Impact of Resonant Magnetic Perturbation Fields on NSTX-U Advanced Divertor Topologies

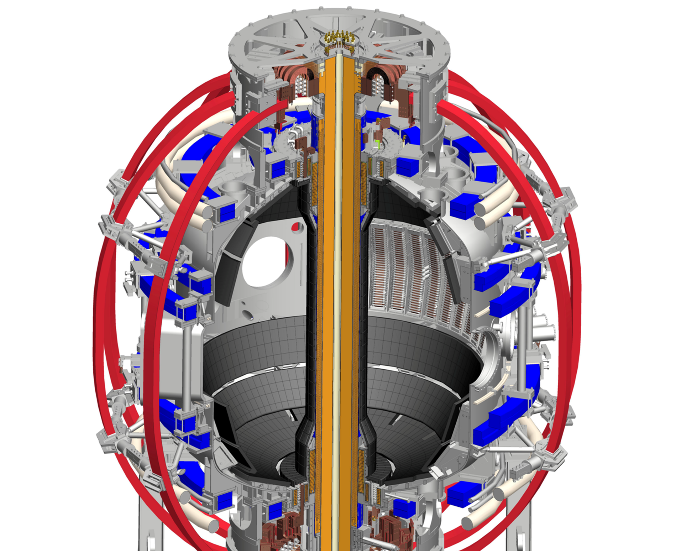
I. Waters[1], H. Frerichs[1], O. Schmitz[1], J.-W. Ahn[2], G. Canal[3], T.E. Evans[3], V. Soukhanovskii[4]

[1]University of Wisconsin-Madison, Madison, WI, USA [2]Princeton Plasma Physics Laboratory, Princeton, NJ, USA [3]General Atomics, San Diego, CA, USA [4]Lawrence Livermore National Laboratory, Livermore, CA, USA

College of Engineering
UNIVERSITY OF WISCONSIN–MADISON

Introduction

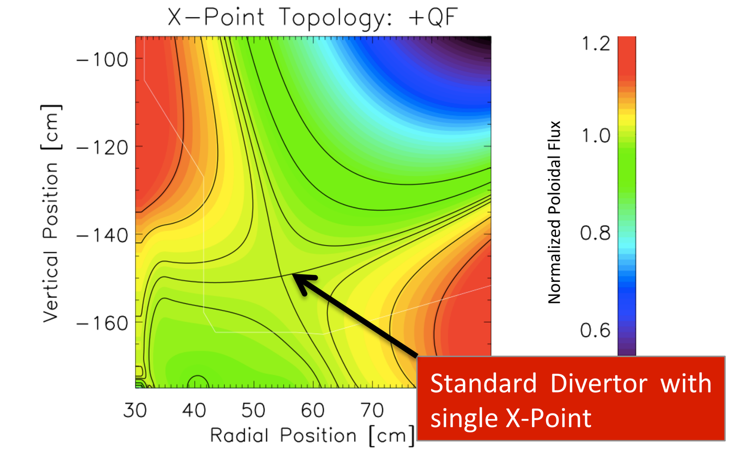
- There is ongoing research into **Advanced Divertor** configurations at both high and low aspect ratio tokamaks
- Simultaneous studies are ongoing into the effects of **Resonant Magnetic Perturbations** (RMPs) on divertor heat loads, particle exhaust, and impurity screening
- Given the use of RMPs for edge localized mode suppression and density control, need to understand how RMPs will behave with Advanced Divertors



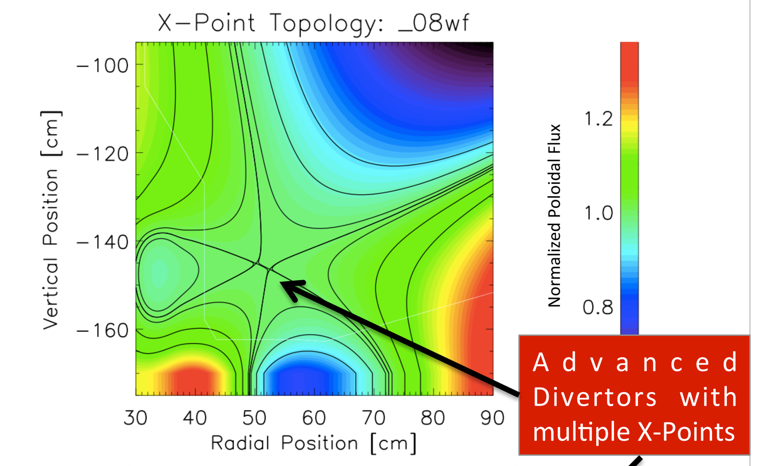
The National Spherical Tokamak Experiment-Upgrade (NSTX-U) [shown at left] has begun operations to explore ITER and ST-FNSF relevant physics regimes and innovative divertor concepts. Image Credit: PPPL.

Magnetic Configurations

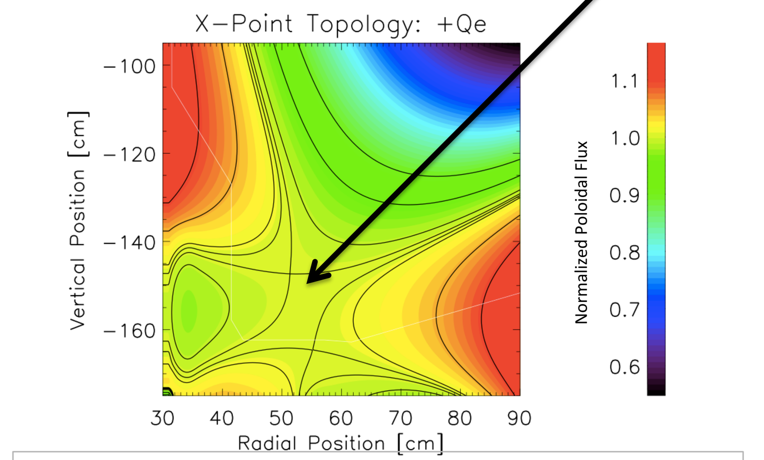
- Three configurations compared:
  - Standard Divertor (+QF)



  - Near Exact Snowflake (_08wf)



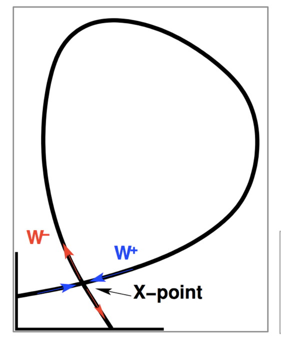
  - Snowflake Minus (+Qe)



Above: Equilibrium plots of the three modeled divertor configurations showing surfaces of constant poloidal magnetic flux normalized to the separatrix.

Perturbed Separatrix

- The separatrix associated with X is made out of 2 branches (invariant manifolds)
- Both branches overlap in the unperturbed configuration

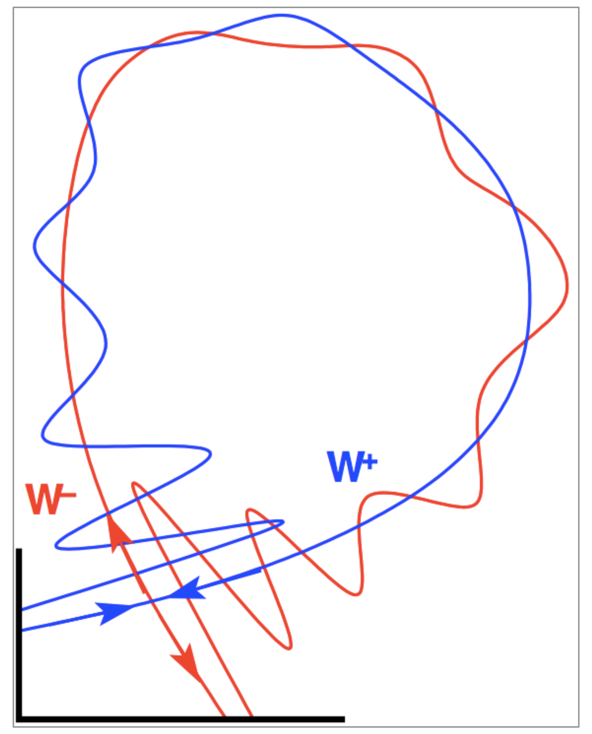


$$W^{+} = \left\{ \mathbf{x} \middle| \lim_{l \to \infty} F_{\mathbf{x}}(l) \to \mathbf{X} \right\}$$

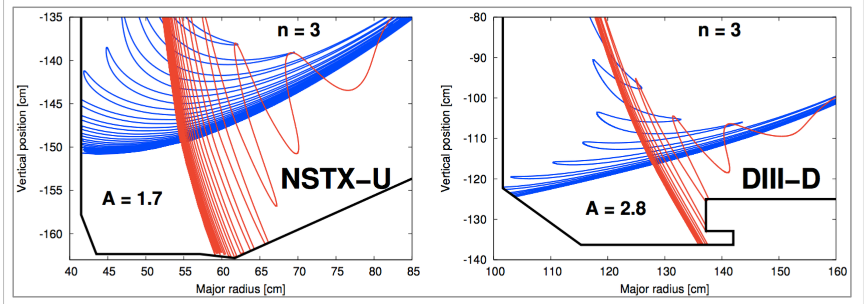
$$W^{-} = \left\{ \mathbf{x} \middle| \lim_{l \to -\infty} F_{\mathbf{x}}(l) \to \mathbf{X} \right\}$$

Evans, T.E. et. al. Homoclinic Tangles, bifurcations and edge stochasticity in diverted tokamaks. Contributions in Plasma Physics, 2004
Image Credit: H. Frerichs, Overview of edge modeling efforts for advanced divertor configurations in NSTX-U with magnetic perturbation fields. ISTW 2015

- Magnetic perturbations split the manifolds and the branches begin to intersect rather than overlap
- These lobes yield direct magnetic connection from the inside of the separatrix onto the divertor targets:



- As the manifolds approach the X-Point, the lobe width and lobe spacing both go to zero



H. Frerichs, Overview of edge modeling efforts for advanced divertor configurations in NSTX-U with magnetic perturbation fields. ISTW 2015

Advanced Divertors

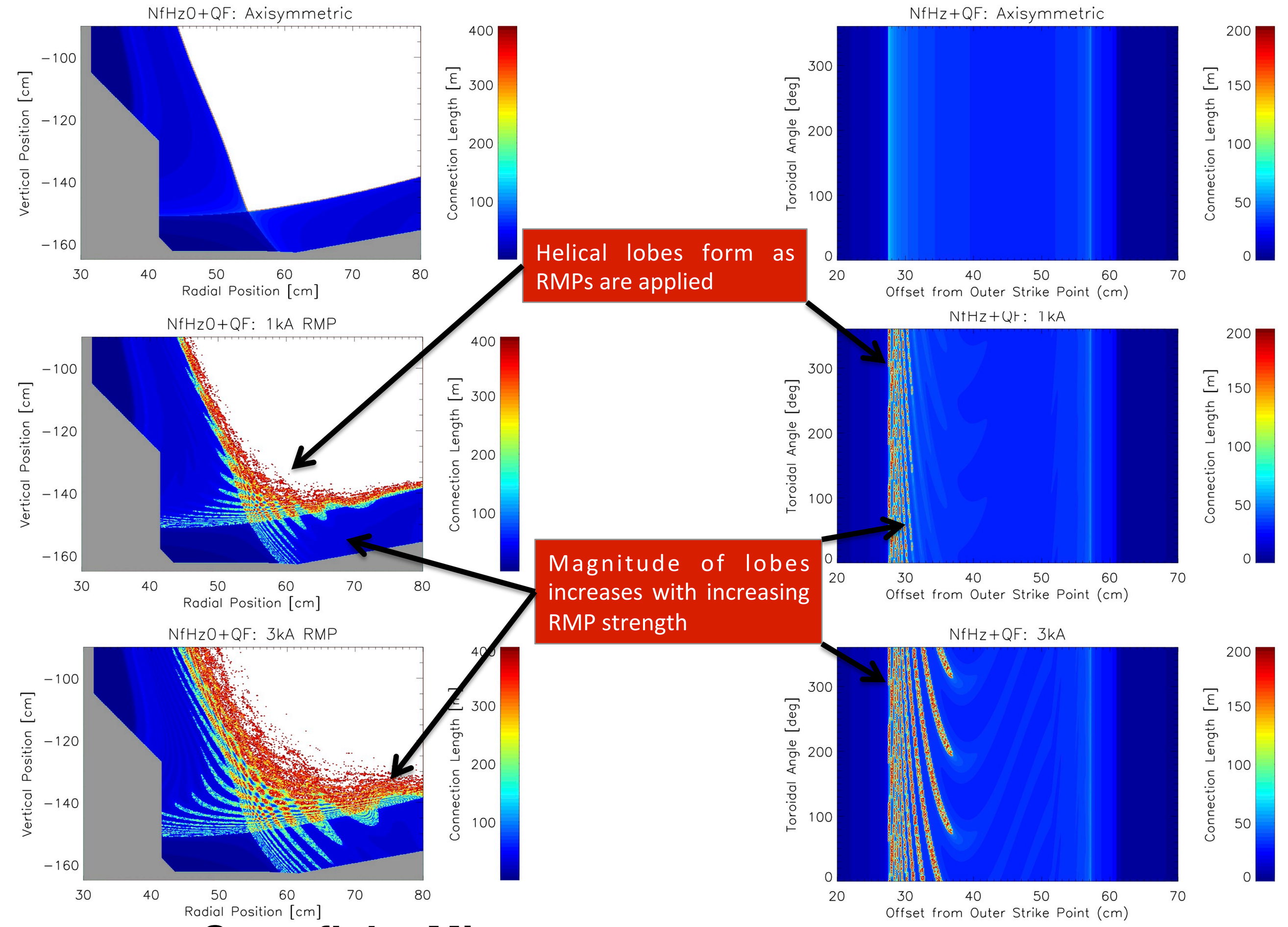
- Divertor Configuration has been critical for the progress in tokamaks towards better:
  - Power Exhaust
  - D/T/He Pumping
  - Impurity Screening
- Significant challenges with scaling towards ITER and DEMO
  - Deposited Power/Area
  - Heat Flux
  - ELM Control
- ADVANCED DIVERTORS use alternate magnetic topologies to mitigate these issues
  - Multiple standard divertors
  - Multiple X-Points
  - Higher order null X-Points

Credit: Soukhanovskii, V. LLNL-PRES-663440 Edge Coordinating Committee Fall 2014 Technical Meeting

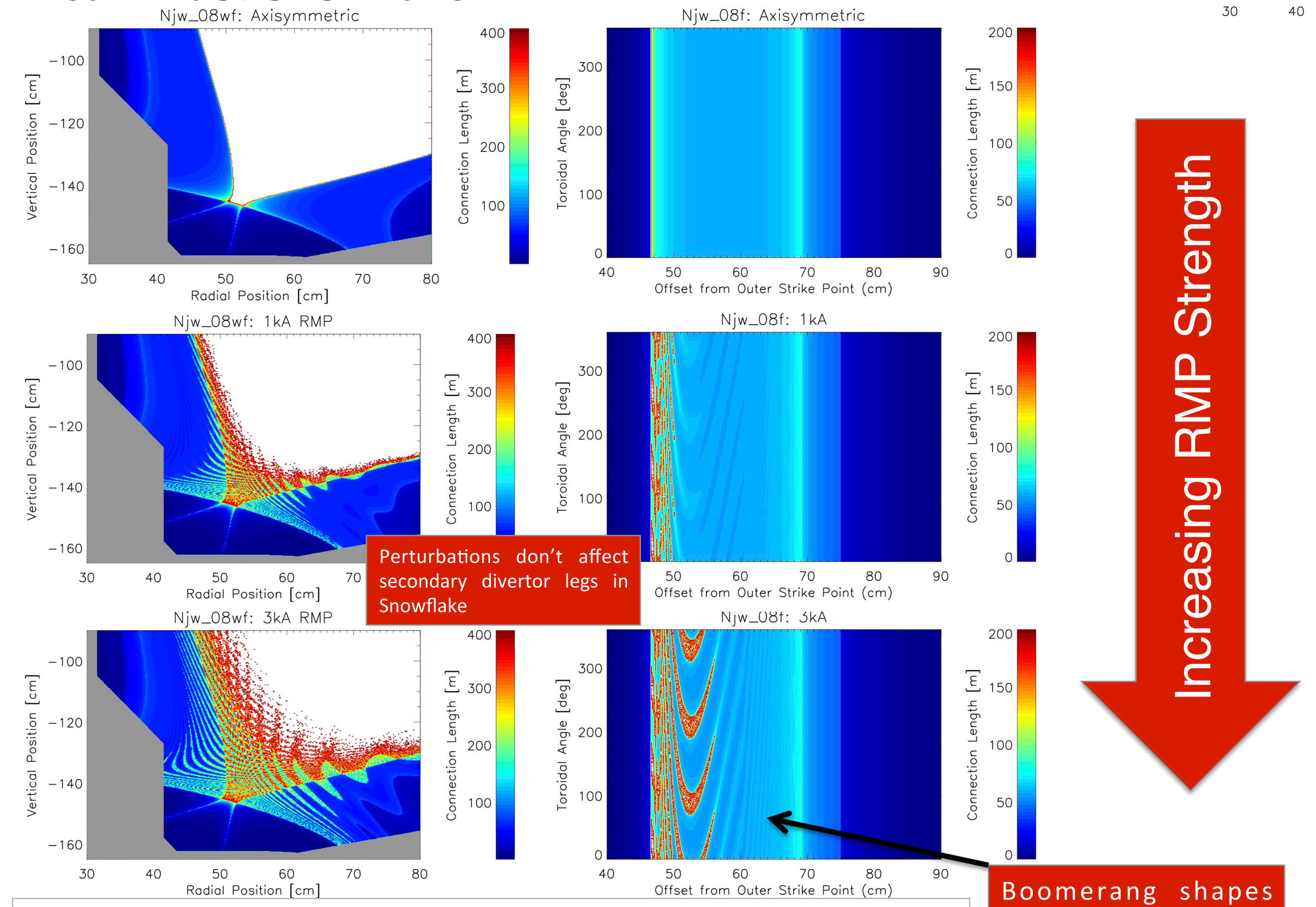
Connection Lengths

- Magnetic field line connection length (L_C) to the wall is the key quantity for the balance of diffusive perpendicular versus convective parallel transport to the divertor targets
- Higher densities near divertor targets can facilitate pump out of exhaust and impurities
- RMP's lead to helical lobes at the inner and outer strike points with varying degrees of bending as the RMP current is increased in all three cases
  - Formation of fine mesh of helical structures
- RMPs applied to near exact snowflake shows perturbation in primary divertor legs
  - 'Boomerang' shaped bending of inner strike point
- Snowflake minus configuration shows flux expansion along the outer strike point

Standard Divertor

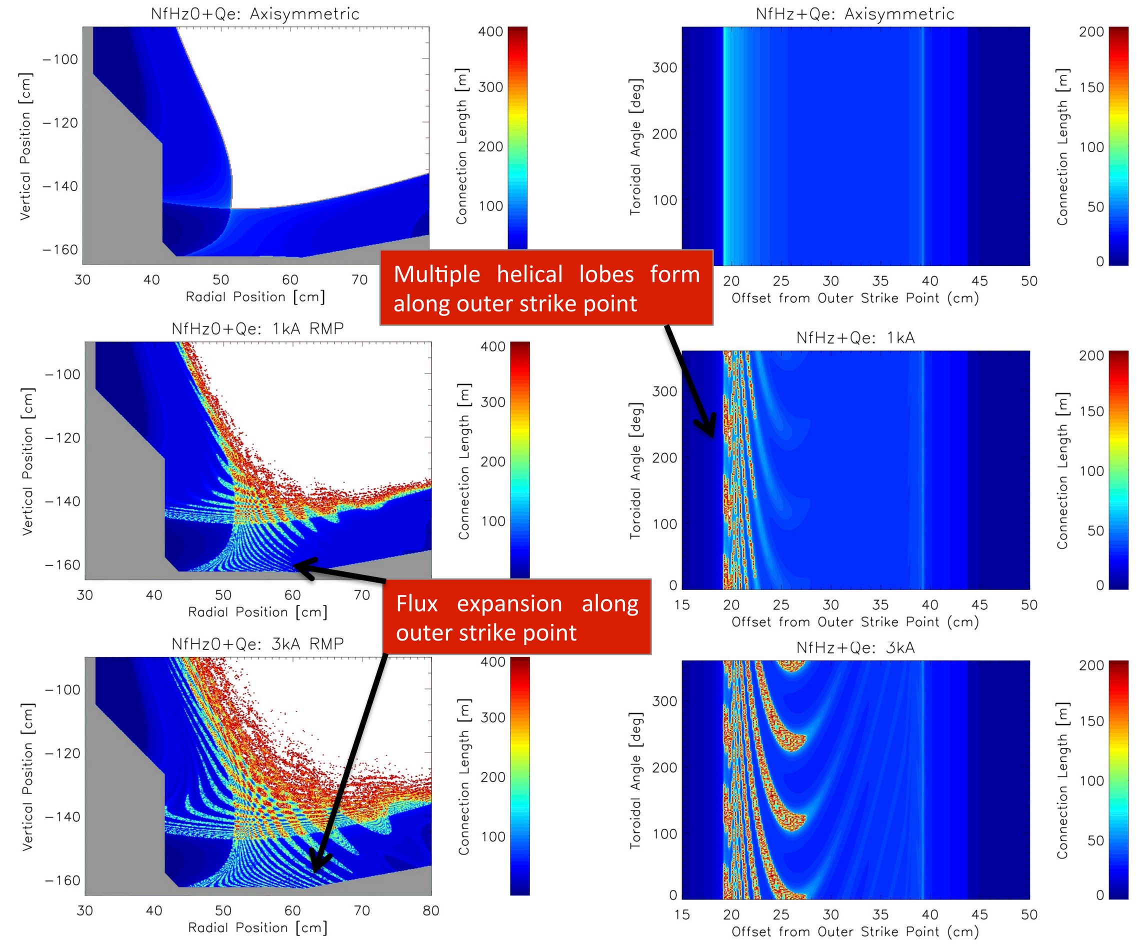


Near Exact Snowflake



Increasing RMP Strength

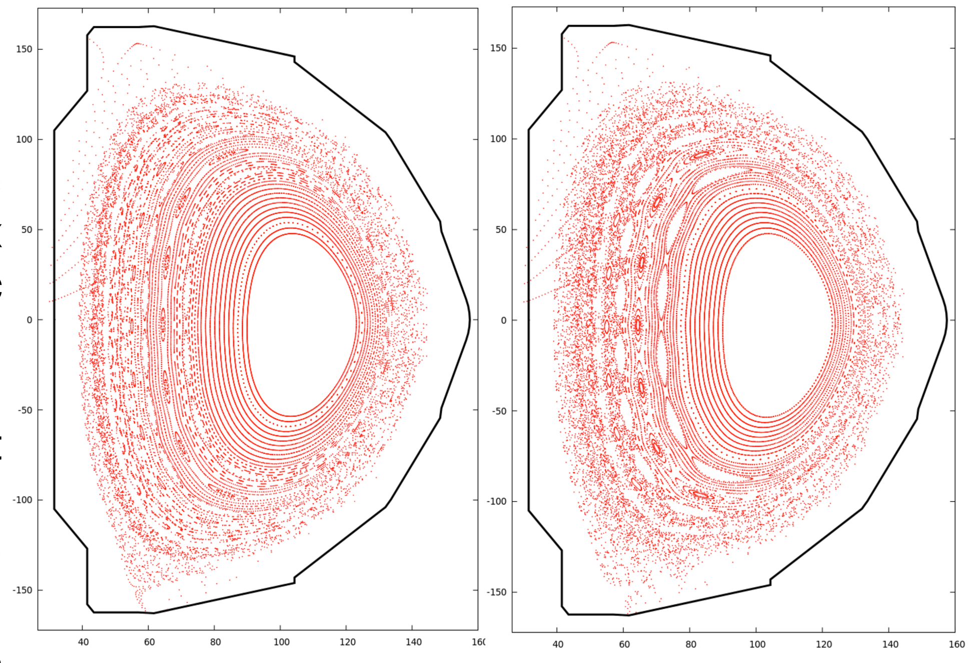
Snowflake Minus



Plots show connection lengths (L_C) of the three analyzed equilibria. Poloidal cut is shown in the left columns with projection on inner divertor targets in the right column.

Resonant Magnetic Perturbations

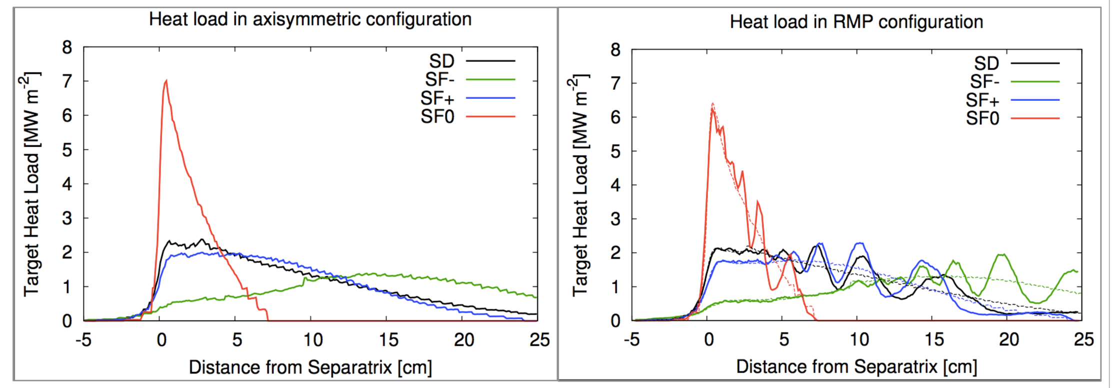
- Resonant Magnetic Perturbations (RMPs) are used to create island chains along flux surfaces which can break up into chaotic regions when islands overlap:
  - These can control damaging ELMs
  - RMPs may also impact particle exhaust and transport in the edge plasma
- Here we study the effects of the NSTX-U n=3 RMP fields
  - Different currents in the RMP coils create varying sizes of chaotic regions
  - Vacuum Field Approach- No plasma response to perturbations yet



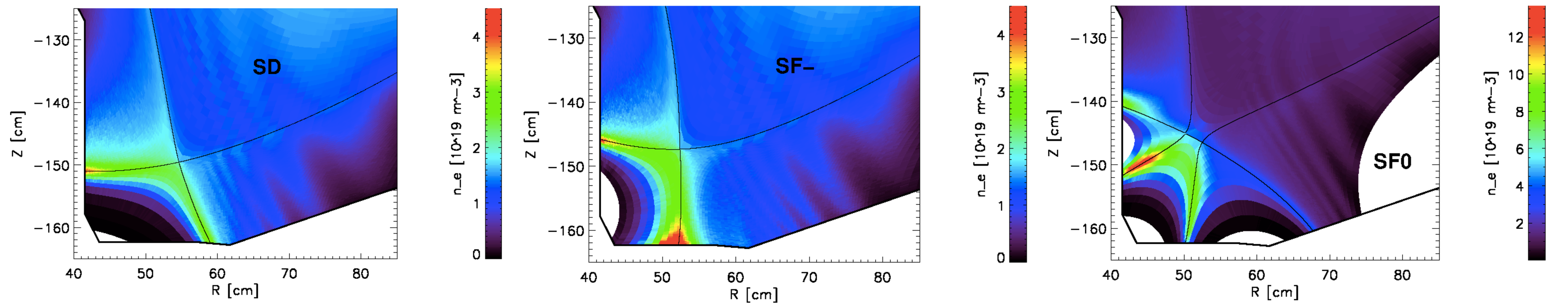
Poincare plots show the effect of the application of the n=3 RMP perturbation on the +QF Standard Divertor configuration. A) (Left) shows the effect of a 1kA RMP coil current whereas b) (Right) shows the larger effects of a stronger 3 kA RMP coil current. In both cases the formation of island chains, chaotic regions, and closed flux surfaces of the confined region can be seen.

EMC3-EIRENE

- Coupled 3D plasma fluid and kinetic neutral transport code
- The user defines a number of boundary conditions and transport assumptions:
  - Edge Input Power
  - Core Plasma Density
  - Perpendicular Heat and Particle Transport Coefficients
- An iterative procedure is used to obtain a self-consistent solution of the non-linear and coupled plasma-neutral gas problem



- Heat loading along the target shows peaking of the near exact snowflake in excess of standard divertor case (left)
- When RMP's are applied, **the heat loads show the expected oscillations (right, solid)**, but when toroidally averaged show no significant change (right, dashed)



- Initial EMC3-EIRENE simulations show that lobe structures **are reflected in electron density**
- Snowflake minus (middle) shows high density at the target on the outboard side while the near exact snowflake (far right) shows the highest density in the secondary divertor leg on the inboard side
- The near exact snowflake shows much greater target densities than either the standard divertor or the snowflake minus divertor, which may have positive pump out and impurity screening effects
- All models share the same boundary conditions and transport coefficients

H. Frerichs, Overview of edge modeling efforts for advanced divertor configurations in NSTX-U with magnetic perturbation fields. ISTW 2015

This analysis of the 3-D magnetic field topology formed with RMPs in NSTX-U reference equilibria motivates a detailed assessment of fueling, exhaust, and neutral particle transport dynamics in Advanced Divertors with RMPs.

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