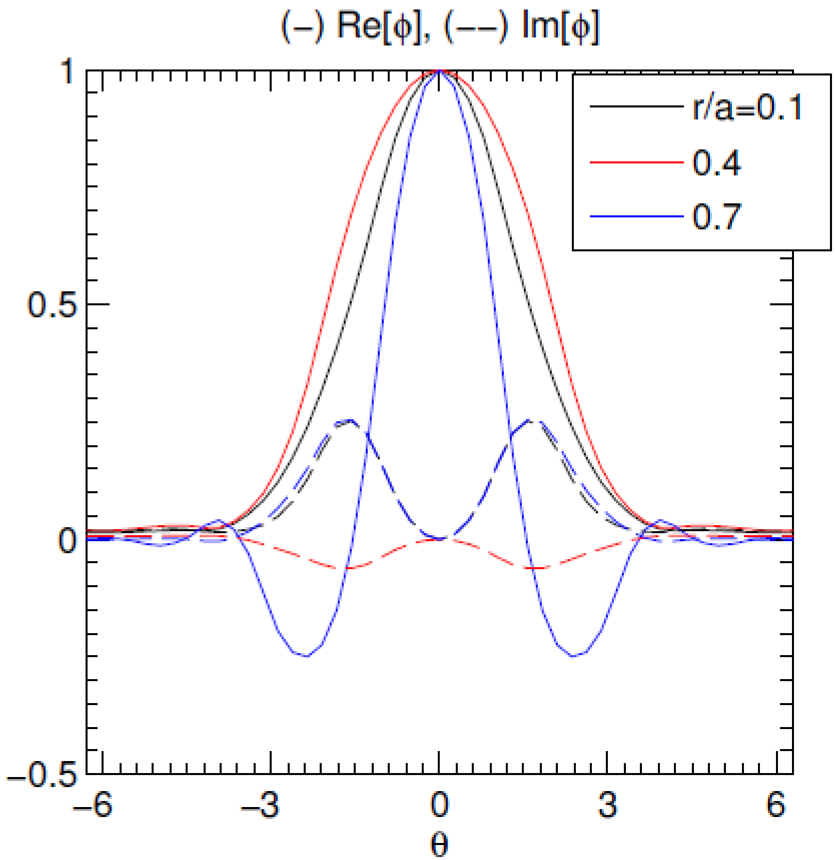
- R/a=3
- r/a=0.5
- a/LT=3
- a/Ln=1
- (ω,γ) = (-0.216,0.324) c_s/a
- **(ω,γ) = (-0.649,0.973) c_s/R**

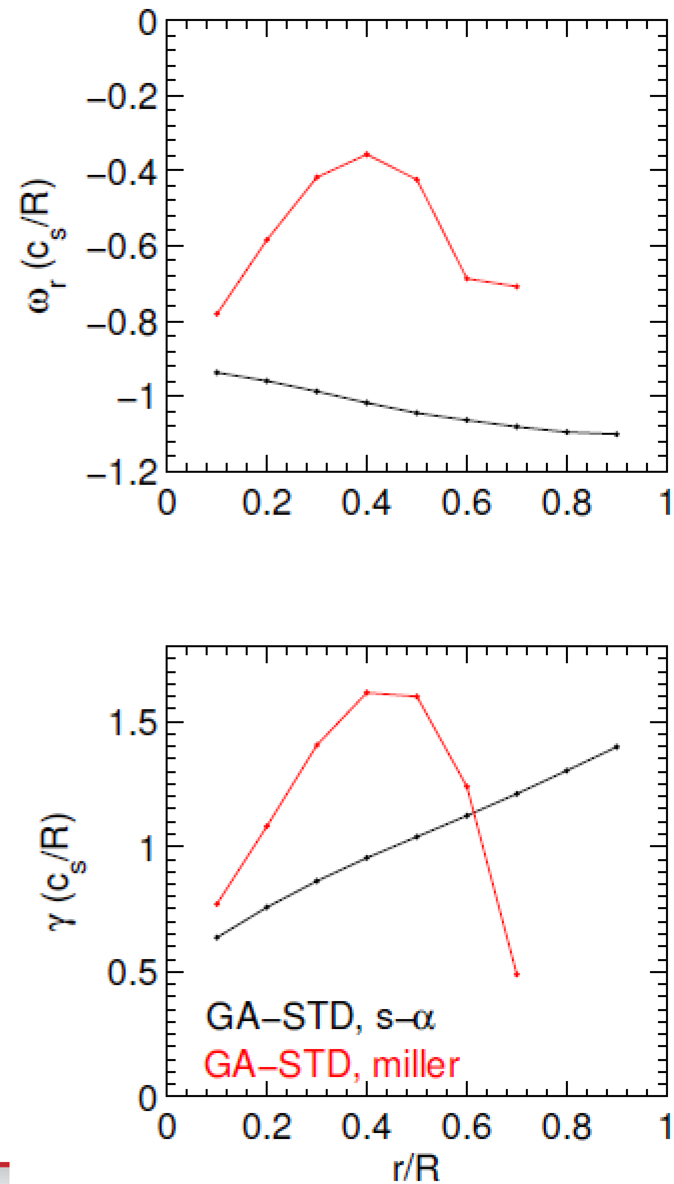
R norm

- R/a=1
- r/a=0.1667
- a/LT=9
- a/Ln=3
- (ω,γ) = (-0.650,0.973) c_s/a
- **(ω,γ) = (-0.650,0.973) c_s/R**

Growth rates become stabilized at high enough r/R using Miller geometry

- Miller solution approaches s-α as r/R$\rightarrow$0
- Think there must be two distinct roots looking at change in ω_r & eigenfunctions at r/R=0.7





Using Miller geometry, see a dramatic change in geometry metrics at increasing r/R

- Large increase in trapped particle fraction

- Reduced “bad” curvature region at high r/R
  - κ & $\nabla B/B$ identical ($\beta'=0$)
  - Toroidal drift terms are normalized in the way of GS2

- $k_{\perp}^2$ becomes very large at large r/R