Turbulence and Transport in Negative and Positive Triangularity

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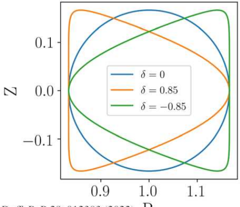
Pushing the PT/NT Boundaries



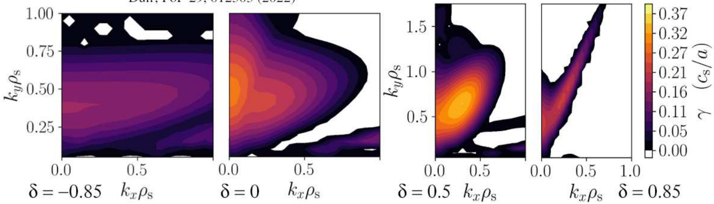
Duff, PoP 29, 012303 (2022)

Duff PoP 2022: extreme $\delta \approx \pm 0.8$
linear & nonlinear toroidal ITGae

Linear local GENE simulations show

- γ dips as $\delta \gtrsim 0.8$ and $\delta \lesssim -0.8$
- substantial finite-k_x growth

Duff, PoP 29, 012303 (2022)



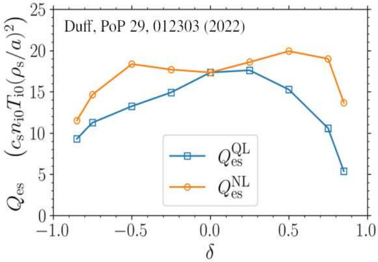
- NT has large outboard region with constant curvature $\mathcal{K} \Rightarrow \gamma$ insensitive to $\theta \sim k_x$
- PT produces strongly varying $\mathcal{K}(z) \Rightarrow$ localized $\gamma(k_x)$

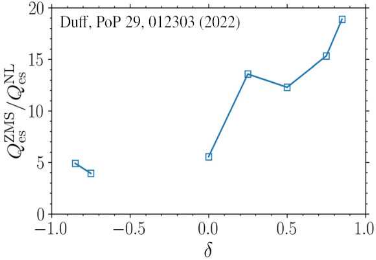
Turbulence at Extreme δ

Nonlinearly,

- reduced flux at $|\delta| \gtrsim 0.7$

- PT: strong zonal flow
- NT: enhanced NL transfer



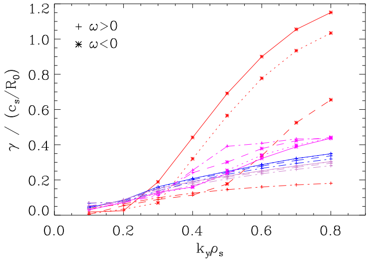


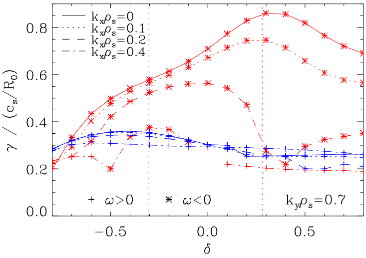
Do these results carry over to realistic situations?

Pushing δ at TCV I

RT07 TCV campaign: only $\delta \approx \pm 0.3$ achievable at $r/a = 0.7$
$\Rightarrow$ extrapolate using Miller (ignores edge-$\delta \approx 0.6$, ρ^* effects)

CHEASE geometry — PT,NT — Miller geometry

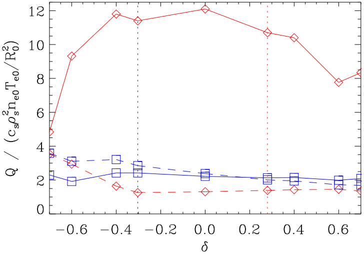


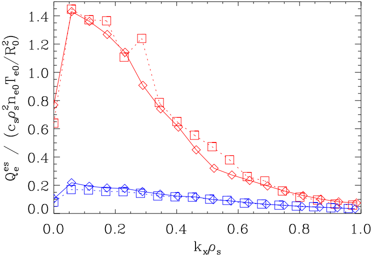


- at experimental gradients, stiff TEM, ITG growth
- confirms idealized ITG case, finite-k_x contribution at $\delta > 0$
- TEM: $\gamma(\delta < 0)$ insensitive to k_x like ITG, $\delta > 0$ TEM dominated by $k_x \approx 0$

Pushing δ at TCV II

Are the nonlinear Duff ITGae flux trends recovered?





- substantial zonal flows
- near ITG/TEM thresholds; approx. matches Q_e^{exp}
- quasilinear modeling: need to include finite k_x?

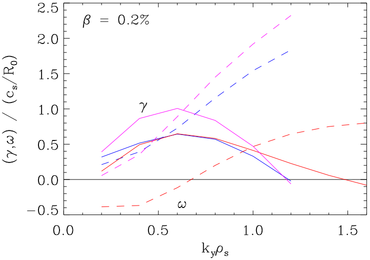
- Q_e: like γ, slight shift to higher k_x at $\delta < 0$
- **extreme δ can be highly beneficial**; too low $|\delta|$ in TCV core

High-β in PT/NT

Now, TCV shots studied in TSVV2, #69515 (PT), #69340 (NT)
At $r/a = 0.72, 0.8$, well-matched gradients, β, except R/L_{Ti}

Useful to look at *flipped gradients* scenario (PT geometry)

PT, NT, and PT+flipped:



$r/a = 0.72$ (similar for 0.8)
$\longleftarrow$

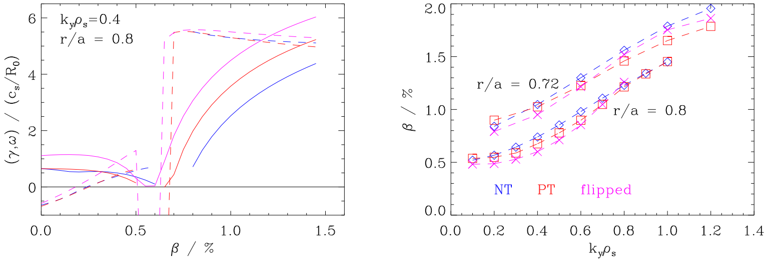
- linearly, mixed ITG, TEM, & ITG-TEM-hybrid regime
- low ω: possible impact on saturation efficiency

- nonlinearly, fluxes peak near $k_y = 0.4$
- ν_{ei} makes enormous difference nonlinearly, reduces Q

Electromagnetic Effects

Increasing normalized electron pressure β affects instabilities

Kinetic Ballooning Mode (KBM): kinetic sibling of IBM

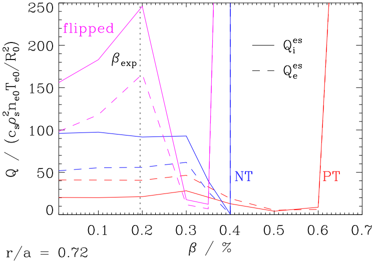


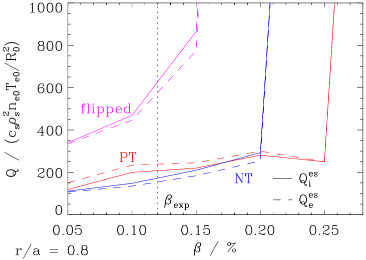
- ITG β-stabilized, TEM unaffected $\Rightarrow$ **here, hybrid mode**
- PT has higher $\beta_{\rm crit}^{\rm KBM}$ than NT, **only due to lower gradients**
- **PT-flipped: lower threshold** than NT
- more substantial increase in $\beta_{\rm crit}^{\rm KBM}$ for more negative δ

Nonlinear β Scans

PT, NT approximately match Q_e, but higher Q_i in NT (higher $R_0/L_{T\mathrm{i}}$); fluxes from GENE match experimental fluxes

Mixed ITG-TEM; moderate zonal flow, substantial zonal field





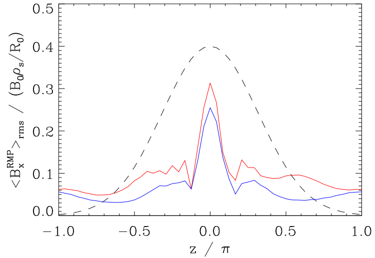
- flipped: **NT geometry produces less flux**
- strong **nonlinear β stabilization** possible
- **saturation fails at $\beta \approx 2\beta_\mathrm{exp}$**, far below $\beta_\mathrm{crit}^\mathrm{KBM}$

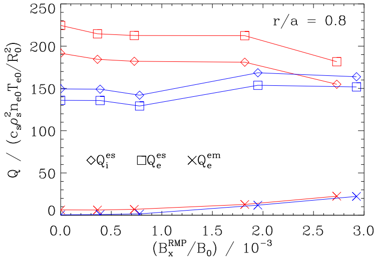
$\Rightarrow$ **Non-Zonal Transition**, very restrictive at steep gradients

RMP Impact on PT/NT Turbulence

Gu NF 2022: analysis of PT experiments (DIII-D, AUG, EAST)
$\Rightarrow$ *RMP impact weaker as δ is increased*

Here, **add RMP** (Williams PoP 2017, NF 2020)
to PT vs. NT shots at $k_y \rho_s = 0.1$





- **very little impact** on transport (low $|\delta|$: $\sim 10\% - 30\%$)
- at very high B_x^{RMP}, PT $\approx$ NT flux

Summary

- **extreme triangularity** $|\delta| \gtrsim 0.6$ **promising** from turbulence standpoint, *but is it realistic in reactors?*
- **KBM threshold increased** for negative triangularity
- β factor two below **non-zonal transition** threshold, shaping optimization may mean NZT limits gradients
- **RMP** impact rather **comparable for PT, NT**
- *Next steps:*
  - compare QL vs. NL for β scan; test τ-improved QL
  - determine how saturation mechanisms are impacted by NT
  - look at large-$|\delta|$ reactor, including fast ions

EUROfusion

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