Recent Progress in MHD Stability Calculation of Compact Stellarators *

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Outline

1. Introduction
2. The 3D Equilibrium and Stability Codes
3. Stability Analysis of MHD Modes:

   $\longrightarrow$ Vertical Modes ($n = 0$)

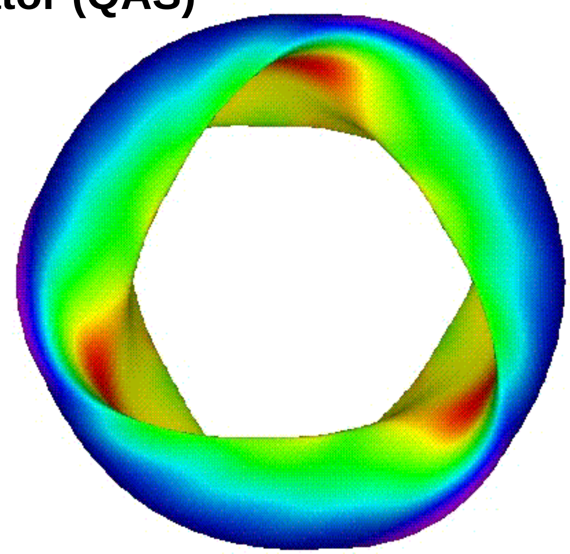
   $\longrightarrow$ External Kink Mode ($n = 1 \sim 4$)

   $\longrightarrow$ Ballooning Modes ($n \sim 20$ and infinite n)
4. Stability of The Proposed National Compact Stellarator Experiment (NCSX)
5. Conclusions

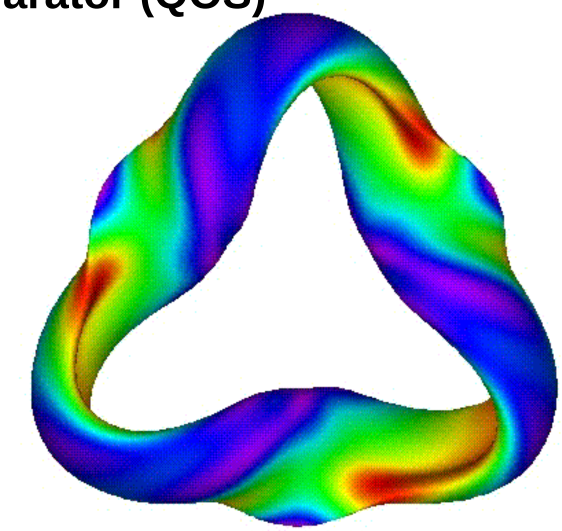
I. Introduction

- Recent intense efforts in U.S. to design compact stellarators ($R/\langle a \rangle \sim 4$, $N_p \sim 3$, $\beta \sim 4\%$).
- MHD Stability is a key issue for design of compact stellarator at finite beta and bootstrap current.

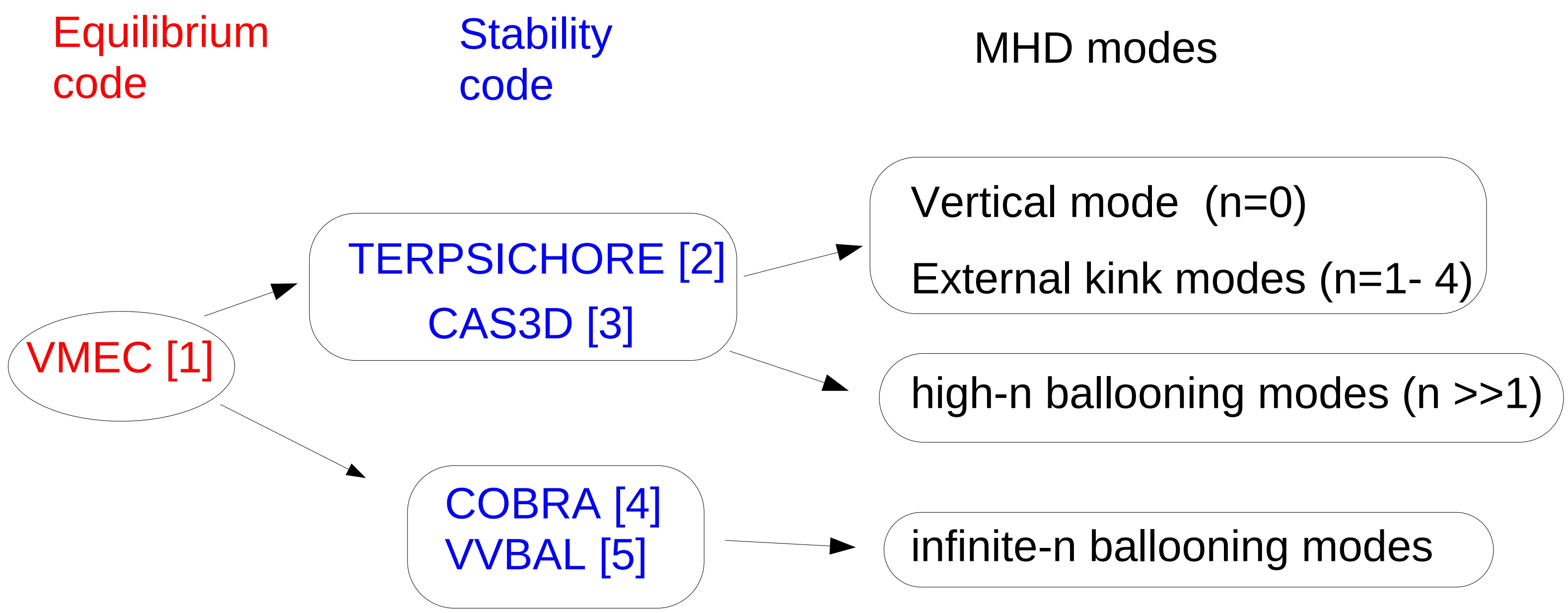
Quasi-Axisymmetric Stellarator (QAS)



Quasi-Omnigeneous Stellarator (QOS)



II. The 3D Equlibrium and Stability Codes



[1] Hirshman S. P. and Whitson, J. C., Phys. Fluids **26** (1983) 3553.

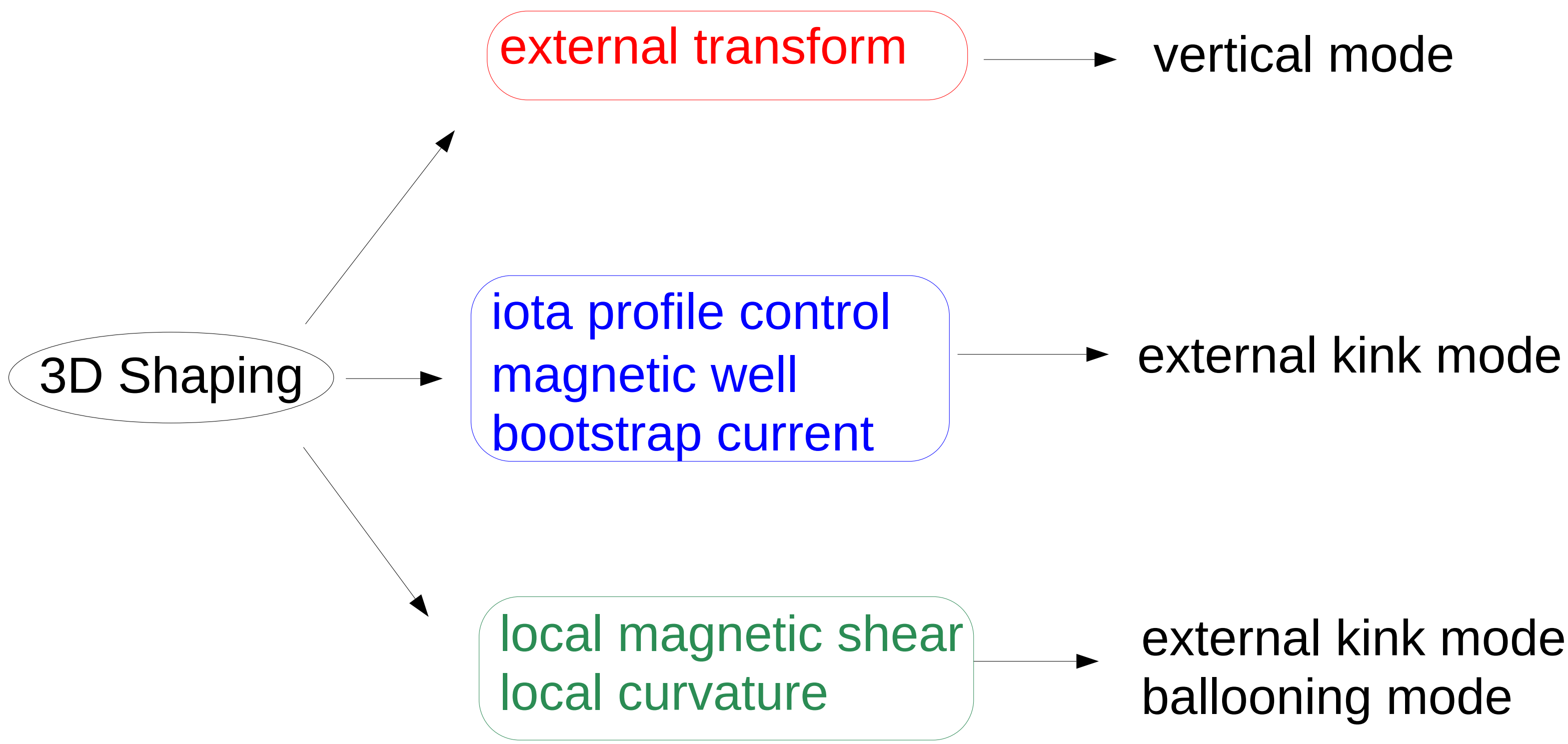
[2] Anderson, D. V. *et al.*, Scient. Comp. Supercomputer II, (1990) 159.

[3] Nüehrenberg, C., Phys. Plas. **3**, (1996) 2401.

[4] Sanchez, R. *et al.*, J. Comp. Physics **161**, (2000) 576.

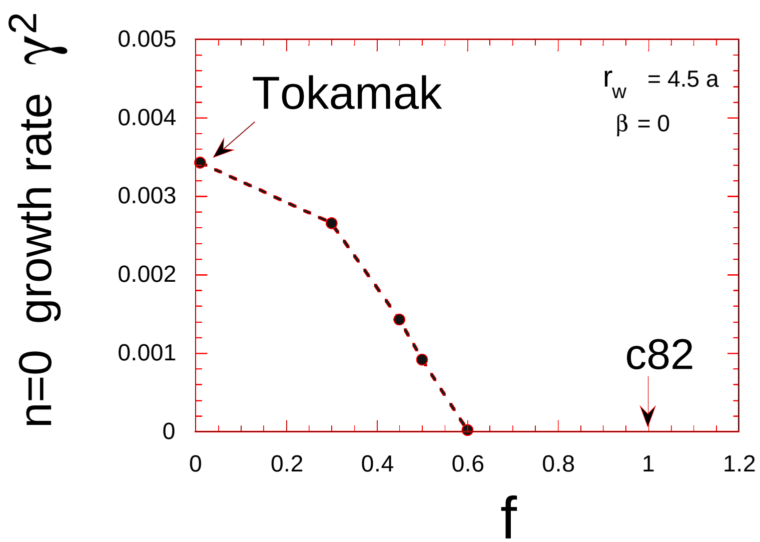
[5] Cooper, W. A., Phys. Plasmas **3**, 275(1996)

Key Stabilization Mechanisms via 3D Shaping

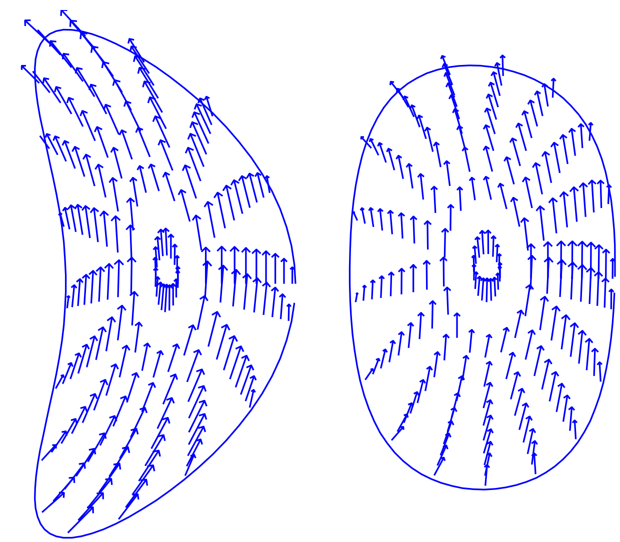


The Vertical Mode is Stabilized by Nonaxisymmetric Shape

The vertical mode is found to be robustly stable in a $N_p = 3$ QAS (c82) with $R/\langle a \rangle = 3.5$ and $\beta = 3.9\%$.



Eigenvalue as function of fraction f of c82's non-axisymmetric shape



Plasma displacement at f=0.45

Fu, G. Y. *et al.*, Phys. Plasmas **7**, (2000) 1809.

Analytic Stability Criterion for Vertical Mode

- Assume $R/a >> 1$, $\beta = 0$, $j(r)$ =constant, $\iota(r)$ = constant.

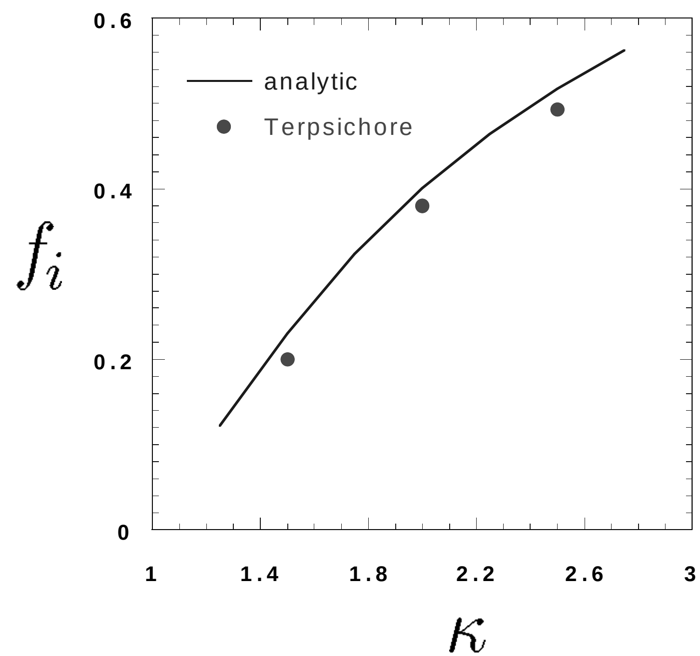
$$\delta W_p + \delta W_{vac} = \frac{1}{2}\int d^3x \quad [\delta \mathbf{B}^2 + \mathbf{j}_{\|} \cdot \xi \times \delta \mathbf{B}]$$

$$\propto \quad [\kappa + 1 - (1 - f_i)(\kappa^2 + 1)]$$

$$f_i = \frac{\kappa^2 - \kappa}{\kappa^2 + 1}$$

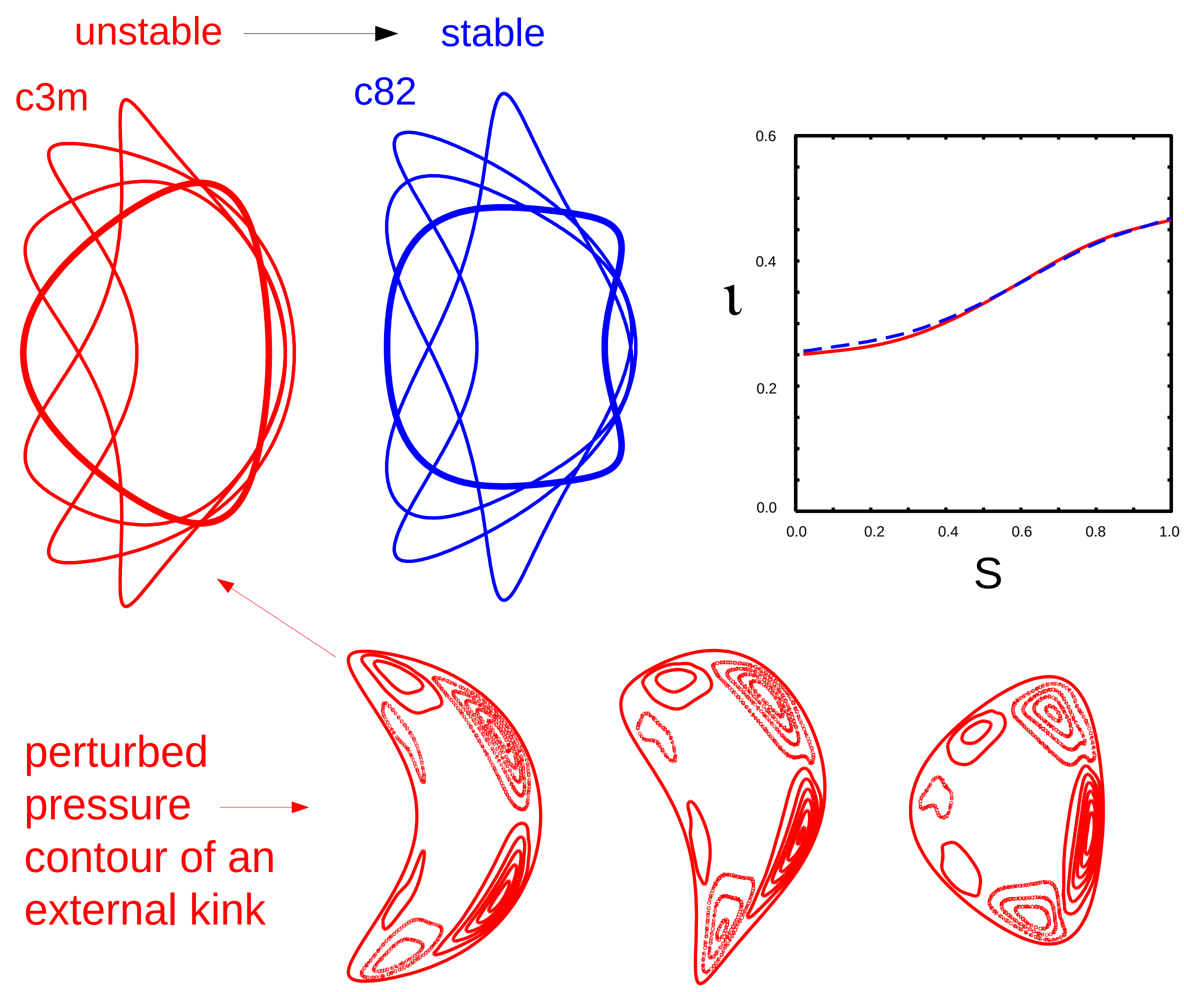
f_i : fraction of external transform needed for stabilization

κ : averaged elongation



Fu, G. Y. *et al.*, Phys. Plasmas **7**, (2000) 1079.

Cross-sections before and after stabilization by 3D shaping.



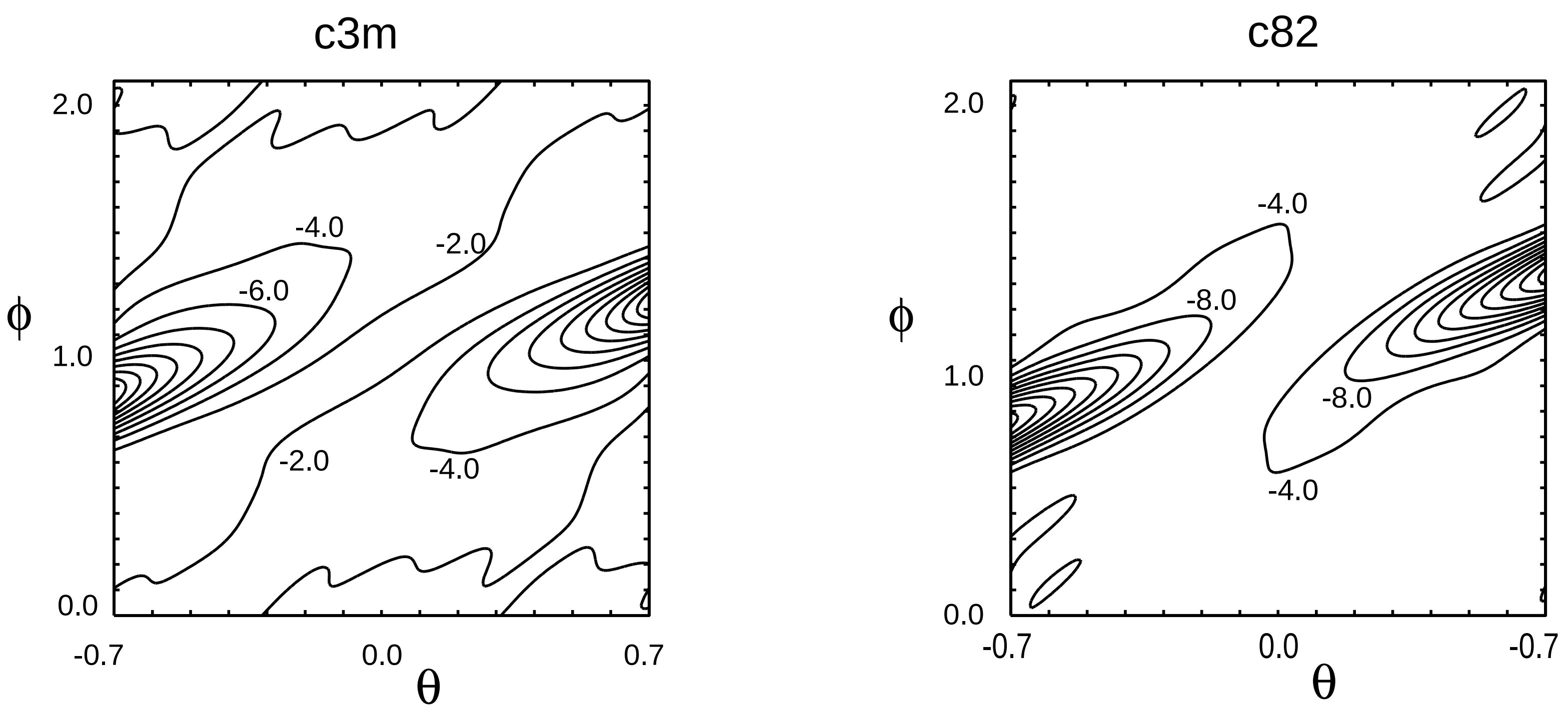
3D Shaping Can Enhance the Local Magnetic Shear and Stabilize the External Kink Modes

$$\delta W_p = \frac{1}{2}\int_p d^3x[\delta \mathbf{B}_\perp{}^2 + (\delta B_\| - \frac{\xi^s p'}{B})^2 + \mathbf{j}_\| \cdot \xi \times \delta\mathbf{B} - 2\xi \cdot \nabla p\ \xi \cdot \kappa]$$

	vacuum	bending	kink	ballooning
c3m	1.00	4.05	−3.98	−1.72
c82	1.00	4.51	−3.87	−1.64
diff.		0.46	0.11	0.08

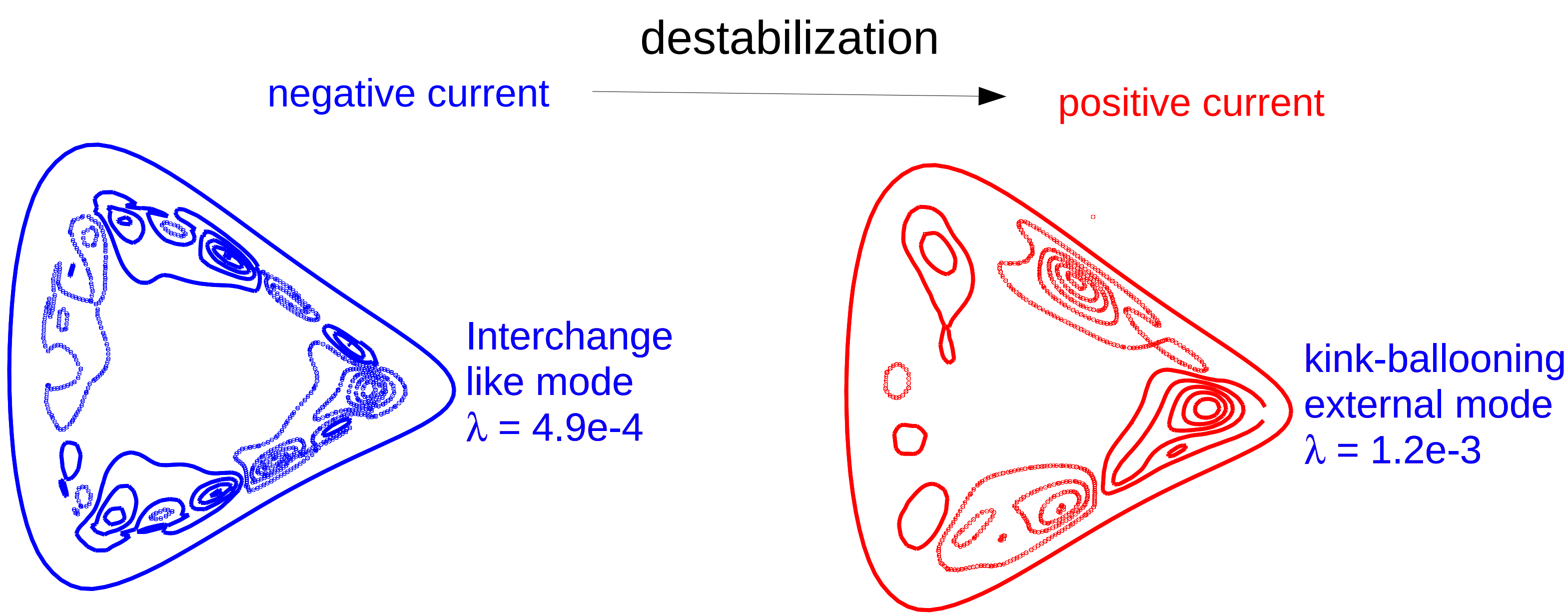
The difference in the field line bending energy is related to an enhancement of local magnetic shear on the outboard side.

Local Magnetic Shear is Larger in c82



External Kink Stability in the QOS is due to a Small Negative Current

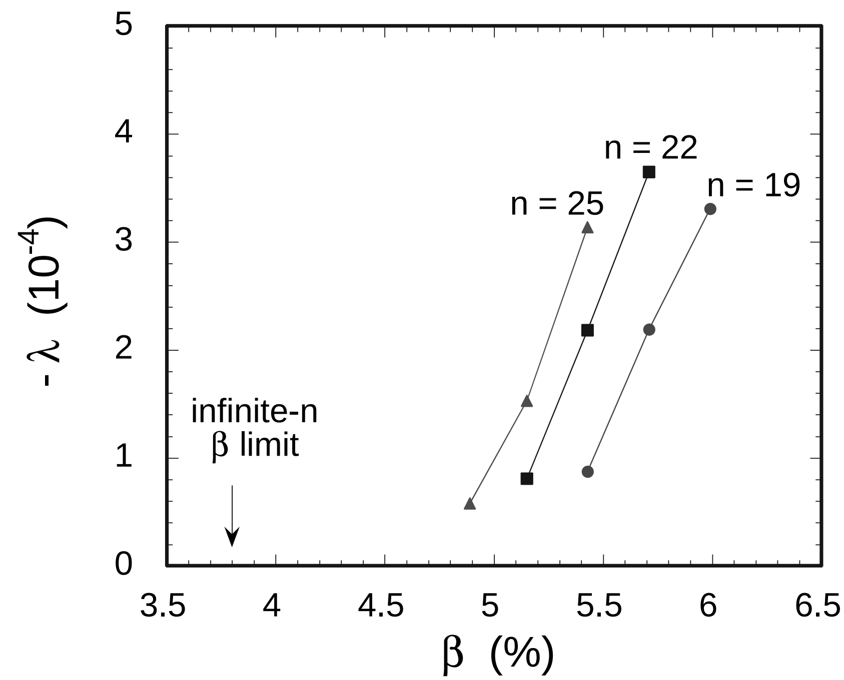
Consider a $N_p = 3$, $R/\langle a \rangle = 3.6$ QOS at $\beta = 3.7\%$. The bootstrap current is small ($\Delta\iota/\iota \sim -15\%$) It is stable to external kink modes. It becomes unstable at $\beta \sim 5\%$.



→ 3D shaping can be used to control the bootstrap current and external kink modes.

Stability of High-n Ballooning Modes

Eigenvalue of high-n ballooning modes from Terpsichore for a Np=3 QAS (c82).

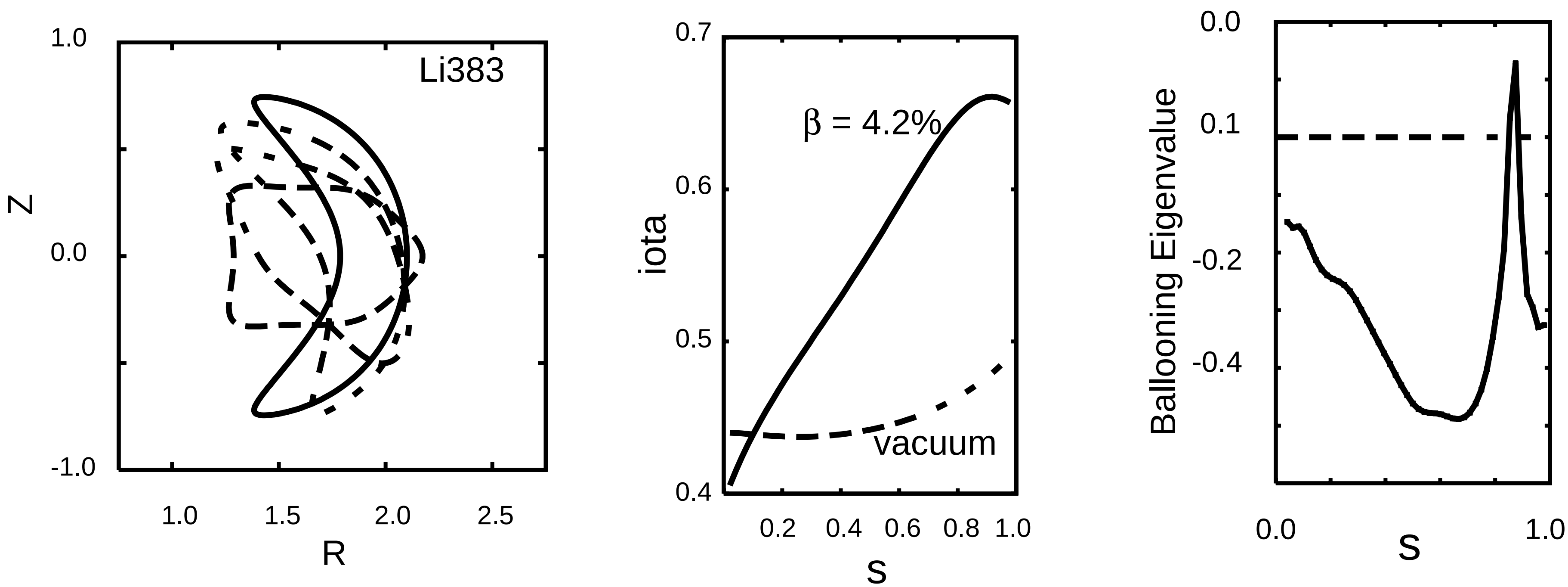


→ high-n global ballooning modes are significantly more stable than the infinite-n limit.

→ FLR effects are important for determining the ballooning beta limit.

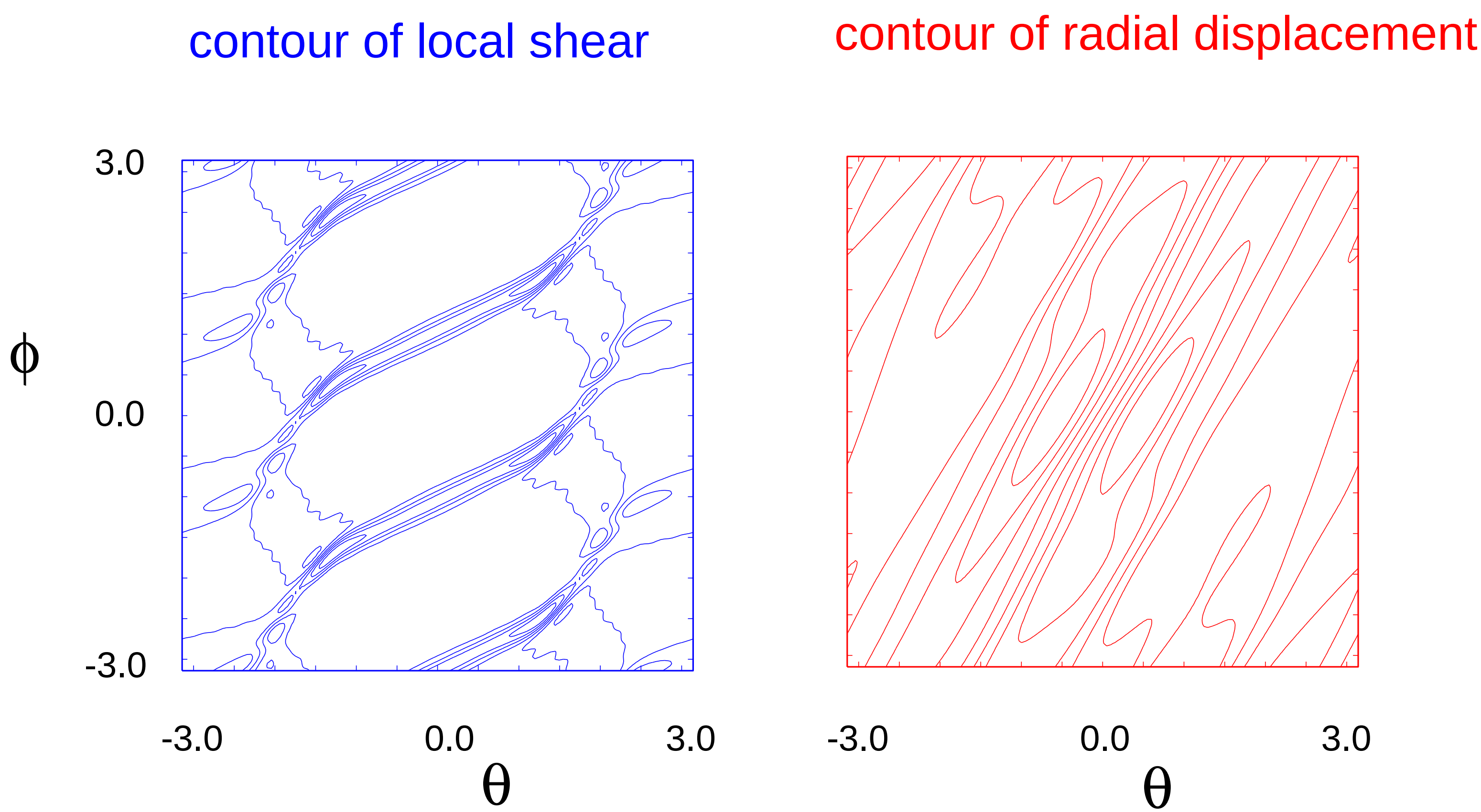
The NCSX Design is Stable to the Vertical Mode, External Kink Modes and Ballooning Modes

The current candidate for the National Compact Stellarator Experiment (NCSX) is a three field period QAS at $R/\langle a \rangle = 4.4$, $\beta = 4.2\%$.



Zarnstorff, M. et al., this conference

Local Shear and Kink Mode Structure



→ The helical stripes of large local magnetic shear helps to stabilize the external kink modes.

V. Conclusions

- The MHD stability of current-carrying compact stellarators are investigated using fully 3D calculations.

- The vertical mode in stellarators is much more stable than in tokamaks due to stabilizing effects of externally generated rotational transform.

- The external kink modes in compact stellarators can be stabilized in the absence of a conducting wall by appropriate 3D shaping through control of iota profile, local magnetic shear and bootstrap current.

- The beta limits of high-n global ballooning modes are significantly higher than the infinite-n limit.