Comparing Negative and Positive Triangularity for an ARC FPP

DIFFER M.J. Pueschel TU/e EINDHOVEN UNIVERSITY OF TECHNOLOGY

C. Holland, P. Rodriguez-Fernandez, E.M. Bass,
N.T. Howard, A. Mishchenko, J. Ball, T. Görler, M.M. Skyllas,
K.C.F. Koolen, A. Claassen, J.J. ten Houten, and E. Westerhof

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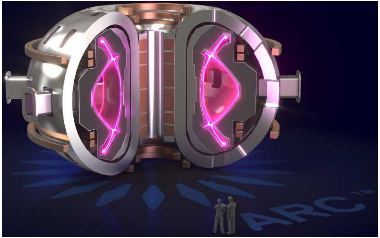
NT and Reactor Relevance

TSVV2: assess NT reactor relevance $\rightarrow$ let's look at ARC

- following SPARC success, ARC finalization/construction, fast deployment planned
- substantial PT planned
- exhaust still open question

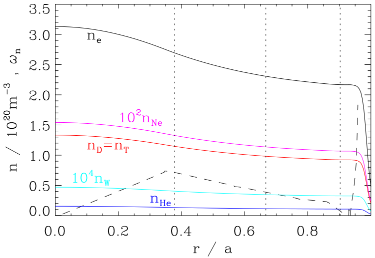


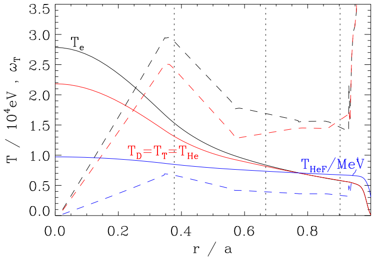
"standard" ARC shape: substantial positive δ

Here, try to determine how NT geometry would impact turbulence/transport in ARC

ARC Pressure Profiles

Source of ARC profiles:
C. Holland's GYRO inputs from transport calculations

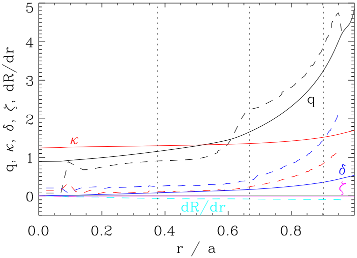




- pick three r/a for instability/turbulence analysis, run GENE
- D, T, He, Ne, W, e
- using predicted fast-ion profiles
- HeF only has impact at innermost location

ARC Geometry

ARC plans include substantial positive δ,
modify here to compare PT/NT



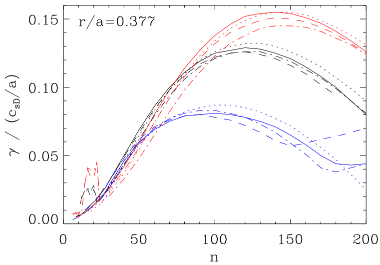
- focus on three r/a: deep core to near pedestal
- change δ to $\{-0.4, 0, 0.4\}$, with $\{+s_\delta, 0, s_\delta\}$

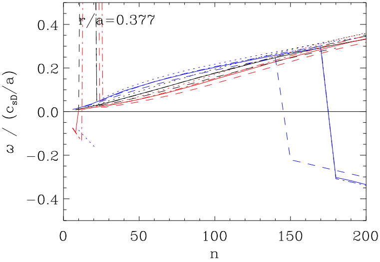
Note: at $r/a = 0.38/0.67/0.9$, our choice of $\delta = \pm 0.4$ is purely academic/a bit much/right on the spot

Instability at $r/a = 0.38$

Innermost radius:

- fast He included
- moderate growth rates
- mostly D/T ITG
- high k_y: incipient ETG
- transport-relevant $k_y \approx 50$: not much difference NT-PT
- low k_y:
  - PT/circular: fast-He-driven KBM (not TAE+)
  - NT: MT (but slightly stabilized by β

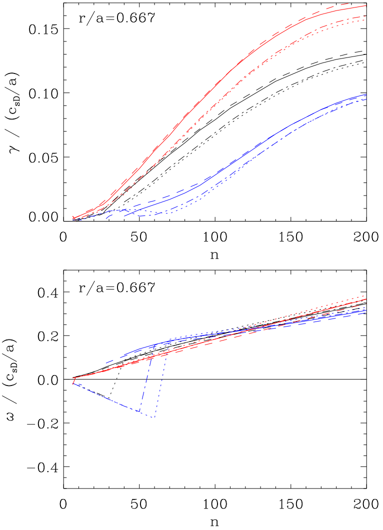




Instability at $r/a = 0.67$

Middle radius:

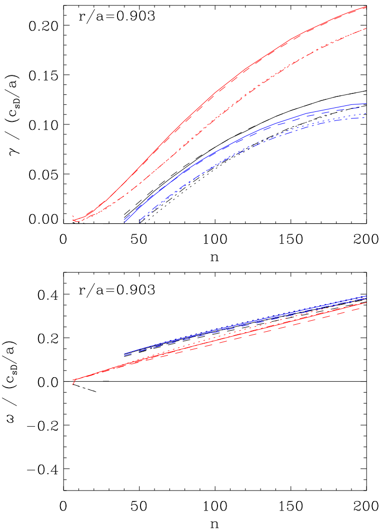
- *needed to double* $\omega_{TD,T}$ *to get substantial instability*
- thermal He
- moderate growth rates
- mostly $\mathrm{D/T}$ ITG,
  NT at low k_y has MT
- transport-relevant
  $k_y \approx 50$: PT much more unstable



Instability at $r/a = 0.9$

Outer radius:

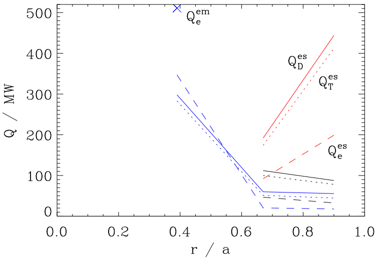
- *needed to double* $\omega_{TD,T}$ *to get substantial instability*
- thermal He
- moderate growth rates
- mostly $\mathrm{D/T}$ ITG
- transport-relevant $k_y \approx 50$: PT much more unstable
- $\pm s_\delta$ makes factor 2 difference (vs. not at $r/a = 0.38$)



Transport vs. Radius

Nonlinear convergence completed, nonlinear runs finished at outer two radii, *still ongoing at innermost* r/a

Fluxes: compare to $\approx 500\,\mathrm{MW}$ fusion power
(*note:* V' *comparable between* $\delta \leq 0$, *slightly smaller for* $\delta > 0$)

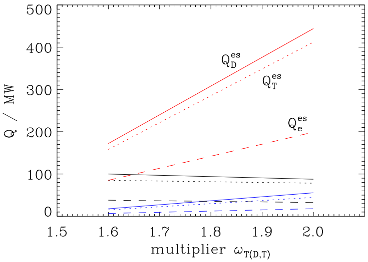


- *recall*: doubled gradients at outer radii
- Q in the ballpark
- electromagnetic channel only relevant at $r/a = 0.38$

Γ_{He} *and especially* Γ_{W} *negligible at all* δ

Transport at $r/a = 0.9$

At outermost r/a, have $Q_{\rm NT} \ll Q_{\rm PT}$, but what about stiffness?

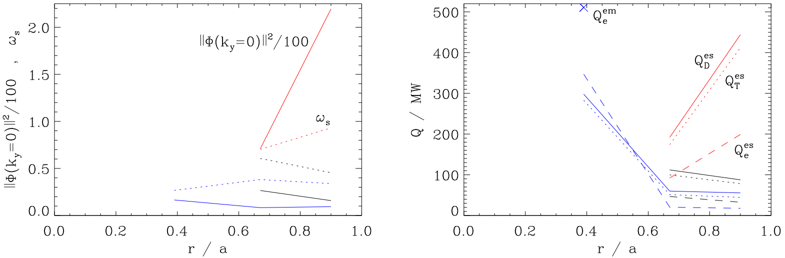


- comparable *relative* flux change NT/PT $\leftrightarrow$ linear critical ω_T?
- need to check $\delta = 0$ case
- Kotschenreuther thermodynamic constraint: similar response to ω_n expected in NT/PT

Note: full NL convergence tested at outer radii, x/y *at* 0.38

Zonal Flows at $r/a = 0.9$

Does zonal-flow saturation change with δ?



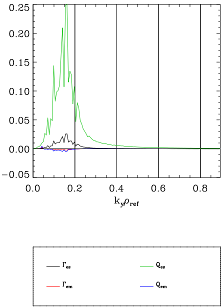
- between outer two radii and between triangularities, relative zonal-flow amplitude $\sim$ constant
- PT: larger-scale ZFs?
- inner radius NT: much less relative ZF (PT coming soon)

Transport at $r/a = 0.38$

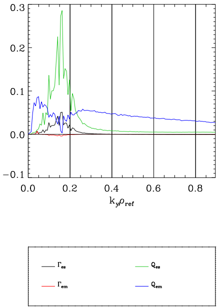
Innermost: look at He vs. HeF
$\Rightarrow$ alphas moderately increase fluxes in NT ($\delta \geq 0$ running)

Flux spectra for HeF runs:

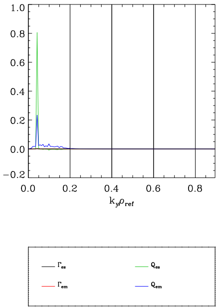
Deuterium:



electrons:



fast Helium:



Likely, mix of MT, KBM, ITG, substantial flutter; here, $n_0 = 2$!

GENE ECCD Implementation

ECCD: electron heating & current drive ⇒ impacts ω_{Te}

However, turbulence also impacts ECCD via beam broadening; **is turbulence affected directly** via δT_e, $\delta\Phi$?

resonance width $= 0.3 v_\mathrm{Te}$

deposition power $\sim 10^{-3}$

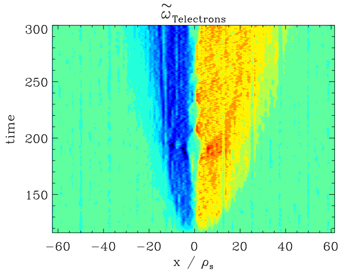
GENE ECCD:
$$\frac{\partial g_\mathrm{e}}{\partial t} = \mathcal{L} + \mathcal{N} + p_\mathrm{EC} \frac{\sqrt{2}}{\pi^{3/2}} \frac{\mu B_0 - 1}{m_\mathrm{e}} \left(\frac{2v_\Delta^2 + 1}{v_\Delta^2}\right)^{1/2} \times \exp\left(-\frac{2v_\Delta^2 + 1}{v_\Delta^2}(v_\| - v_\mathrm{res})^2\right) \exp(-\mu B_0)$$

resonant velocity $= 2 v_\mathrm{Te}$

with Gaussian localization in x, y, z

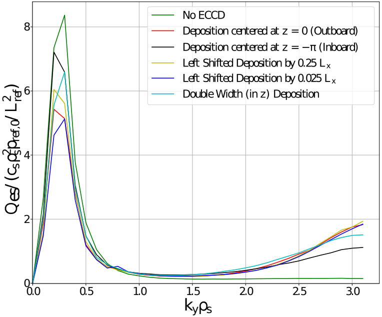
(see Westerhof PoP 2014; implementation: Skyllas & Claassen)

TEM Case



local tripling of ω_{Te}

$\Rightarrow$ **locally destabilizes** (near-marginal) **ETG**

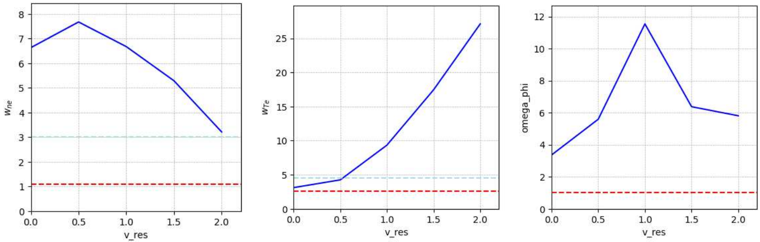


Nonlinearly, **TEM suppressed** by ZF (despite tertiary increase)

Note: **Asymmetry** in zonal T_e likely **due to TEM**, not ETG

Resonant Velocity Impact: Corrugations

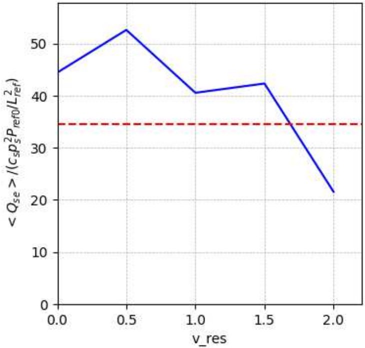
Substantial impact of deposition on profile corrugations

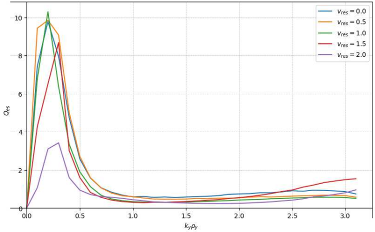


⇒ would expect ∇T-TEM, ETG enhanced at higher v_{res}

Resonant Velocity Impact: Transport

However, clear flux reduction with higher v_{res}
(note: deposition strength held constant here)





- now conducting tertiary analysis ⇒ TEM, ETG response
- shows how tuning ECCD parameters can help regulate turbulence

Summary

- ARC study: NT seems to be rather beneficial from transport standpoint
- no clear ash/impurity removal
- Even if ARC cannot achieve (as good an) H-mode, outer core may have steeper profiles than anticipated
  $\Rightarrow$ could L-mode ARC be practical?
- No fast-ion modes (except alpha-driven KBM)
- ECCD: GENE implementation and results being written up, *where to take next?*

Acknowledgements

EUROfusion

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