Quasi-axisymmetric stellarators with varying rotational transform profiles

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Motivation

- In optimization for quasi-axisymmetry (QA), ι-profile is typically (partially) prescribed as an optimization target
- Example: radial average of ι-profile specified as an optimization target.
  (Landreman-Paul precise QA)

To make well-informed choices of optimization target

$\Longrightarrow$ Need to assess compatibility of ι-profile and other optimization and physics goals.

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- Quasisymmetry (QS)
- Flux-surface elongation
- Fast-particle losses
- Turbulent energy fluxes

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$\Longrightarrow$ **Need to assess compatibility of ι-profile and other optimization and physics goals.**

- Quasisymmetry (QS) $\Longrightarrow$ $\iota < 0.8$ for good QS
- Flux-surface elongation $\Longrightarrow$ Higher elongation for higher ι
- Fast-particle losses $\Longrightarrow$ Lower losses at high ι
- Turbulent energy fluxes $\Longrightarrow$ No clear trend

Optimization for quasi-axisymmetry (QA) at different iota

$n_{\text{fp}} = 2$, $A = 6$, vacuum QA (like Landreman-Paul Precise QA)

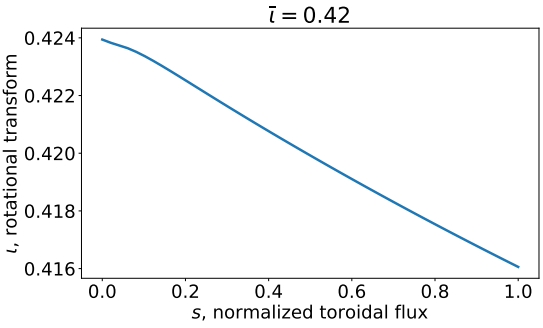
Optimization objective

$$f_{\text{QS}}^2 + (A - A_*)^2 + (\bar{\iota} - \bar{\iota}_*)^2$$

f_{QS} : quasisymmetry objective

$A_* = 6$ (target aspect ratio)

$\bar{\iota}_*$ (target mean iota)



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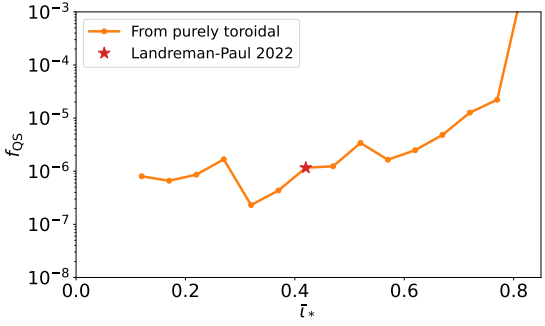


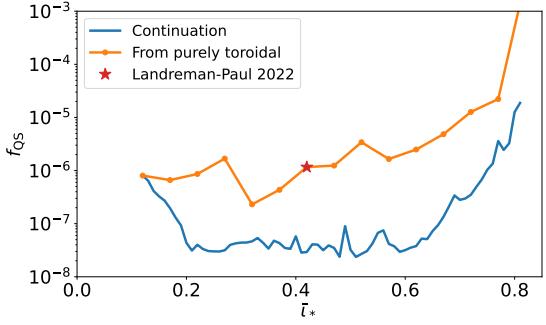
Continuation method

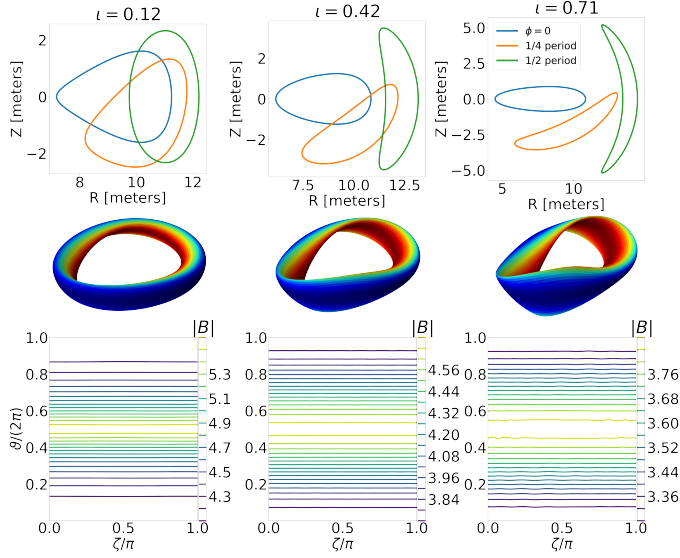
Attempt to find vacuum configuration with good quasisymmetry at even higher ι

Optimization objective: $f_{\mathrm{QS}}^2 + (A - A_*)^2 + (\bar{\iota} - \bar{\iota}_*)^2$

Optimization by continuation

1. Set $\bar{\iota}_* = 0.12$
2. Optimize from purely toroidal initial condition
3. Increment $\bar{\iota}_*$ by $+0.01$
4. Optimize starting from previous optimum
5. Go to (3)

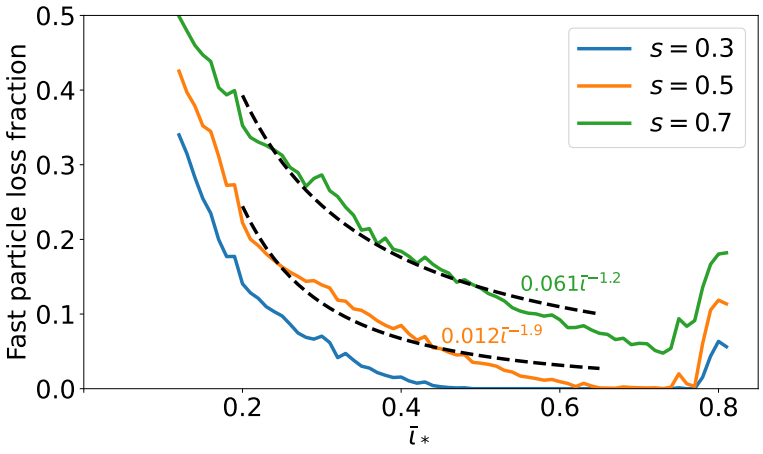



$\iota = 0.12$
$\iota = 0.42$
$\iota = 0.71$
Z [meters]
R [meters]
$\phi = 0$
1/4 period
1/2 period
$|B|$
$\theta/(2\pi)$
ζ/π

Fast-particle losses

For thin drift orbits

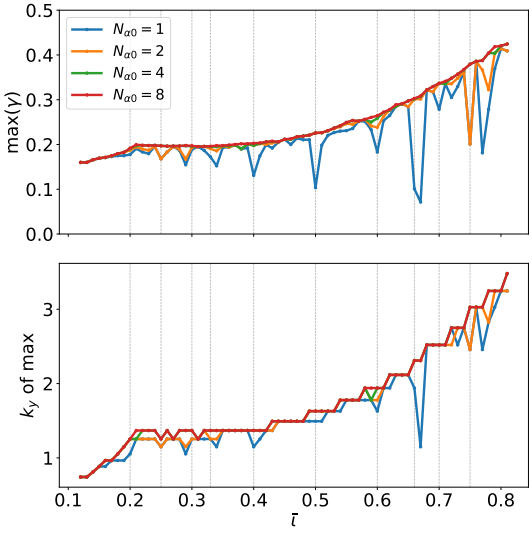
$$\text{orbit width} \propto \frac{1}{|\iota|}$$



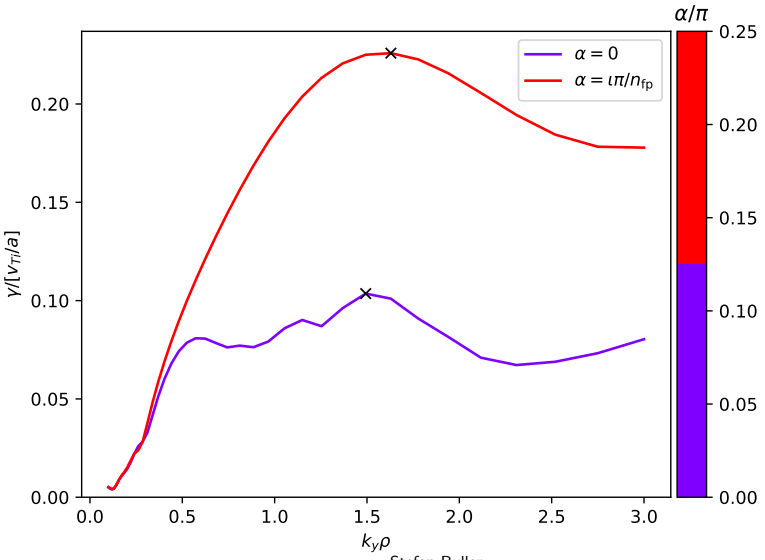
From 5000 3.5 MeV alpha particles launched at three different radii.
Drift orbits traced with SIMPLE code

Linear ITG growth rates

Electrostatic `stella` simulations for different geometries and flux-tubes.
$a/L_T = 3$, $a/L_n = 1$
α_0 : $\alpha = \theta - \iota\zeta$ at the center of flux tube.



Closer look at $\iota = 0.5$



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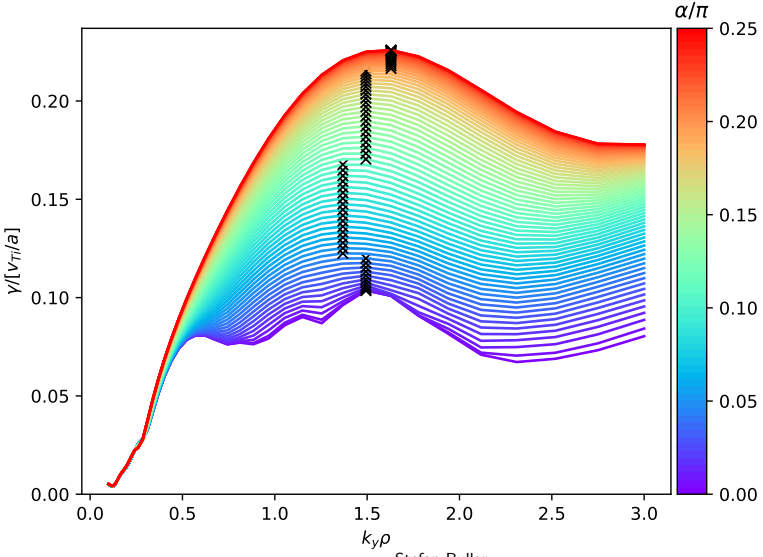

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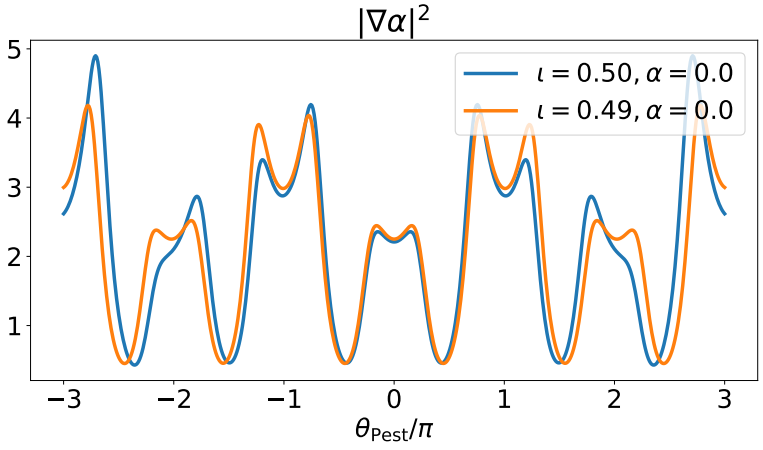
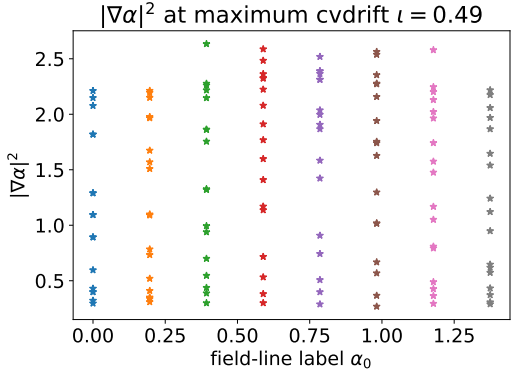
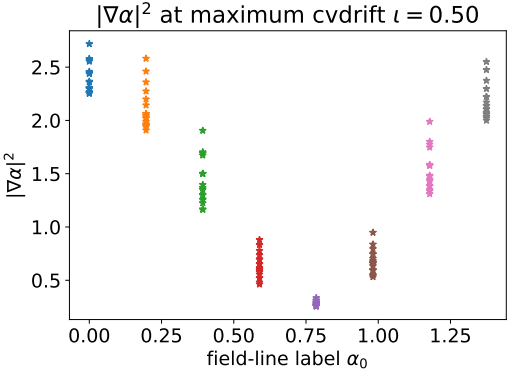
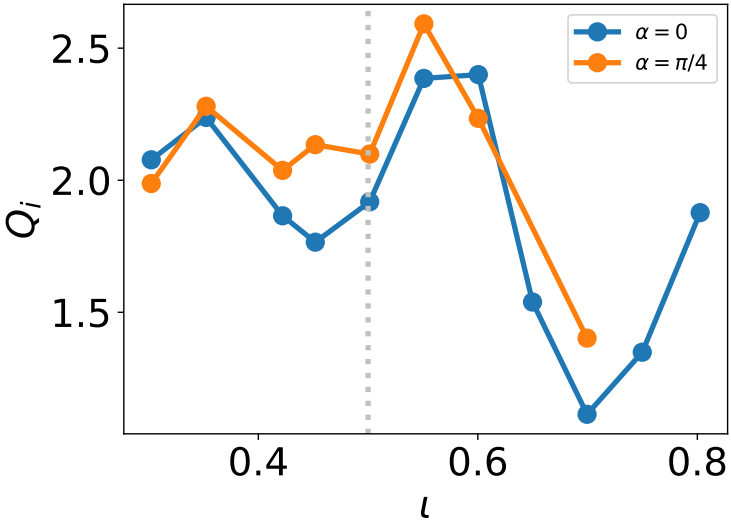


Irrational iota flux-tubes sample very different $|\nabla\alpha|^2$ at bad curvature





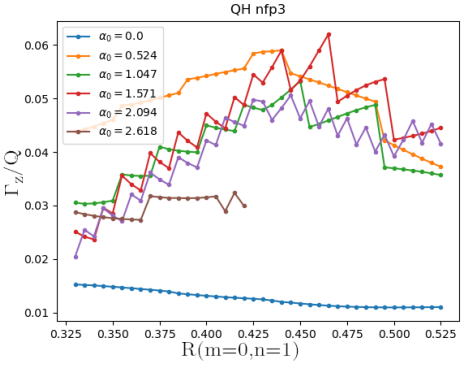
Nonlinear ITG heat fluxes

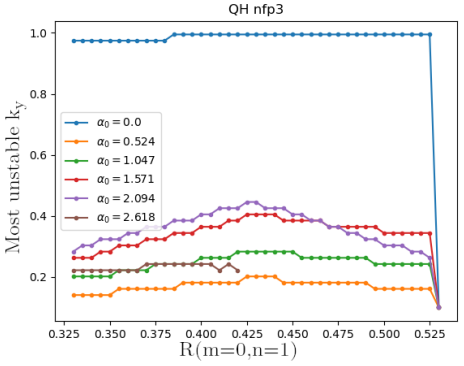


Conclusions & Outlook

- $\iota \in [0.2, 0.6]$ compatible with good quasi-axisymmetry
- Higher ι generally better for fast-particle confinement
- Nonlinear heat flux displays a more complicated trend, but seems to favor $\iota > 0.6$
- Other considerations, such as avoiding rational ι or minimizing elongation likely give stronger constraints
- At finite-beta, bootstrap current will be able provide a sizeable fraction of the ι. Less shaping needed.

Bonus slide


QH nfp3
$\alpha_0 = 0.0$
$\alpha_0 = 0.524$
$\alpha_0 = 1.047$
$\alpha_0 = 1.571$
$\alpha_0 = 2.094$
$\alpha_0 = 2.618$
Γ_z / Q
R(m=0,n=1)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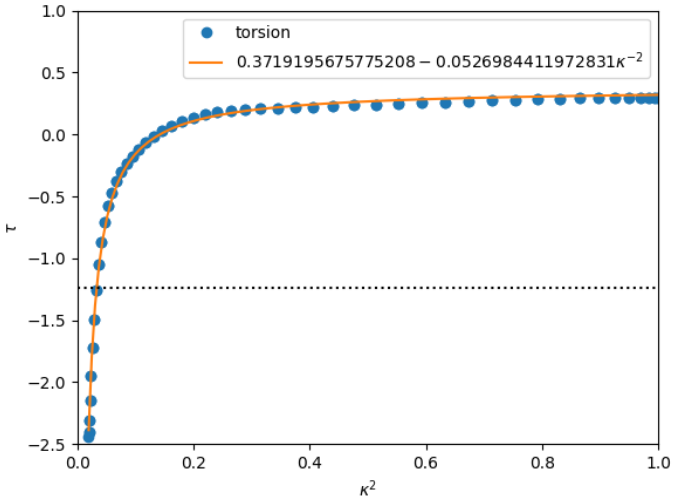
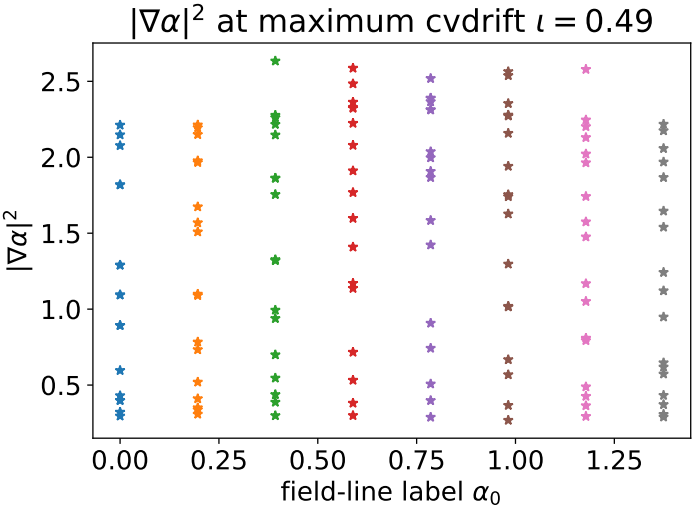
Most unstable k_y
R(m=0,n=1)

Axis curvature goes to zero at points for high ι (Here, $\iota = 0.77$)



Irrational iota flux-tubes $\iota = 0.49$



Rational iota flux-tubes. $\iota = 0.5$