High-β Equilibria and Second Ballooning Stability Access in the Quasi-Poloidal Stellarator

The University of Montana MISSOULA

A. S. Ware, D. Westerly, E. Barcikowski, N. D. Finley

OAK RIDGE NATIONAL LABORATORY

L.A. Berry, S.P. Hirshman, J.F. Lyon, D.A. Spong, D. J. Strickler

Universidad Carlos III de Madrid

R. Sanchez

PPPL PRINCETON PLASMA PHYSICS LABORATORY

G. Fu

Main Topics

- What are the properties of high-β plasmas in the Quasi-poloidal Stellarator?
- Can we control the access to a second ballooning stable regime with variation of external and/or plasma currents?

Outline

- High-β equilibria in the Quasi-Poloidal Stellarator
- Second-stability in free-boundary equilibria
- Impact of plasma current profile variation on second stability in QPS

The Quasi-Poloidal Stellarator

- Main parameters:

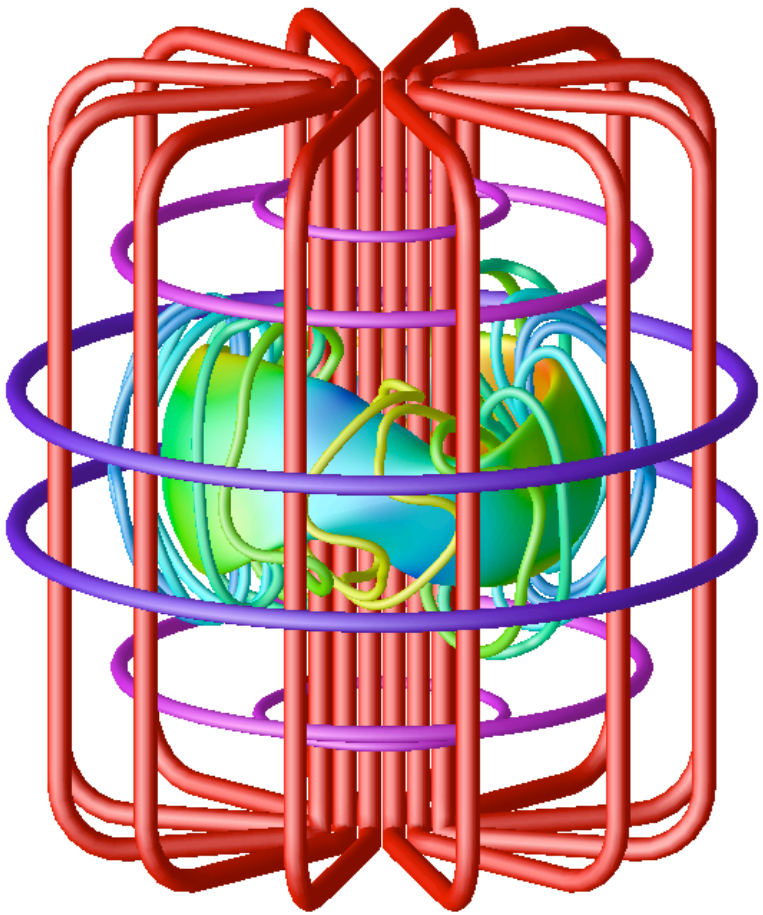
  A = 2.7

  $\langle R \rangle$ = 0.95 - 1.00 m

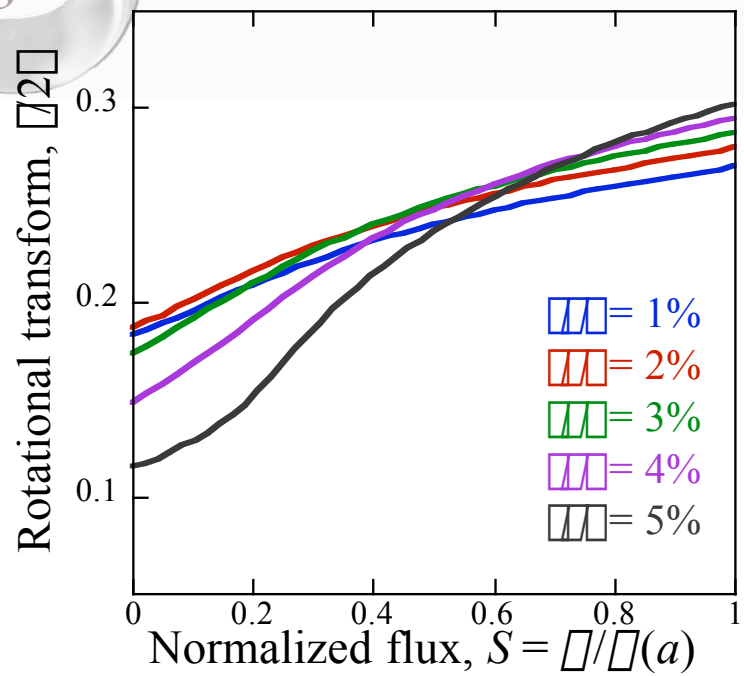
  $\langle a \rangle$ = 0.3 - 0.4 m

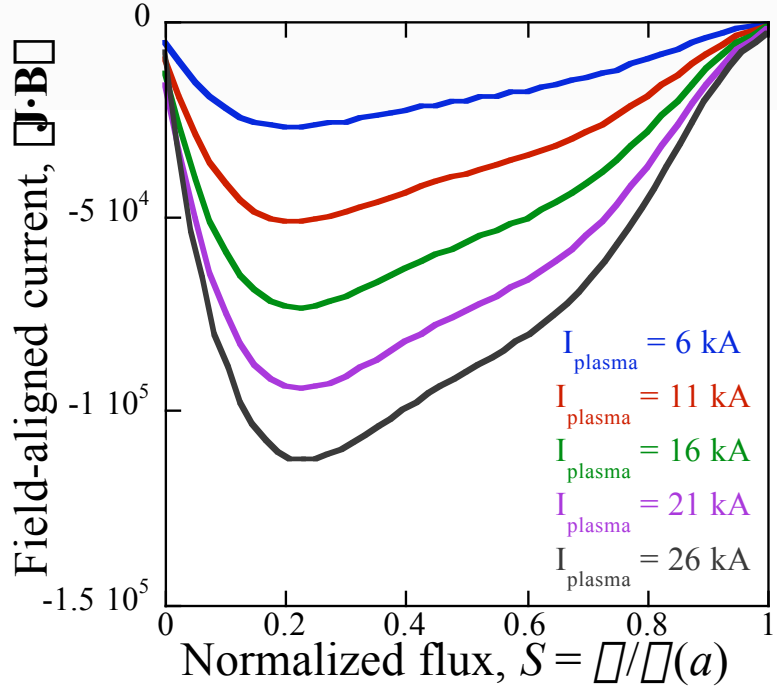
  $\langle B_0 \rangle$ = 1.0 T

- Coil sets:
  - 5 modular (4 coils/group)
  - 3 vertical (2 coils/group)
  - 1 toroidal (12 coils/group)

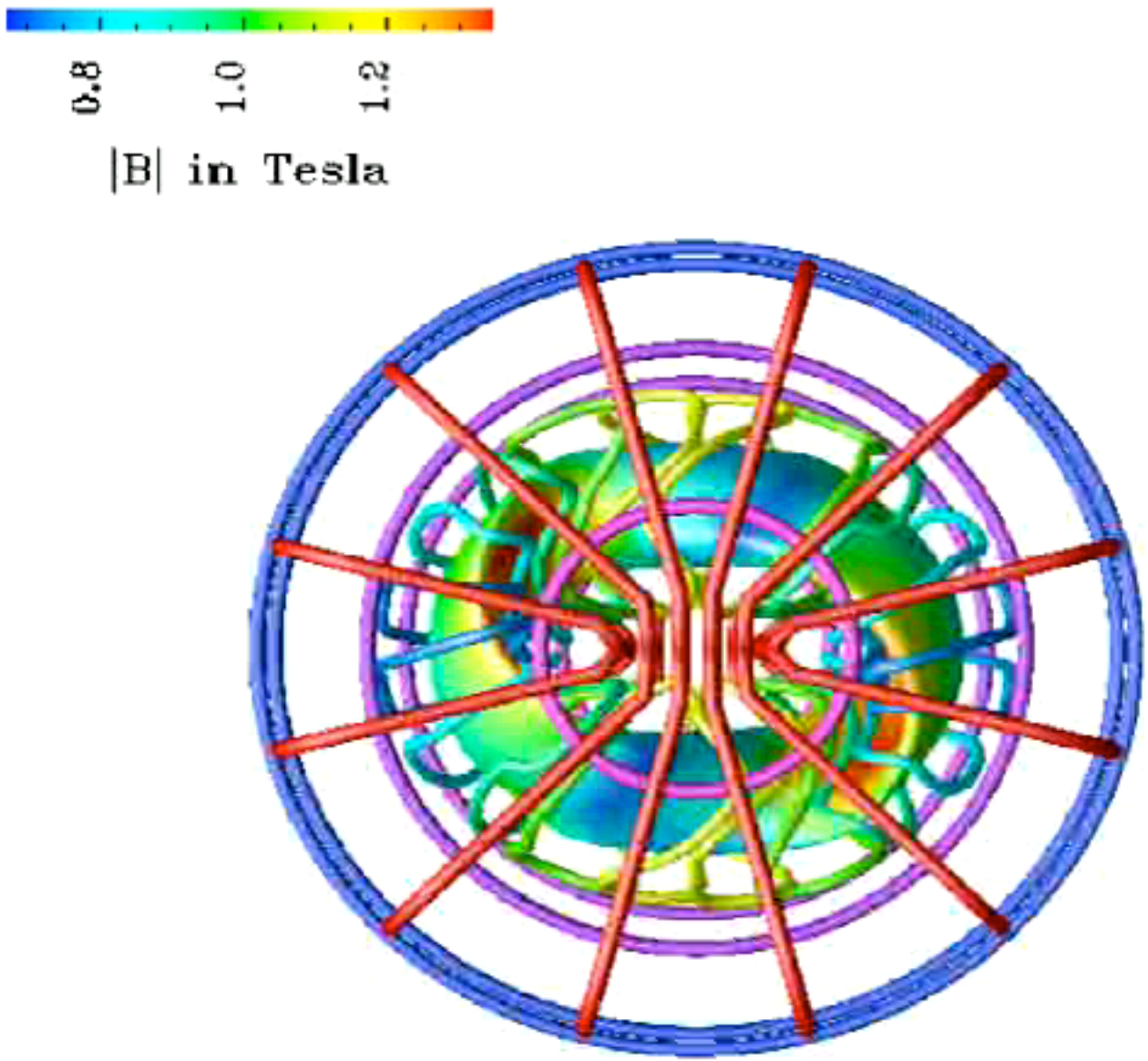


High-β equilibria in QPS



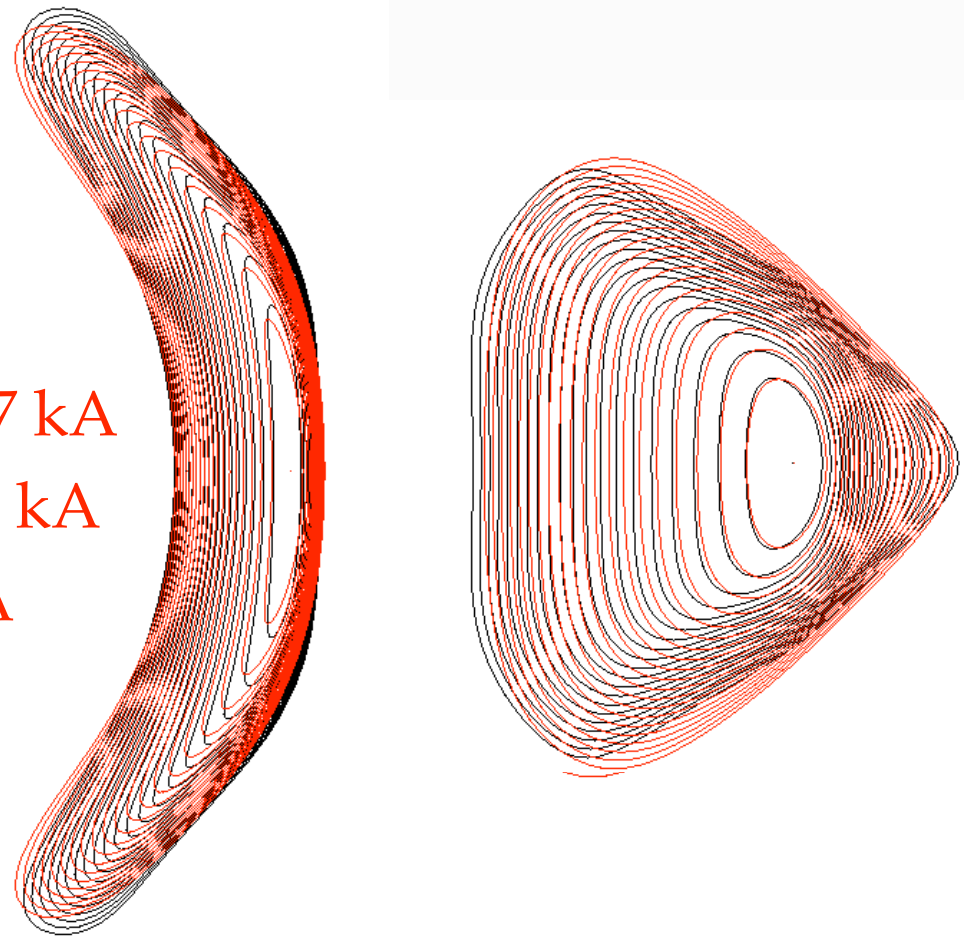


- Base equilibria:
  - $\langle\beta\rangle$ = 0 - 2%
  - I_{plasma} = 0 - 20 kA
- High-β equilibria:
  - $\langle\beta\rangle$ = 5 - 7%
  - I_{plasma} = 20 - 60 kA


0.8
1.0
1.2
|B| in Tesla

Can change the flux surface shape using the vertical field

- $\langle\beta\rangle$ = 7%
- I_{VF1} = -128 kA → -257 kA
- I_{VF2} = -75 kA → -150 kA
- I_{VF3} = 0 kA → -50 kA



Second Ballooning Stability

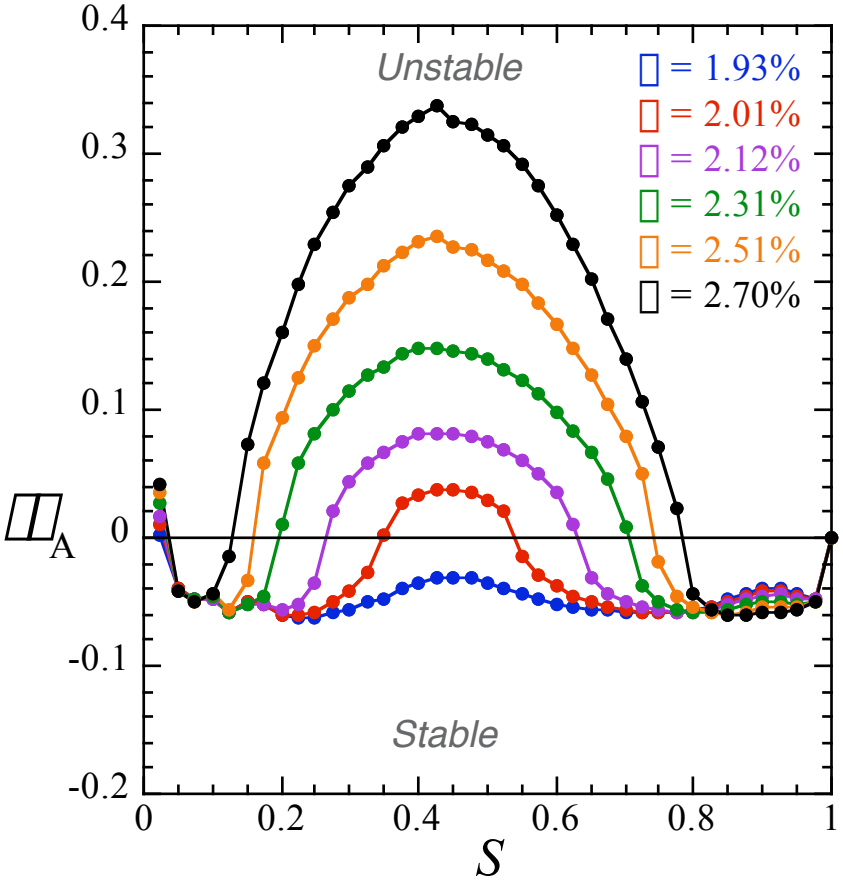
- The ideal MHD beta limits for stellarators are often set by ballooning modes
  - ballooning modes localized to regions of unfavorable curvature (helical & toroidal)
  - these modes set the β limits for QPS plasmas
- For this work, infinite-*n* ballooning mode stability was analyzed using the ballooning code COBRAVMEC

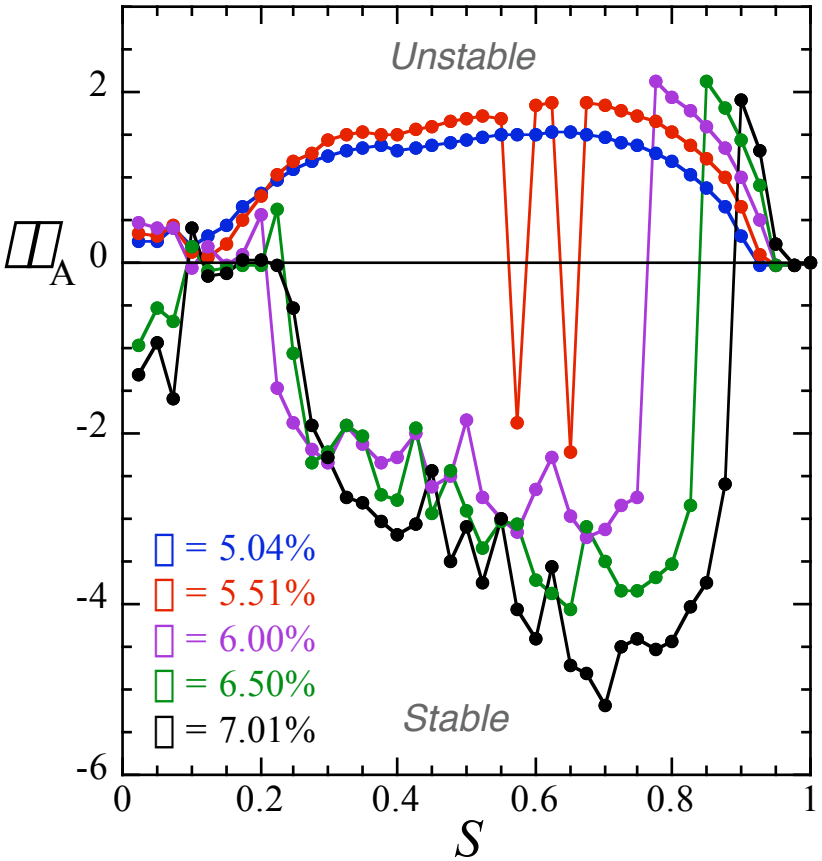
Ballooning Stability: Evidence of Second Stability in QPS

- Second stability is a region in which the plasma becomes stable at large pressure gradient
- In QPS, increasing ι/I for a fixed plasma current results in a region of second stability at high-β
  - Similar to high-β hybrid cases discussed in Ware et al., PRL 2002.
  - A quadratic pressure profile, $p = p_0(1 - S)^2$, was used with fixed plasma current

Ballooning Stability: Evidence of Second Stability in QPS

- First instability at □□ ~ 2%
- Second stability at □□ ~ 6%





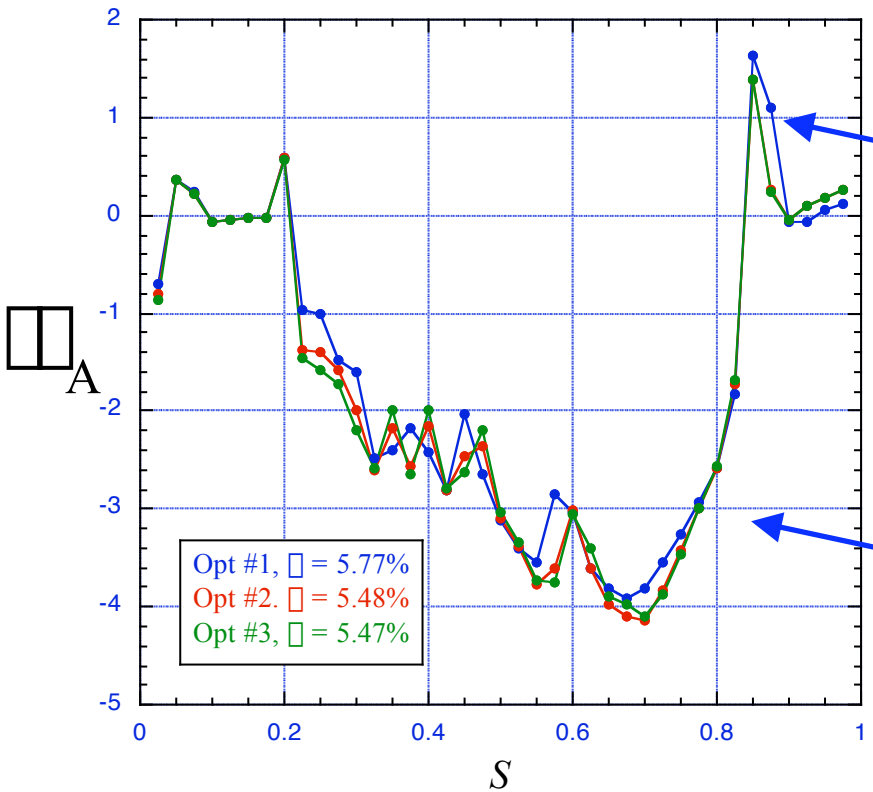
Optimizing for Second Stability

- A $\langle\beta\rangle$ = 6% plasma configuration was chosen as the initial case for an optimization for stability at high-β
- The plasma pressure profile, the plasma current profile, and the external currents were all used as parameters to optimize for second stability

Optimizing for second stability:

Ballooning growth rate of optimized plasma

- Ballooning growth rate calculated using the COBRAVMEC code



A small edge region remains unstable at high β (likely a result of d*p*/d*S*=0)

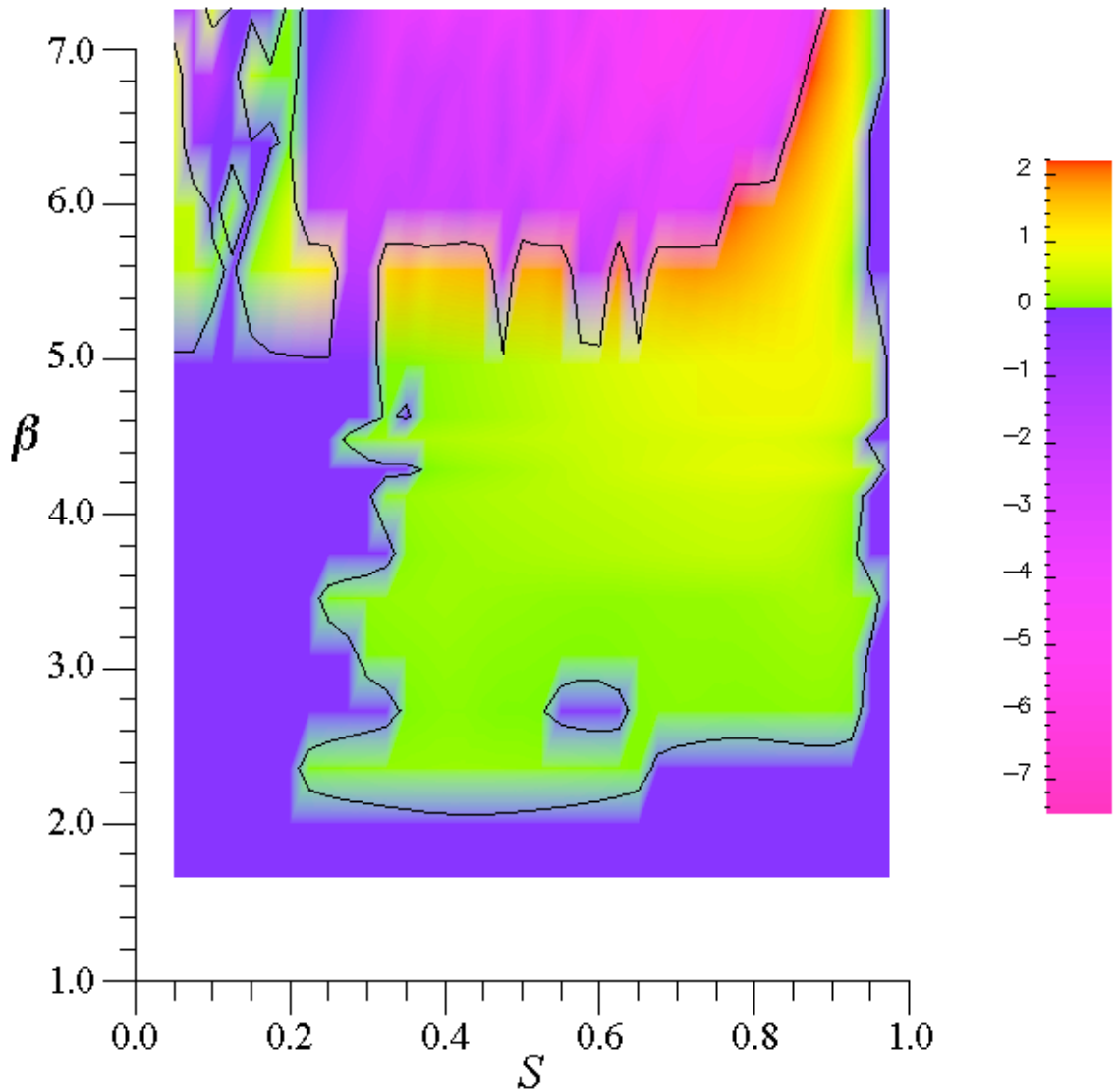
Majority of the core is in a second stable regime

Minimizing the region of instability

- Optimized for ballooning stability at a range of betas from 2% to 6% in order to minimize the gap between first and second stability.

Instability Region: Gap reduced

- Contour plot of ballooning growth rates as a function of S and ι

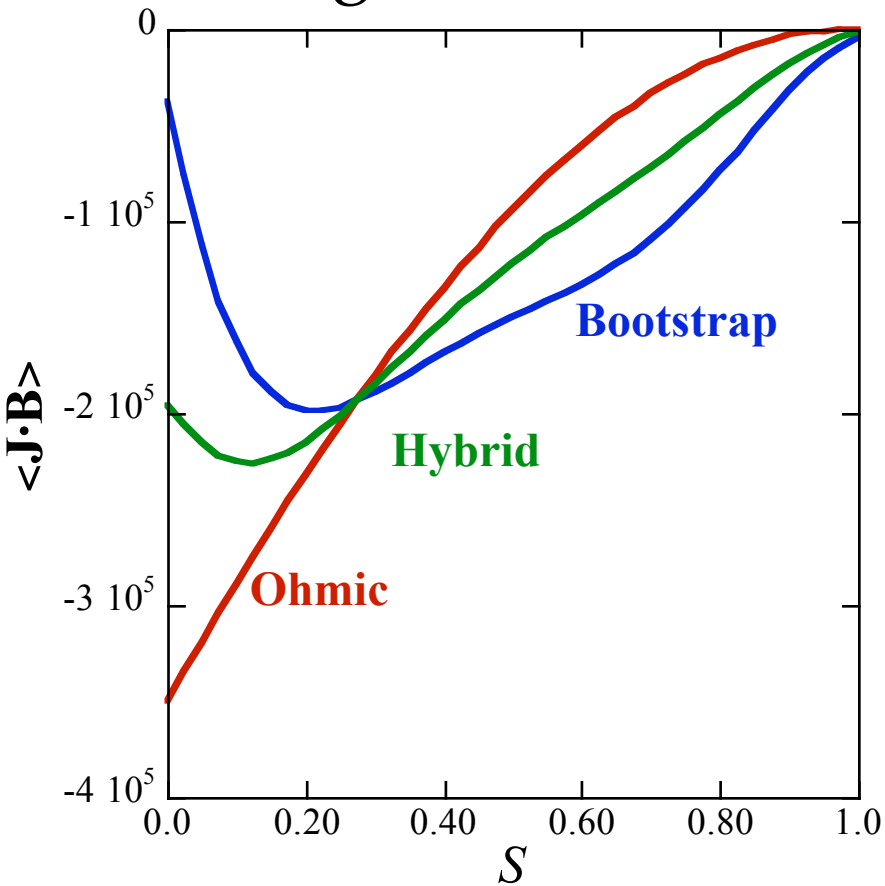


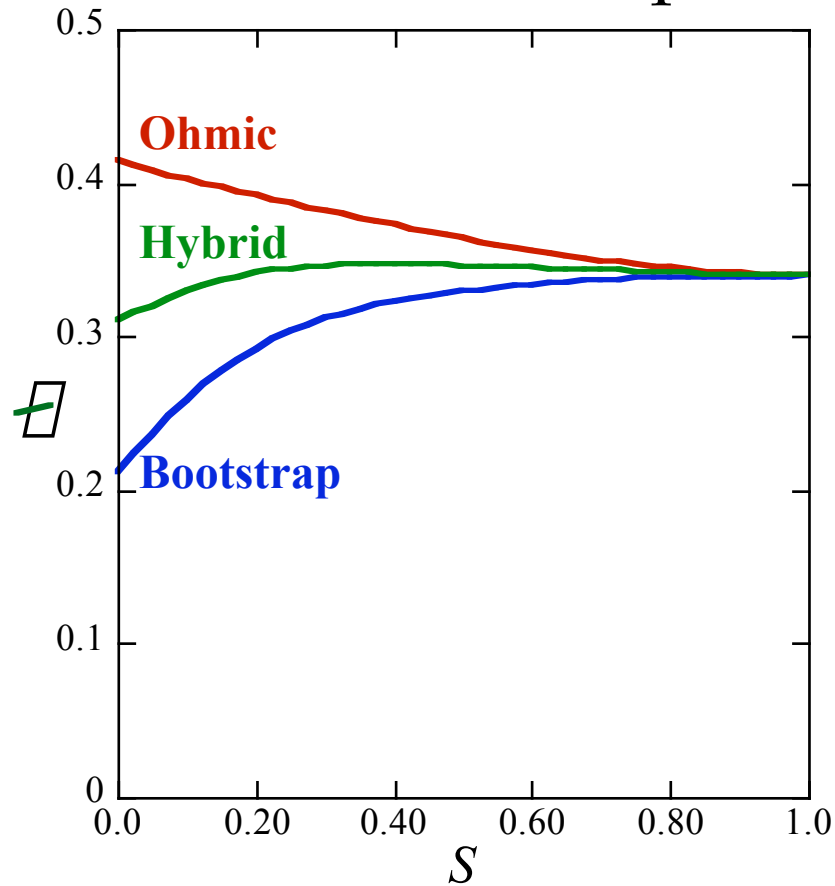
Impact of plasma current on second stability

- QPS will have the capability for Ohmic current drive as well as RF current drive
- The current profile impacts plasma stability and current profile control is a useful tool for accessing second stability

Current Profile Control: Bootstrap, Ohmic, and Hybrid current profiles

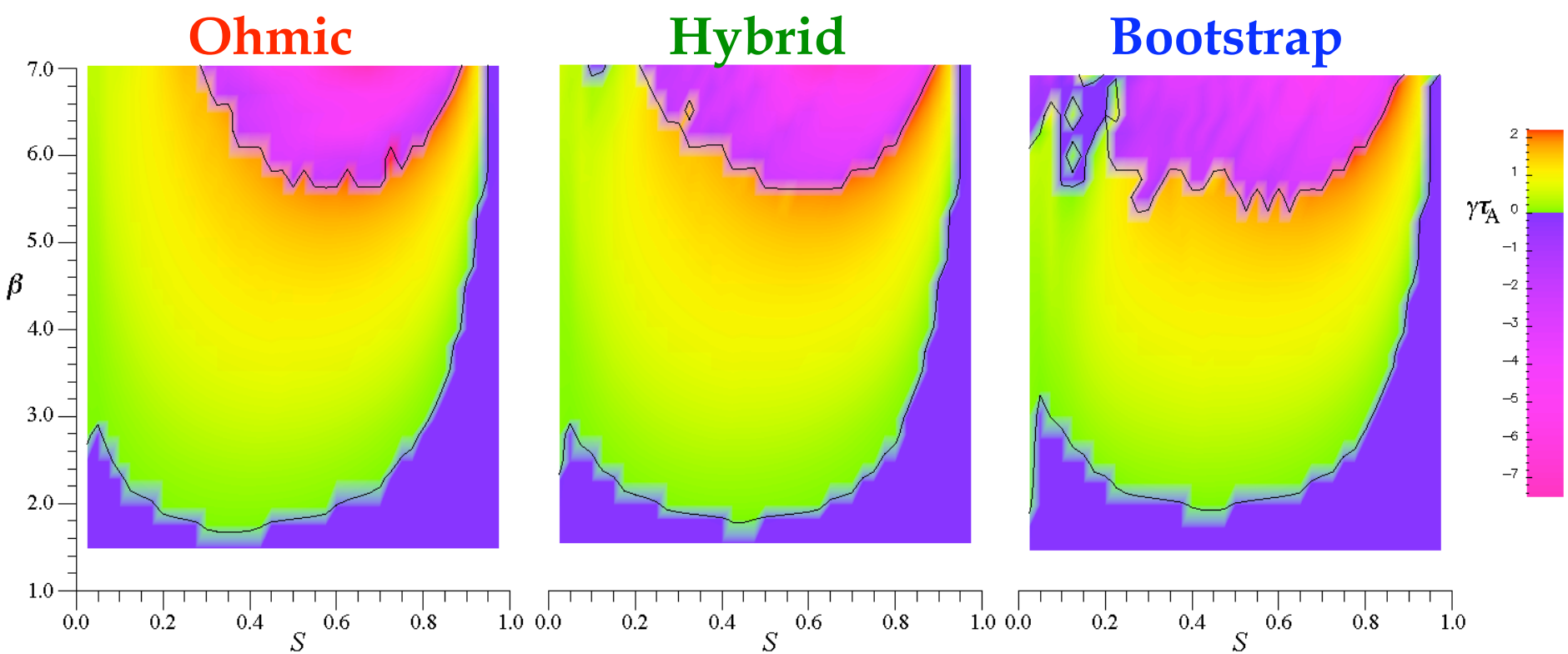
- Field-aligned current & rotational transform profiles





Current Profile Control: Bootstrap current profile has the best stability

- Contours of ballooning growth rates from COBRAVMEC



Summary

- Second ballooning stable plasmas have been found for a reference QPS configuration
  - These are free boundary, stellarator equilibria
  - First stability β ~ 2%
  - Second stability β ~ 6%
- Optimization at different ι resulted in a narrower gap (in ι) between first and second stability