3D Equilibrium Diagnostic Response for W7-X and ITER

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19th ISHW and 16th RFP Workshop

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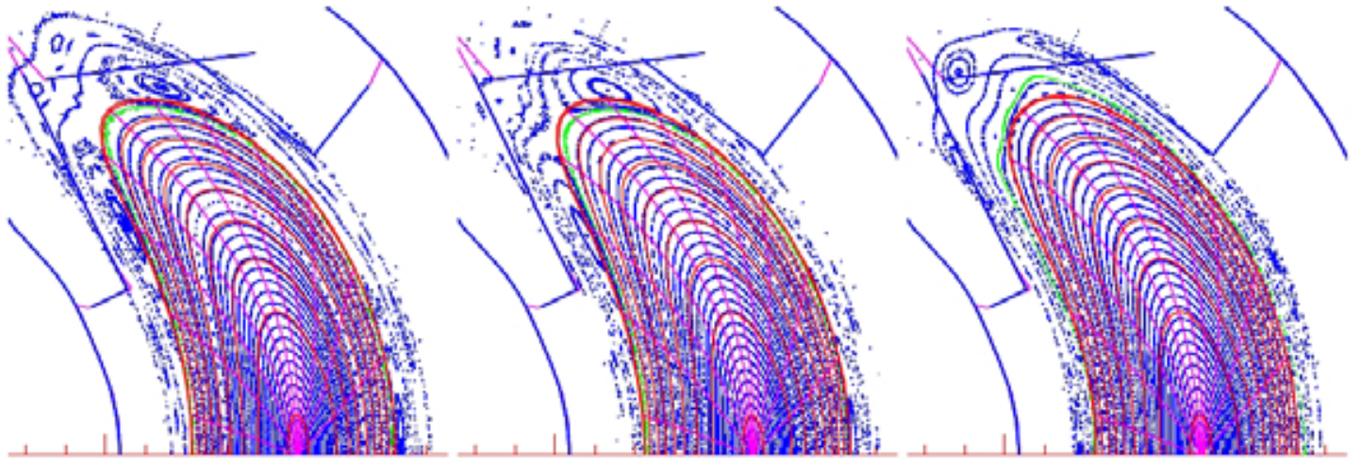
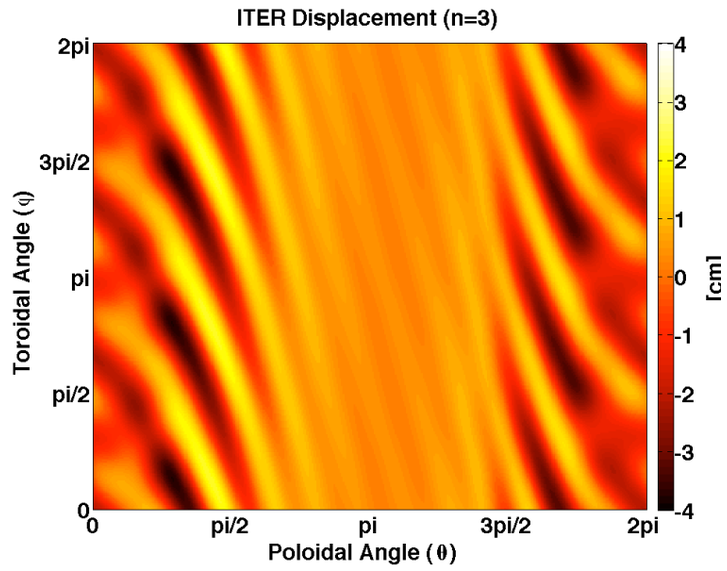
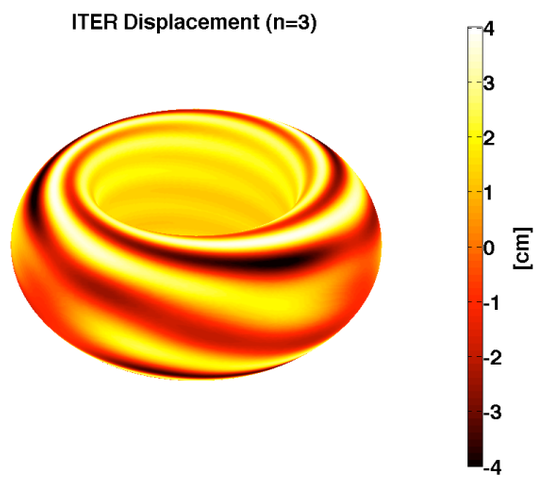
Why are 3D equilibrium effects important?

- Strike point control scenarios for W7-X



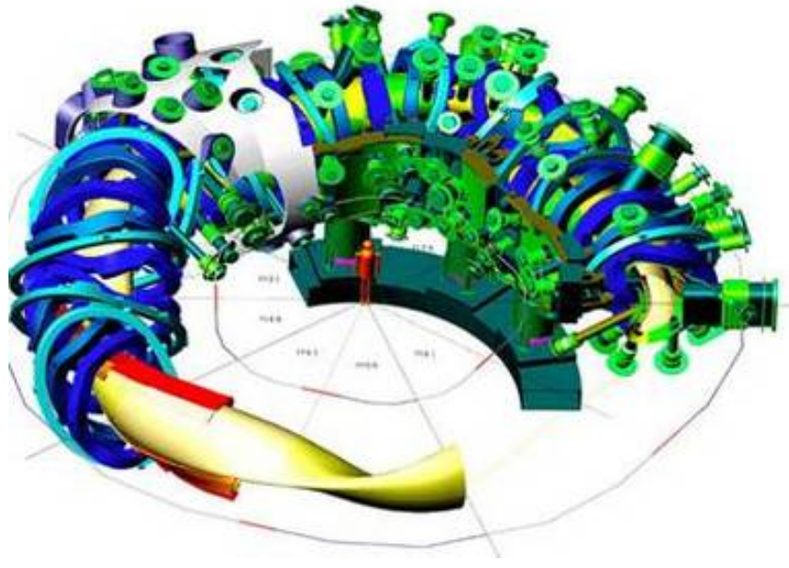
- Effect of RMP application on ITER boundary control

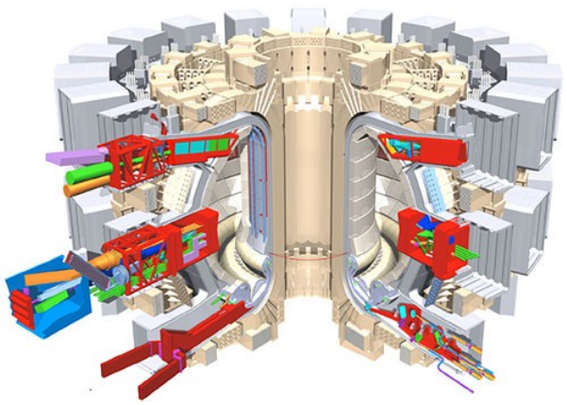




Outline

- Motivation
- Codes
    - VMEC - Equilibrium
    - DIAGNO2 - Magnetic diagnostic response
    - STELLOPT - Forward modeling
- W7-X Results
- ITER Results



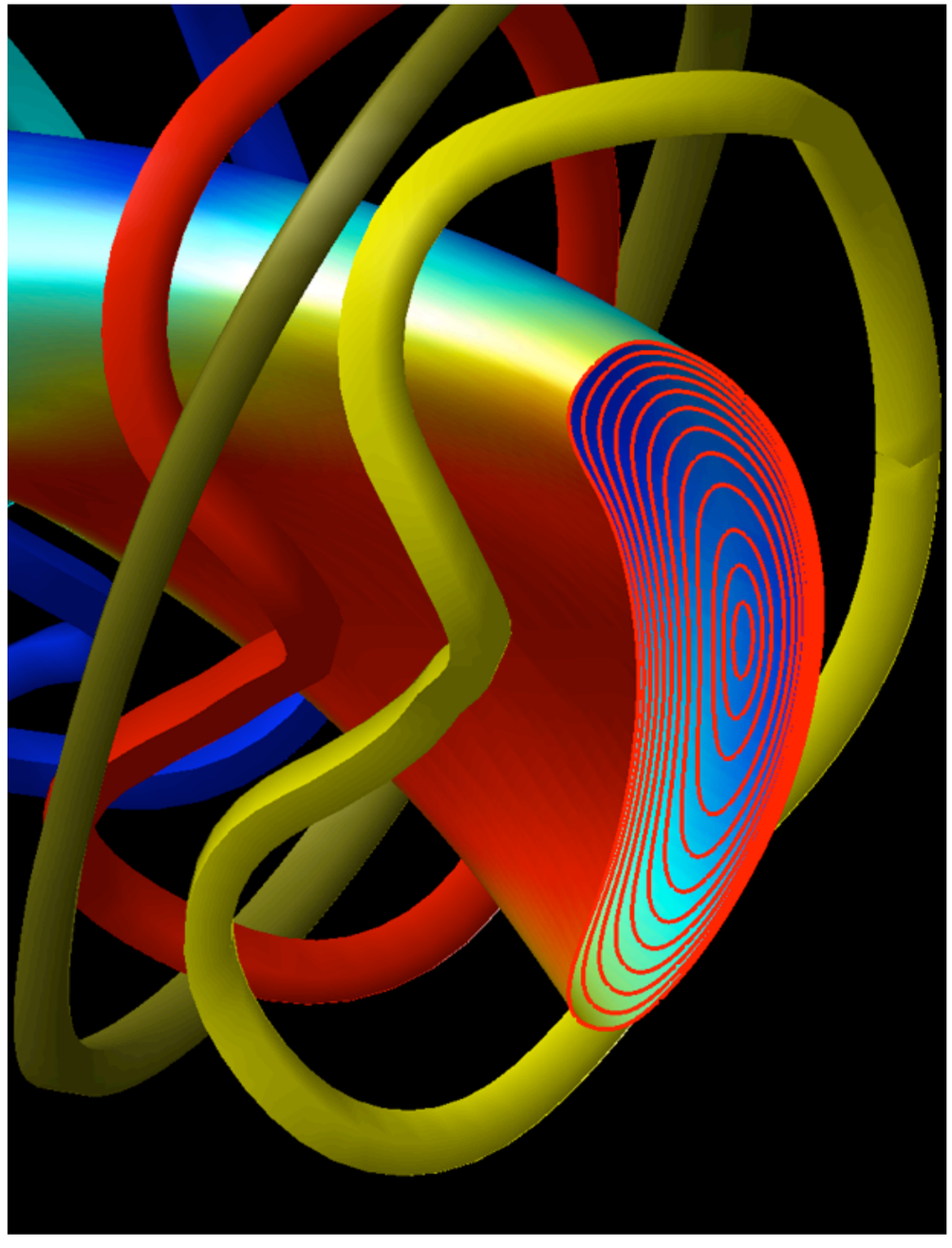


VMEC provides a 3D equilibrium model

- Ideal 3D MHD equilibrium model
- Constraint of nested flux surfaces

$$W = \int \left(\frac{|B|^2}{2\mu_0} + \frac{p}{\gamma - 1} \right) d^3x$$

$$\vec{J} \times \vec{B} - \nabla p = 0$$



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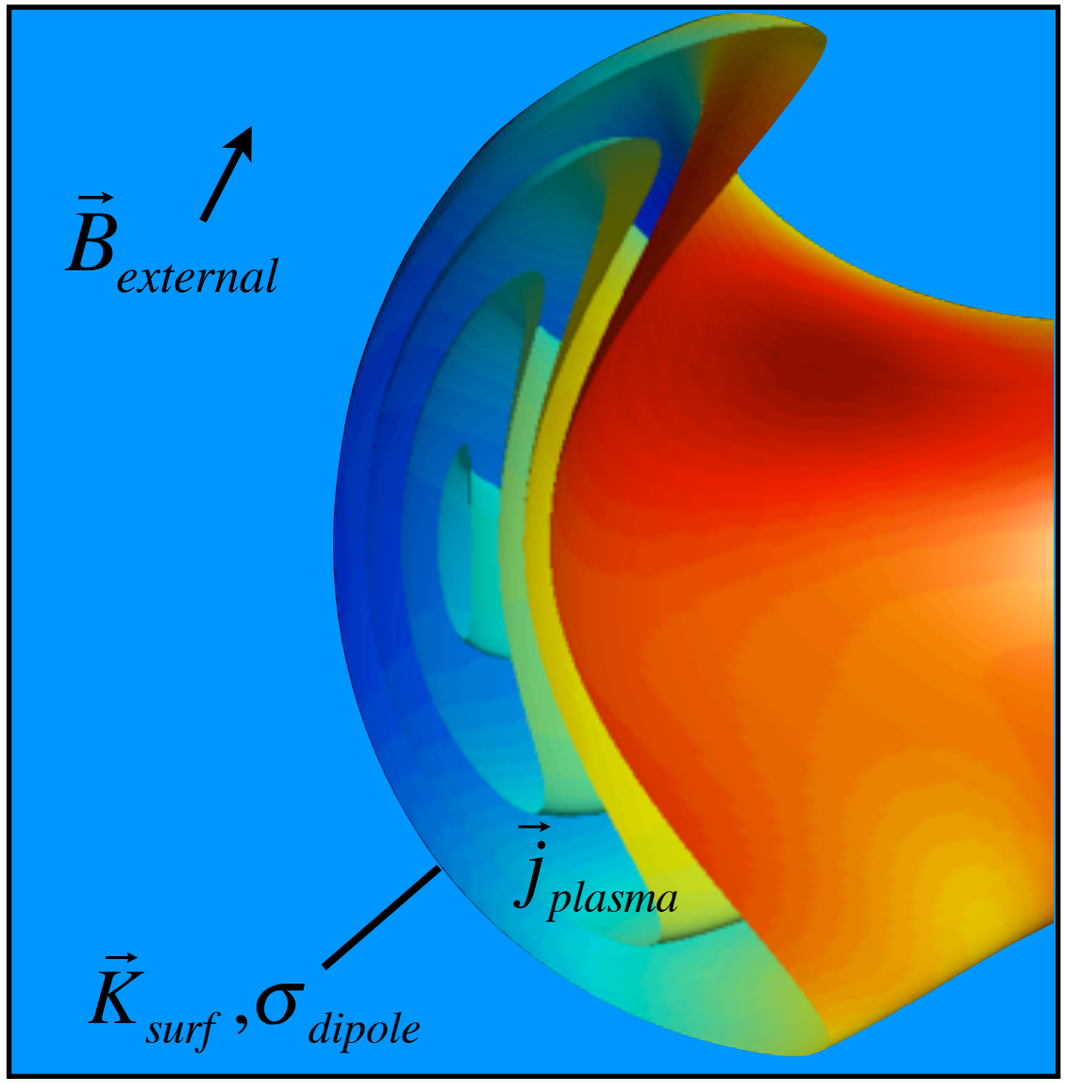
S.P Hirshman and J.C. Whitson, Phys. Fluids 26 (12), 1983

DIAGNO2 - magnetic diagnostic signals

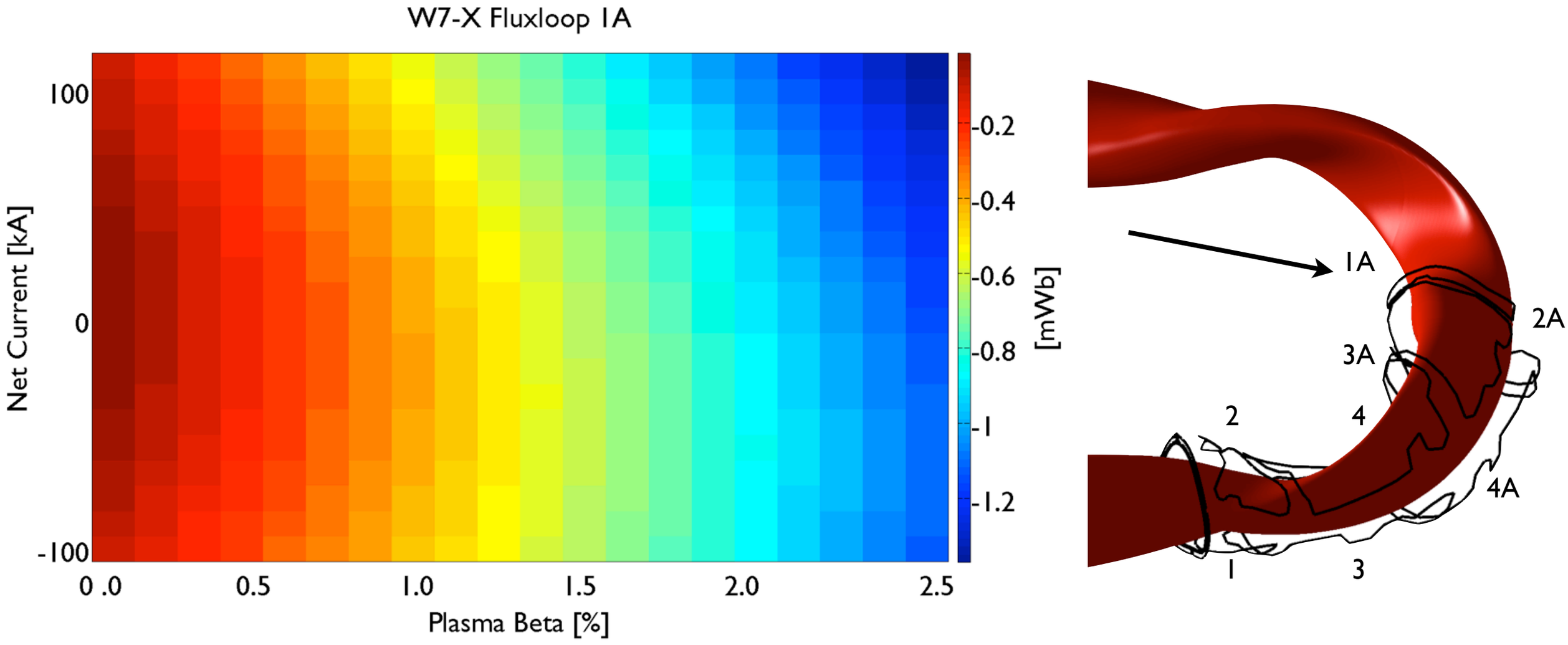
- Calculates magnetic diagnostic signal
- Uses a virtual casing principle
- Fast adaptive surface integral
- Interfaced to VMEC, SPEC, PIES



S. Lazerson et al., Plasma Phys. Control. Fusion 55 025014 (http://dx.doi.org/10.1088/0741-3335/54/12/122002)

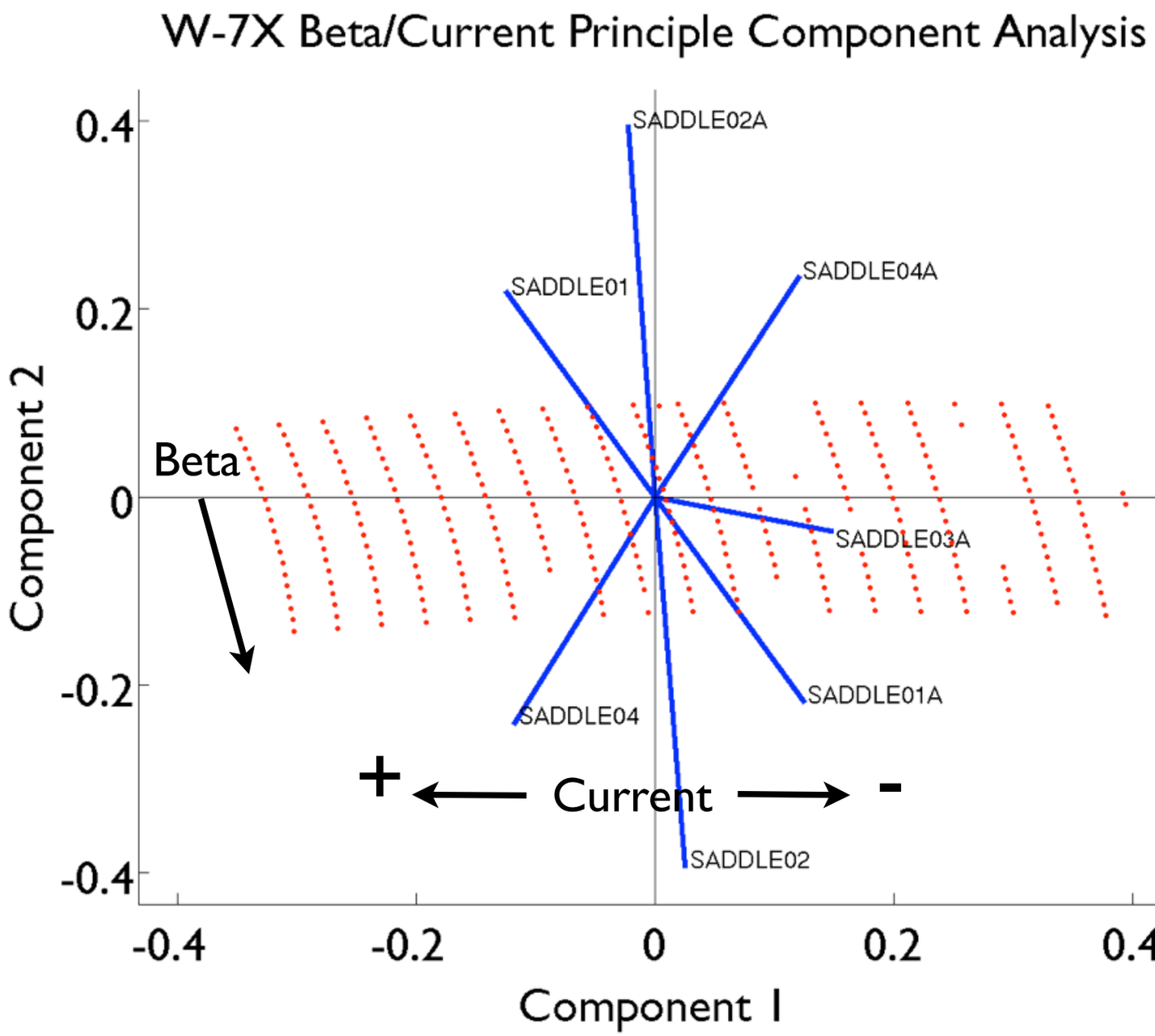
STELLOPT can map parameter space

- STELLOPT modified to perform parameter scans
- Maps of parameter space are now possible



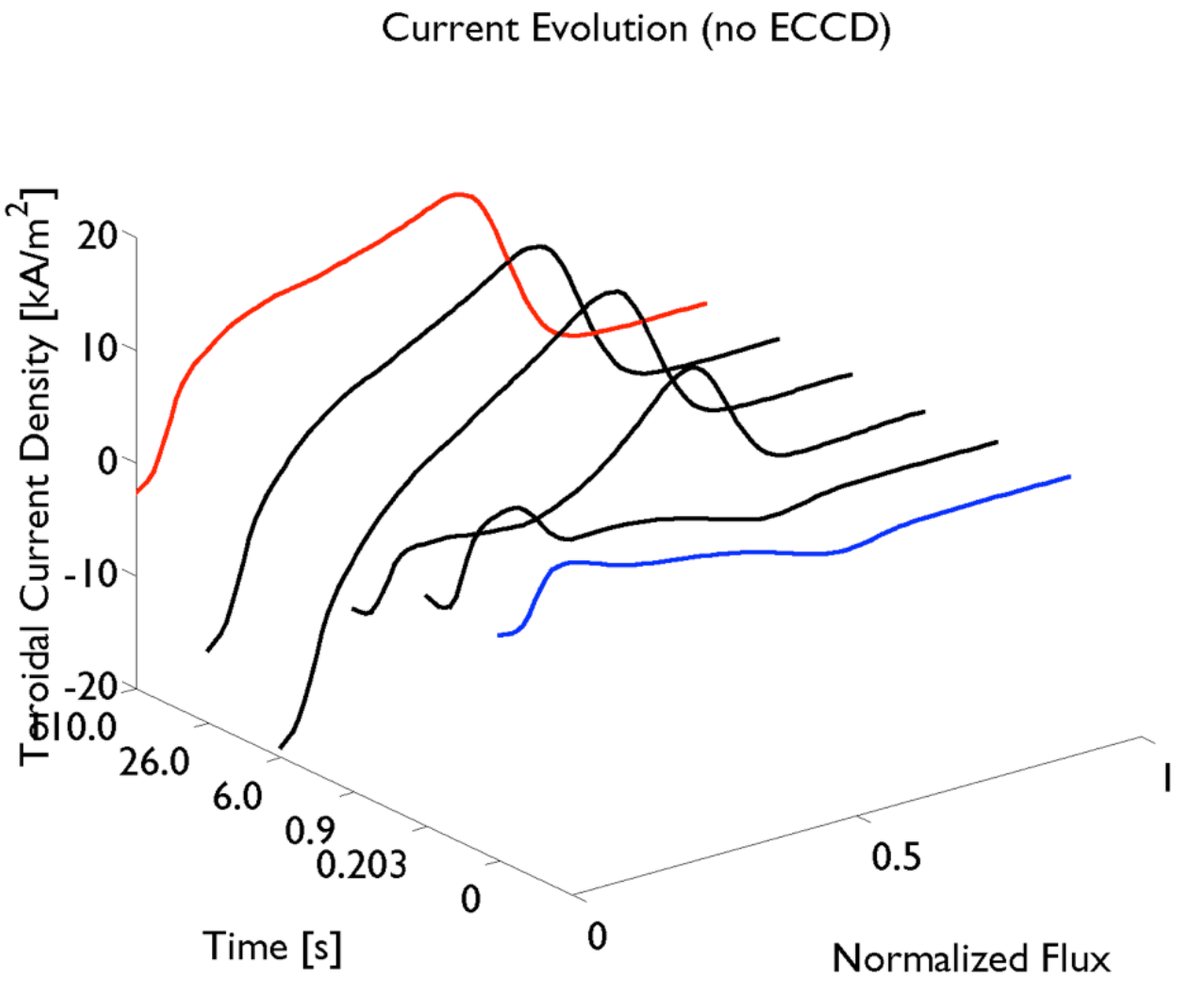
PCA simplifies multivariate data

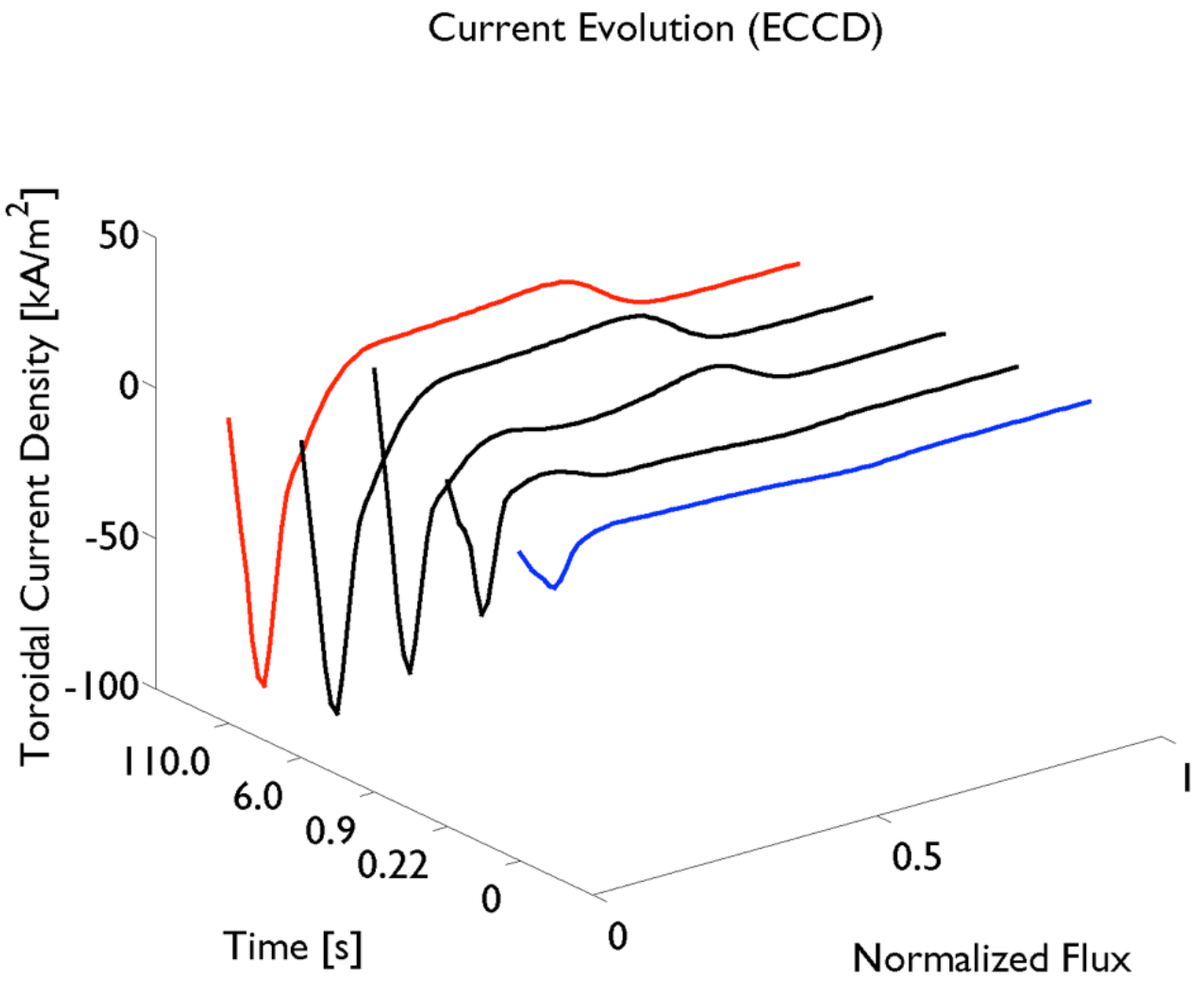
- Extracts variables in datasets
- Stored energy and current scanned
- 400 VMEC Equilibria calculated
- Two principle components identified
- Strong sensitivity to current (~85%)
- Weak sensitivity to beta (~15%)
- Low pressure driven current



The W7-X Bootstrap Profile Evolution

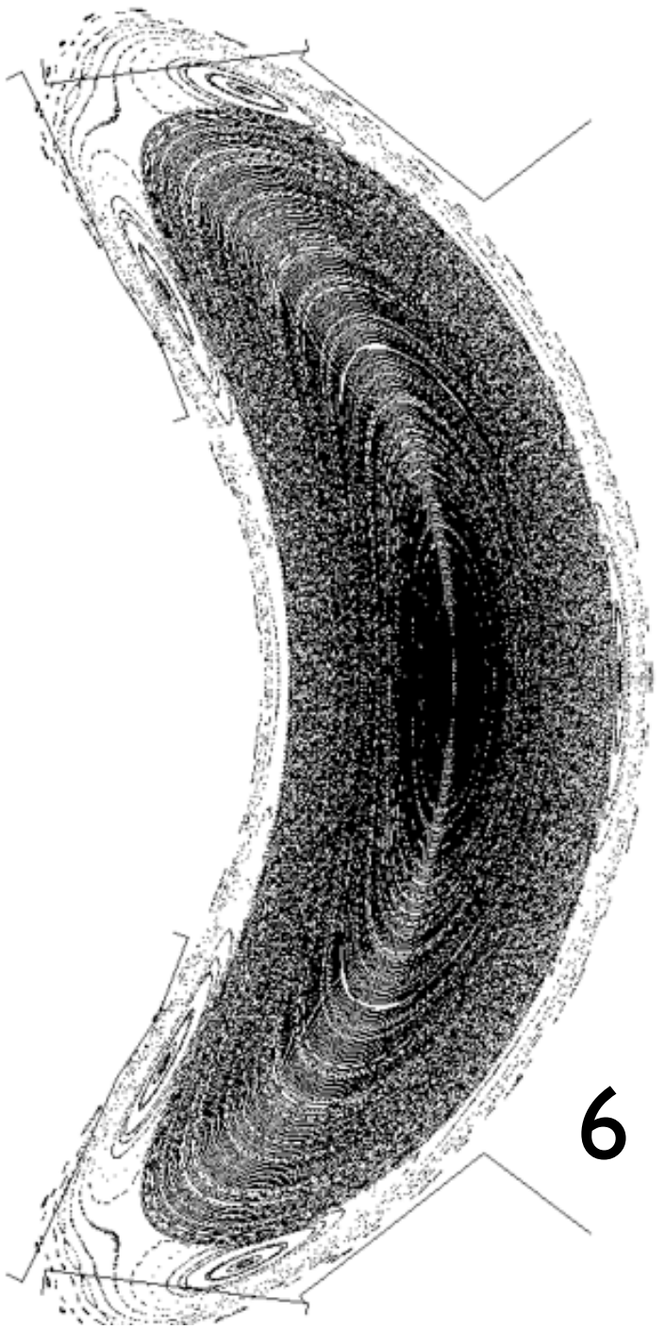
- Boostrap Current rotates divertor islands
- ECCD can be used to counteract the effect



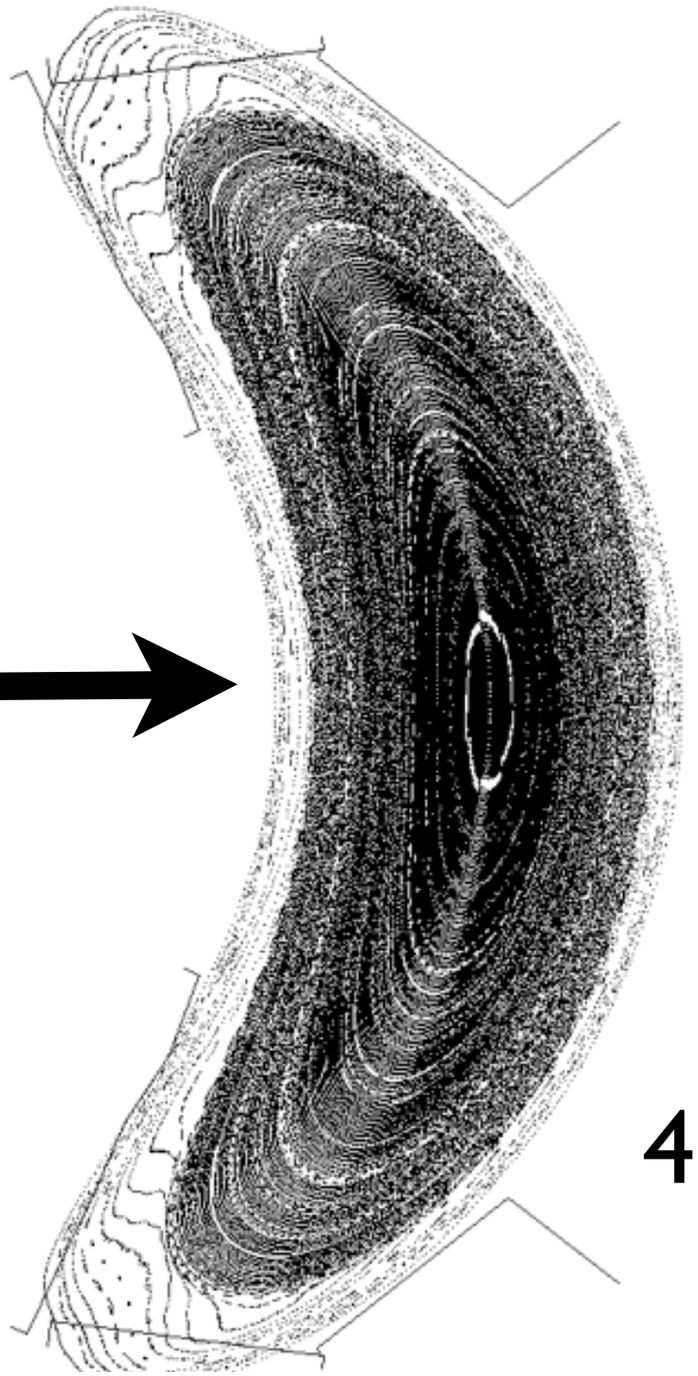


J. Geiger et al. 2010 *Contrib. Plasma Phys.* **50** 770–4

Bootstrap evolution moves strike points



6 [kA]

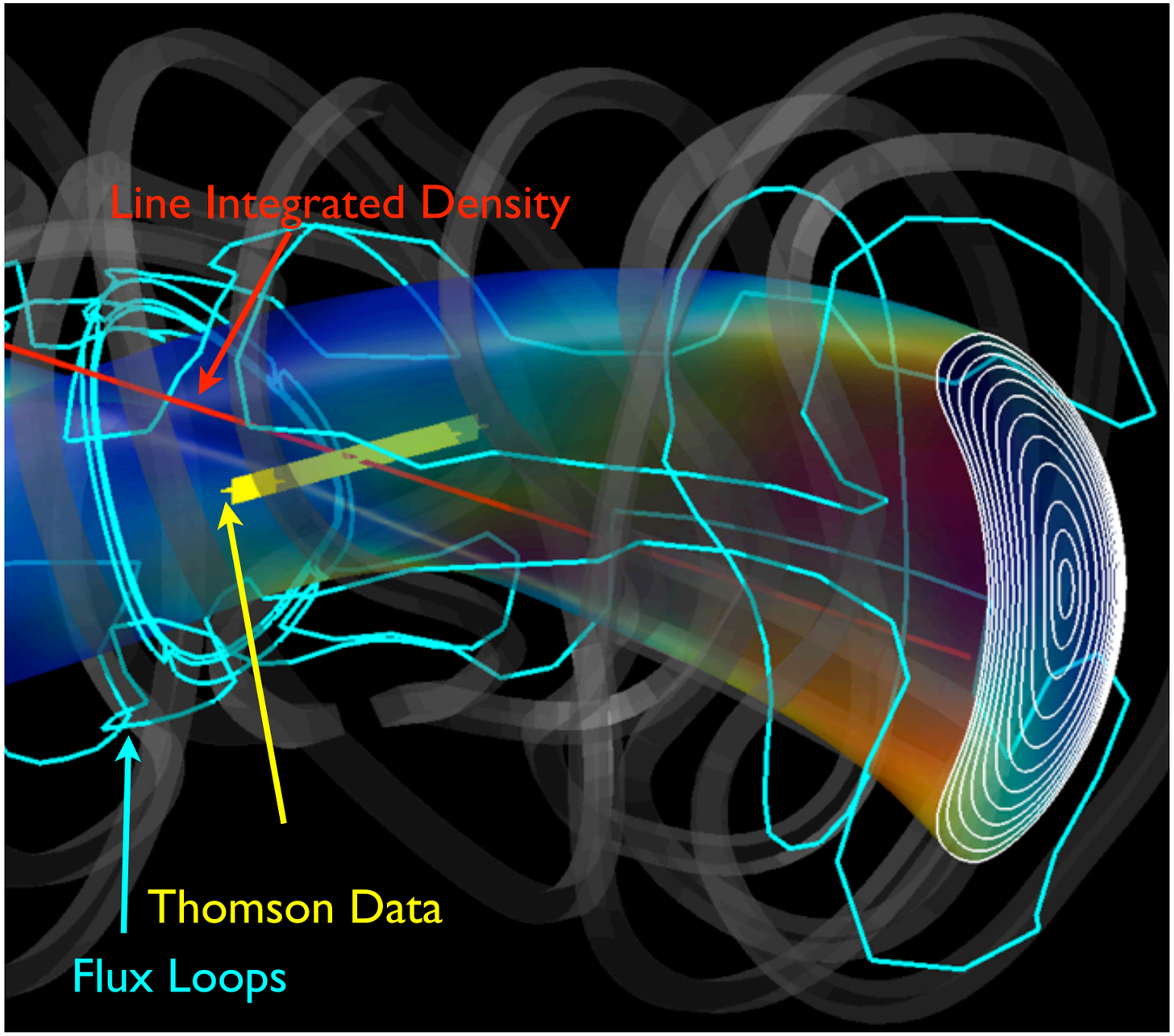


47 [kA]

Calculation using TORLINES Code (S. Lazerson - PPPL)

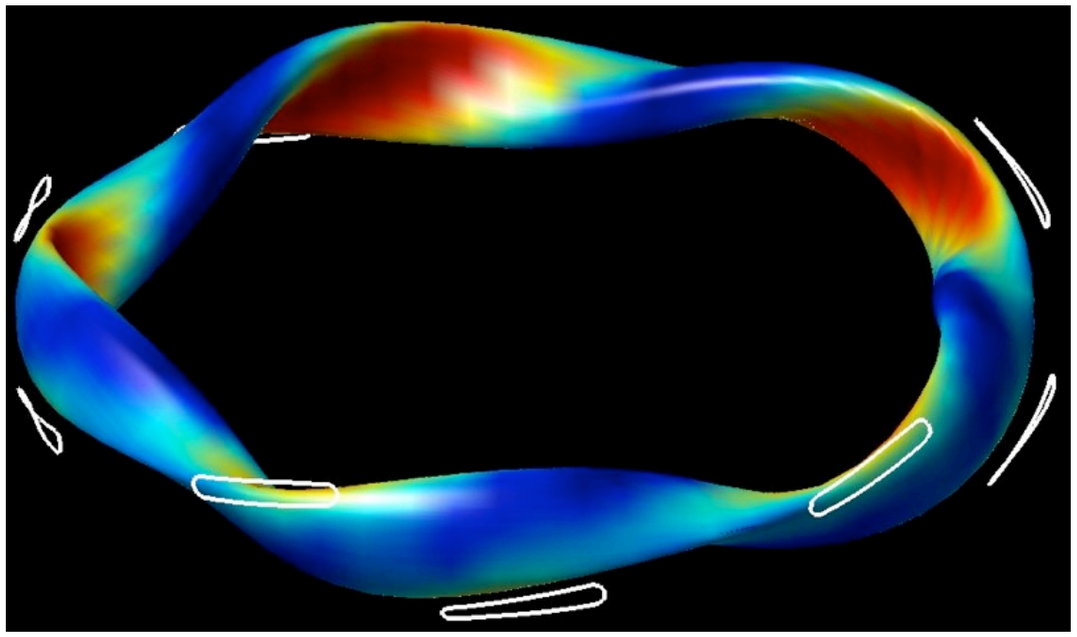
W7-X Diagnostic Set

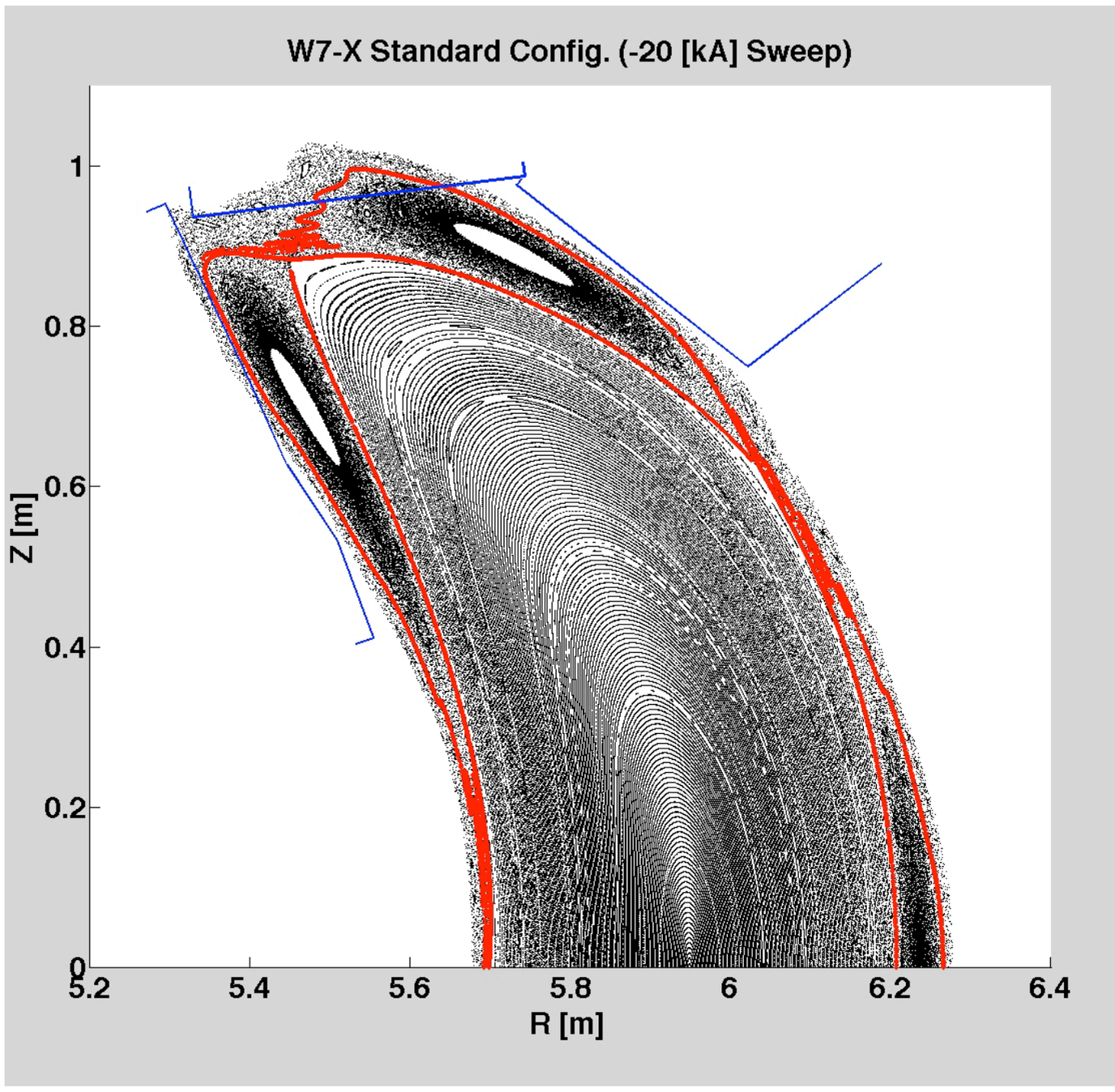
- W7-X will have an extensive diagnostic set
  - Thomson Scattering
  - Inteferrometry
  - Flux Loops
  - Segmented Rogowski Coils
- Low pressure driven current suggests an ability to detect bootstrap current
- Trim and sweep coils can control strike point motion
- Bootstrap current detection?



The divertor sweep coils provide strike point control

- Ten in-vessel stellarator symmetric coils
- Provide a means to control strike points





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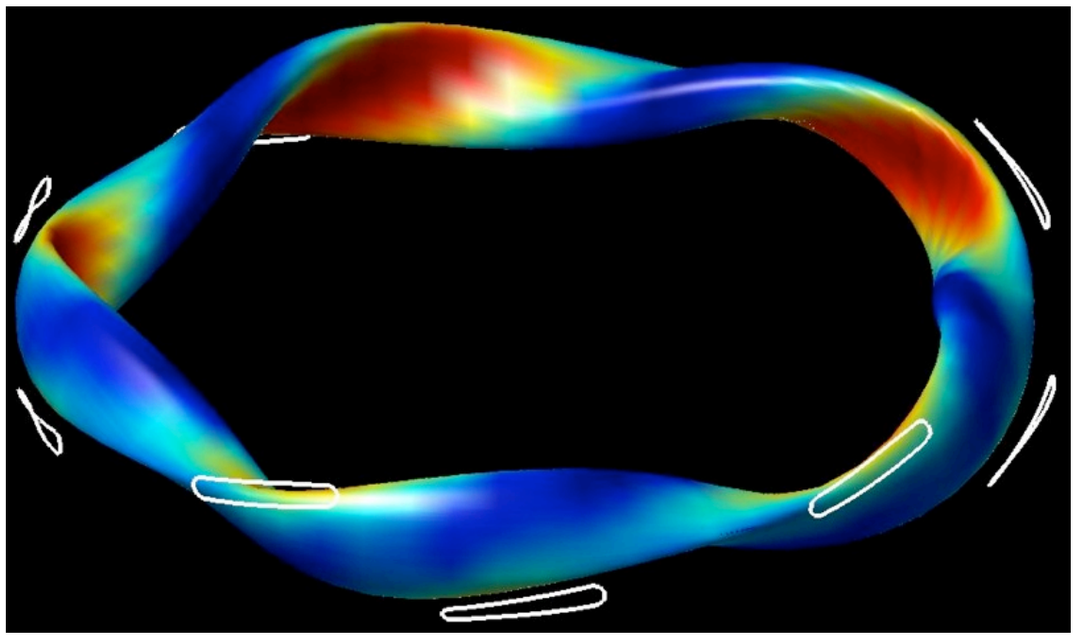

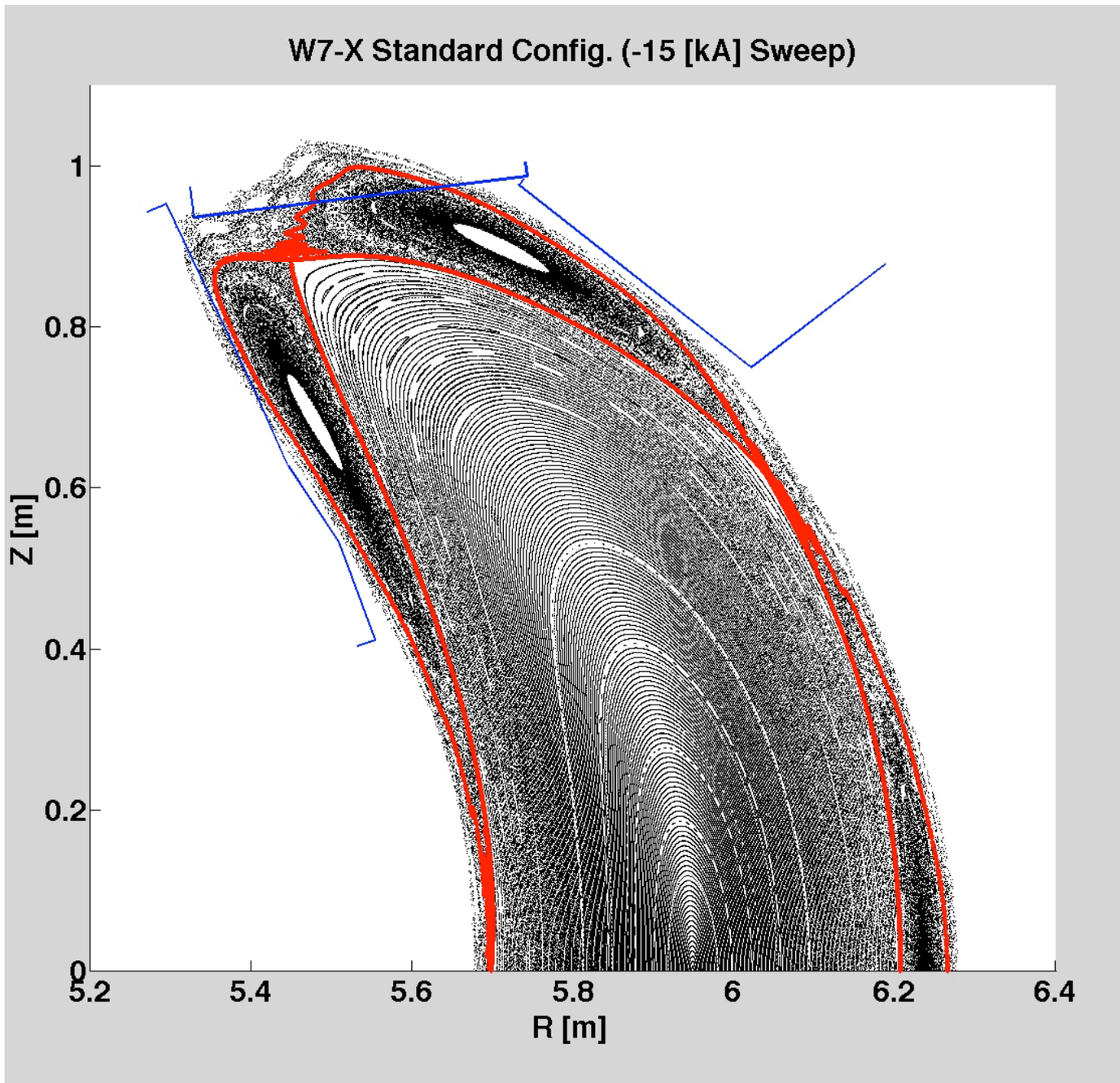

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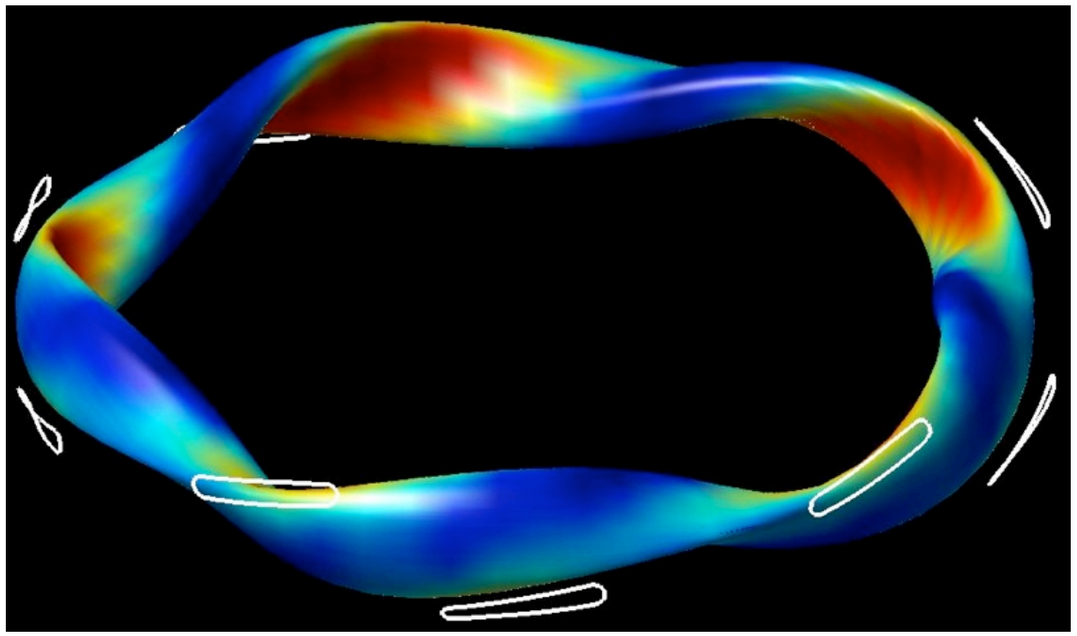

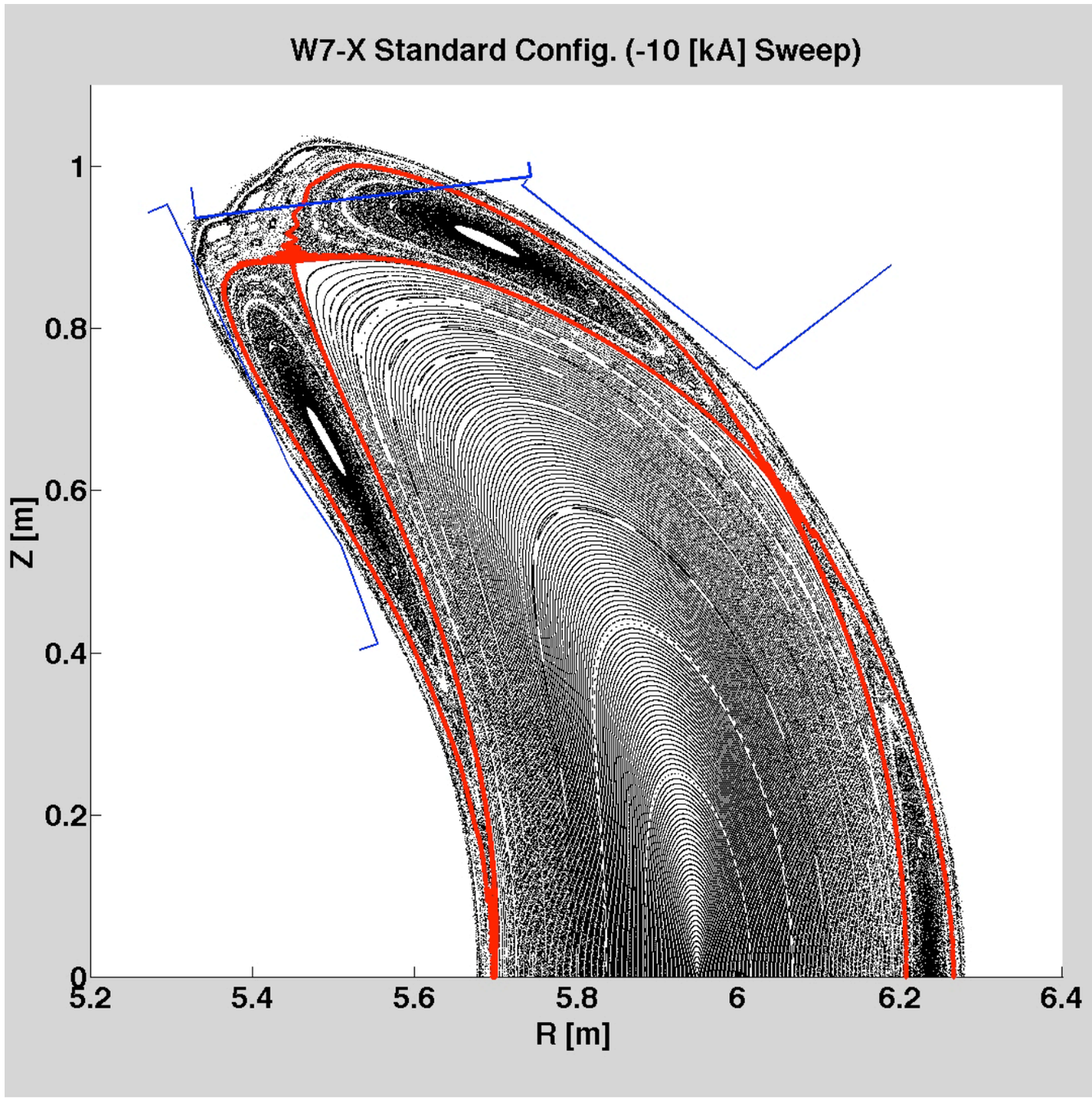

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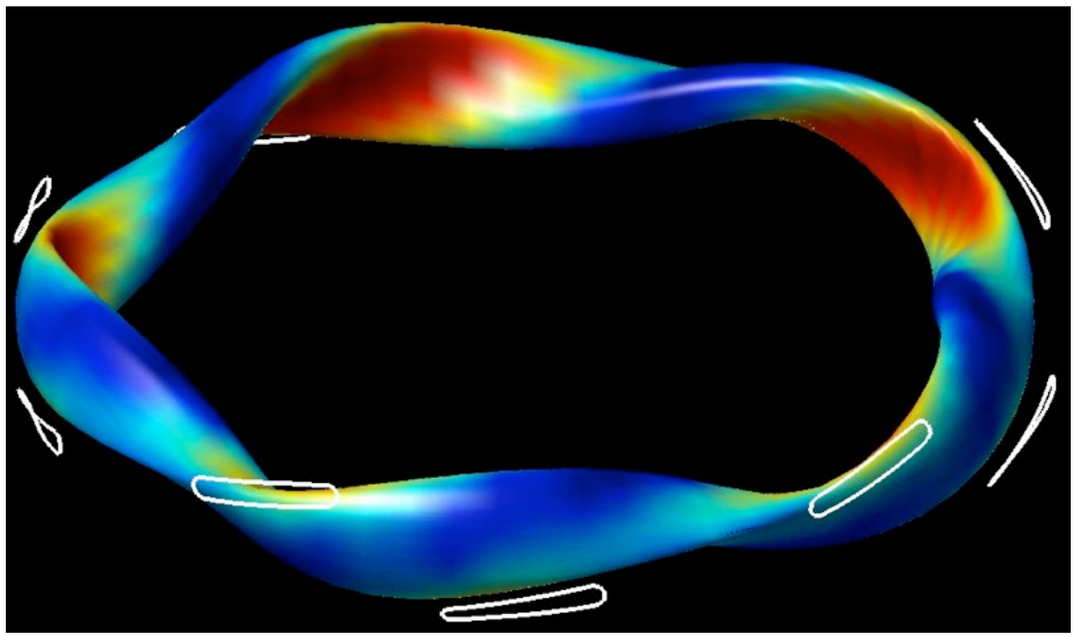

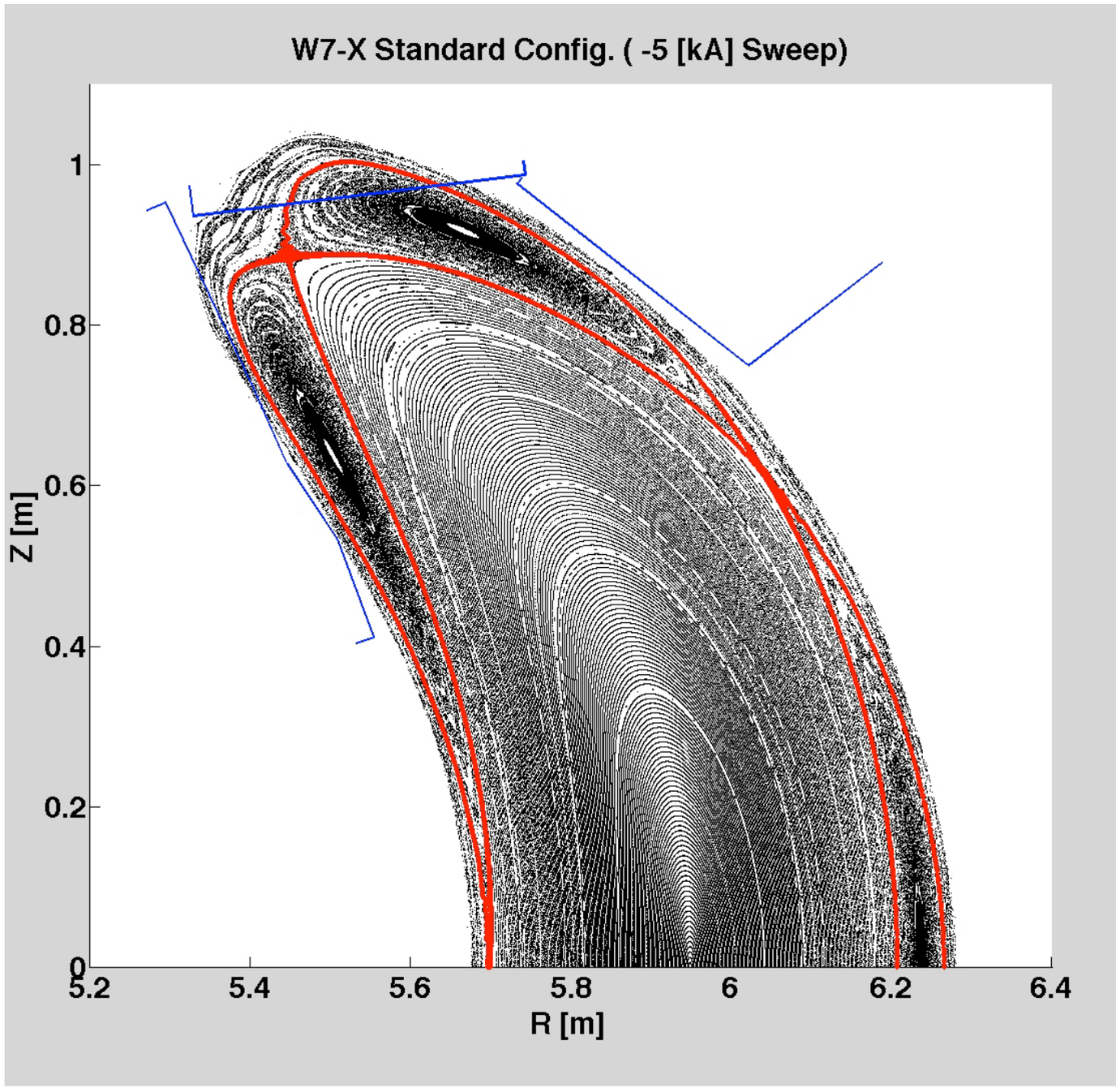

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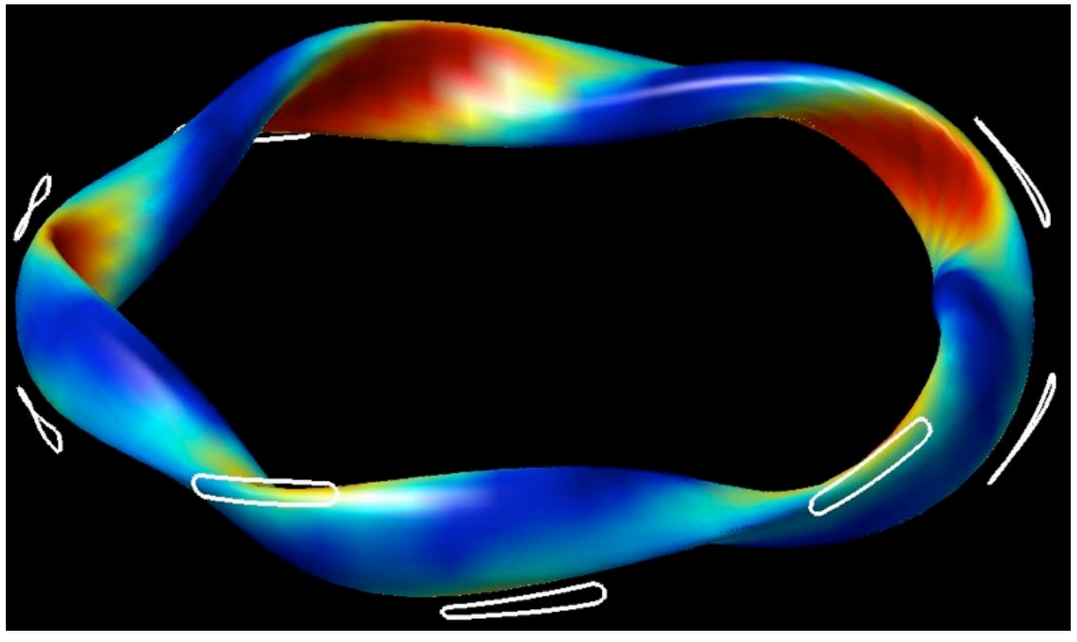

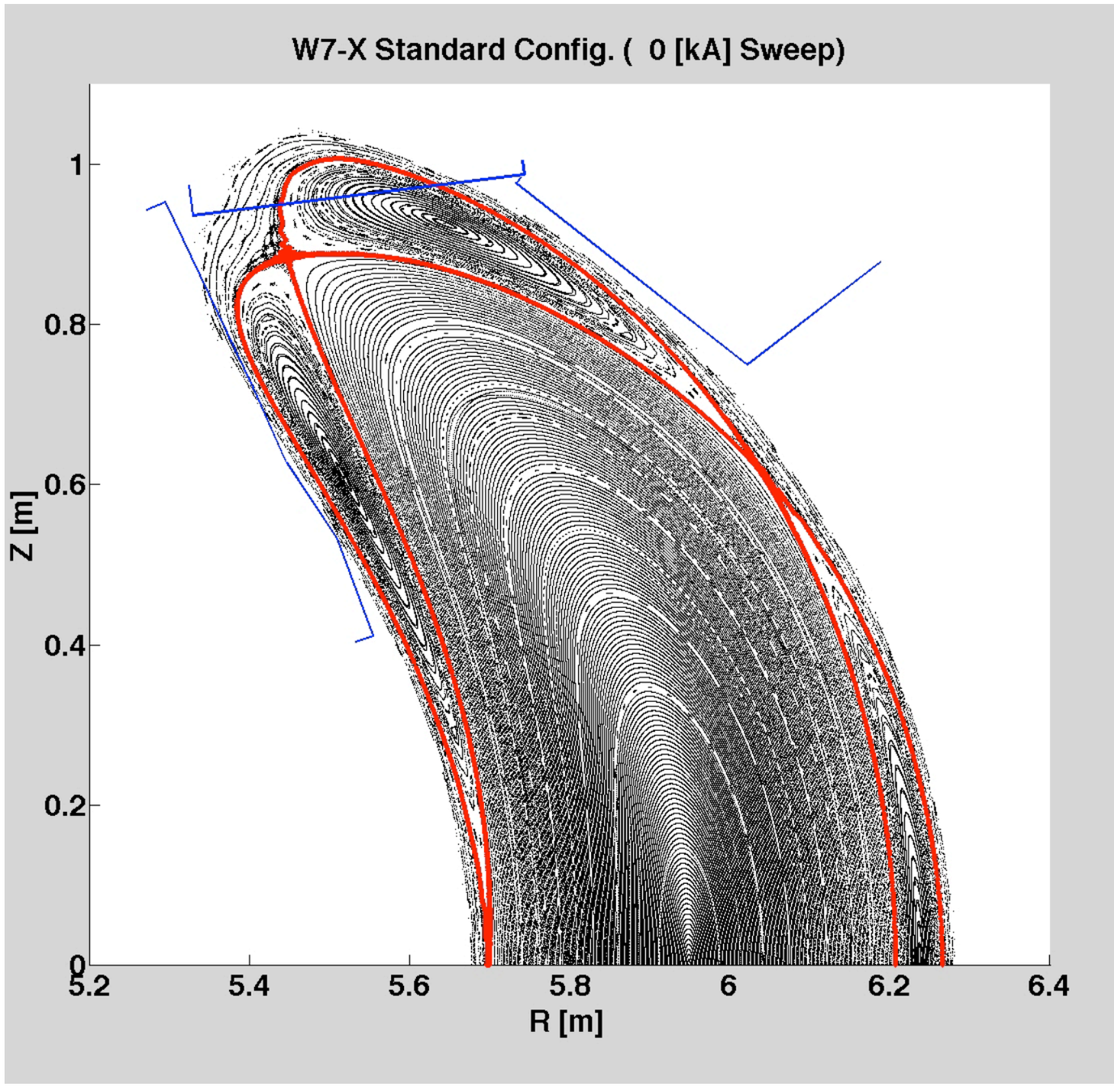

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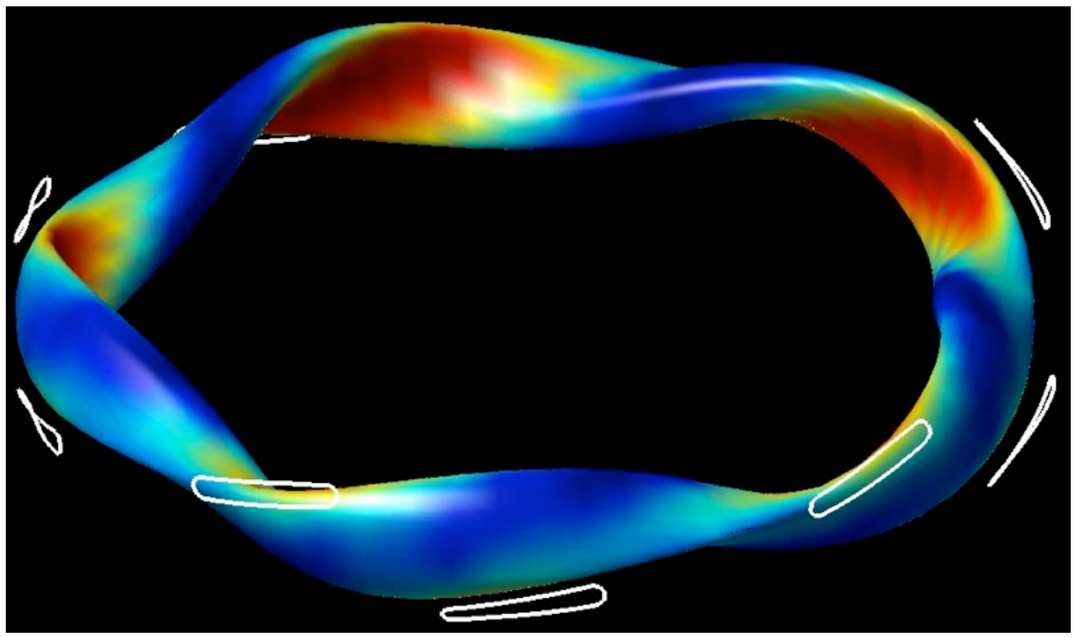

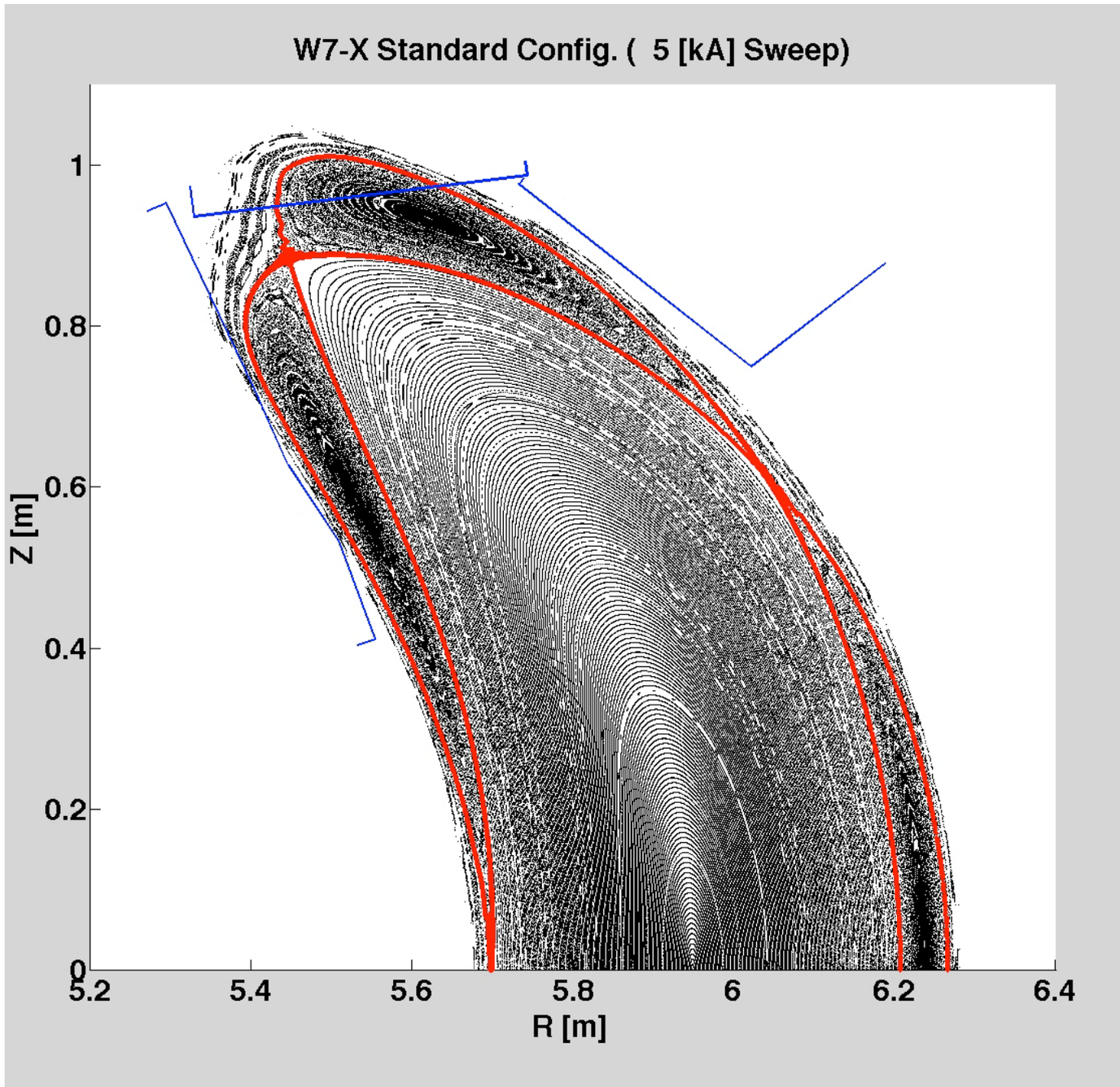

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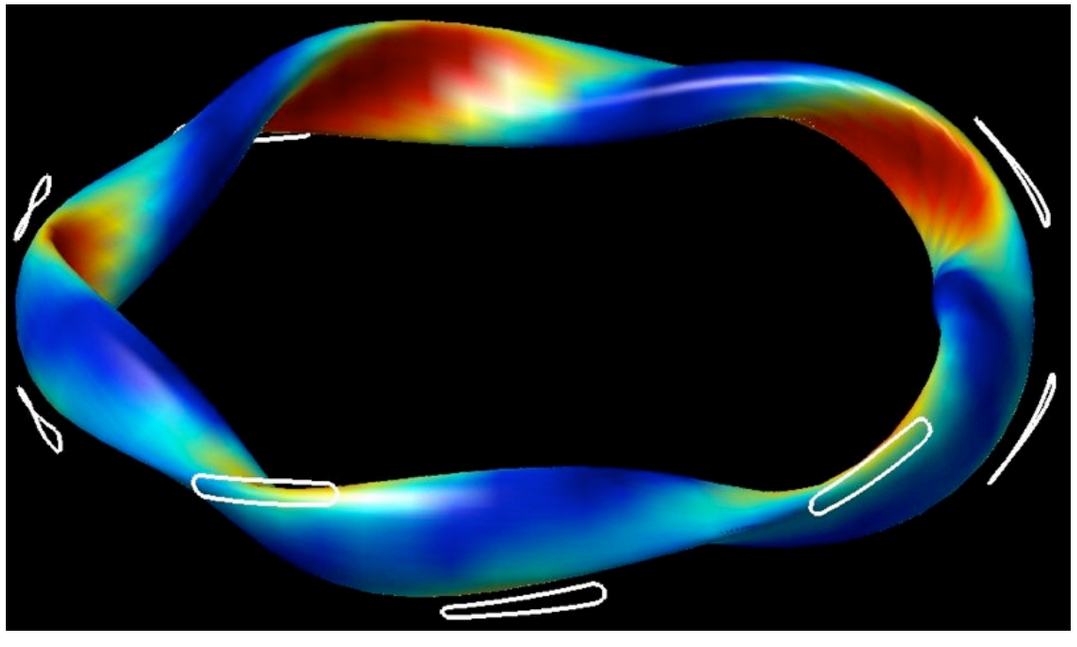

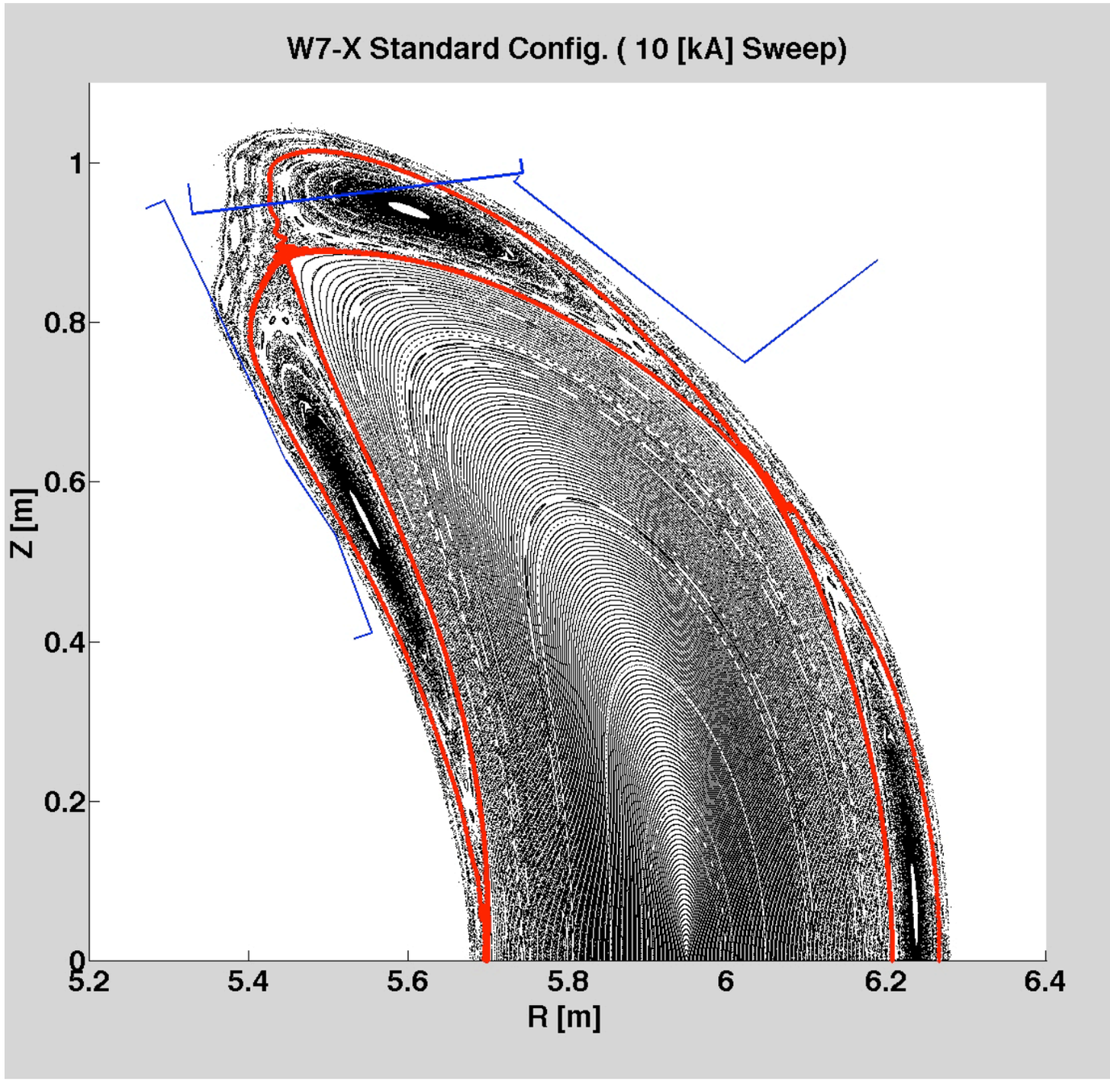

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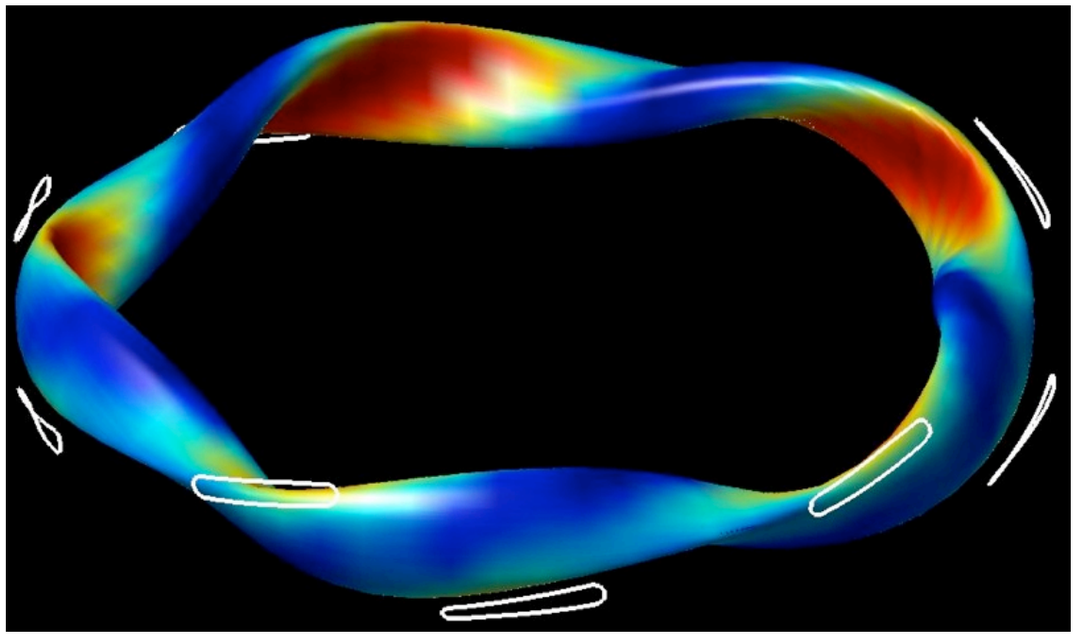

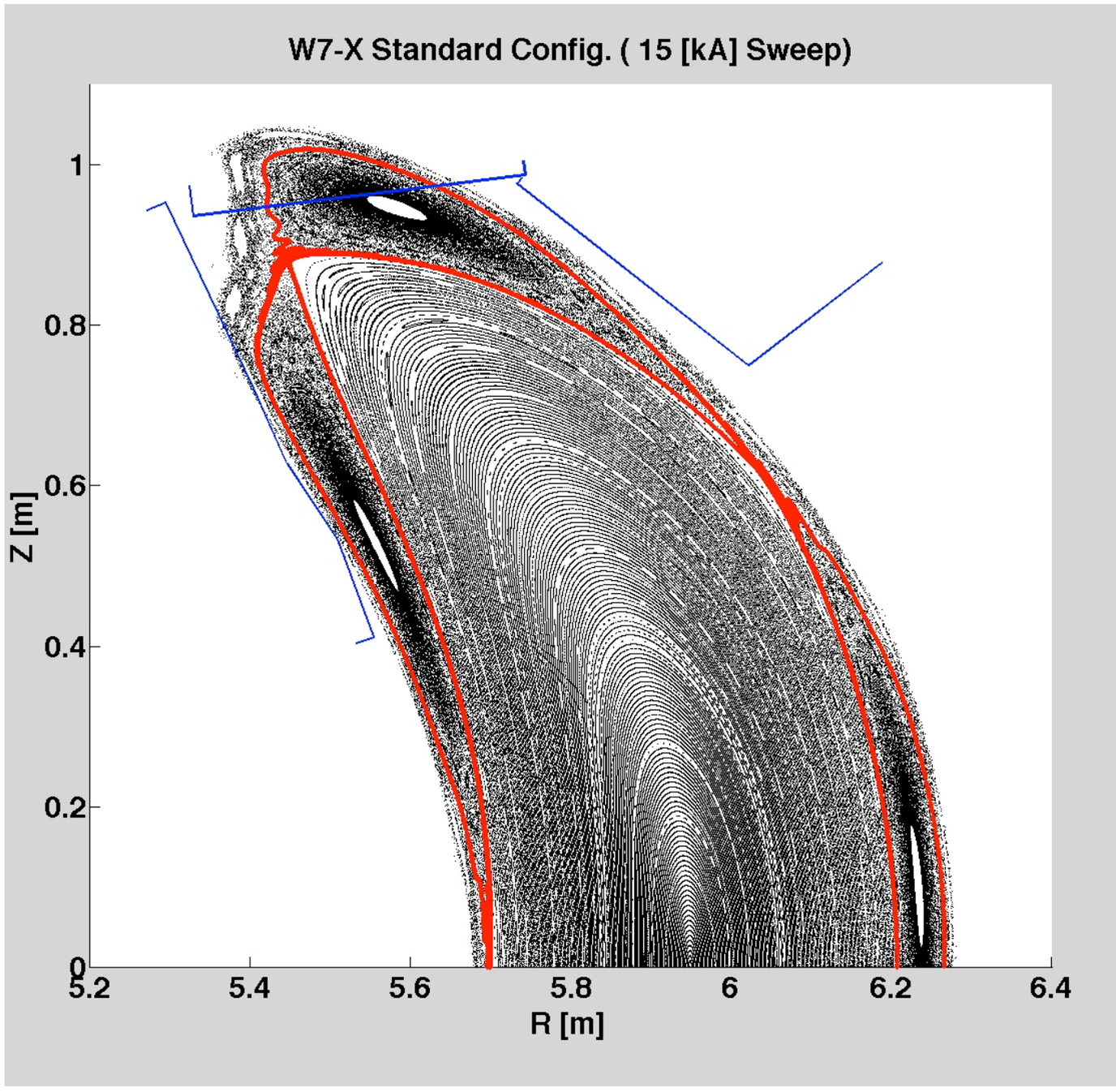

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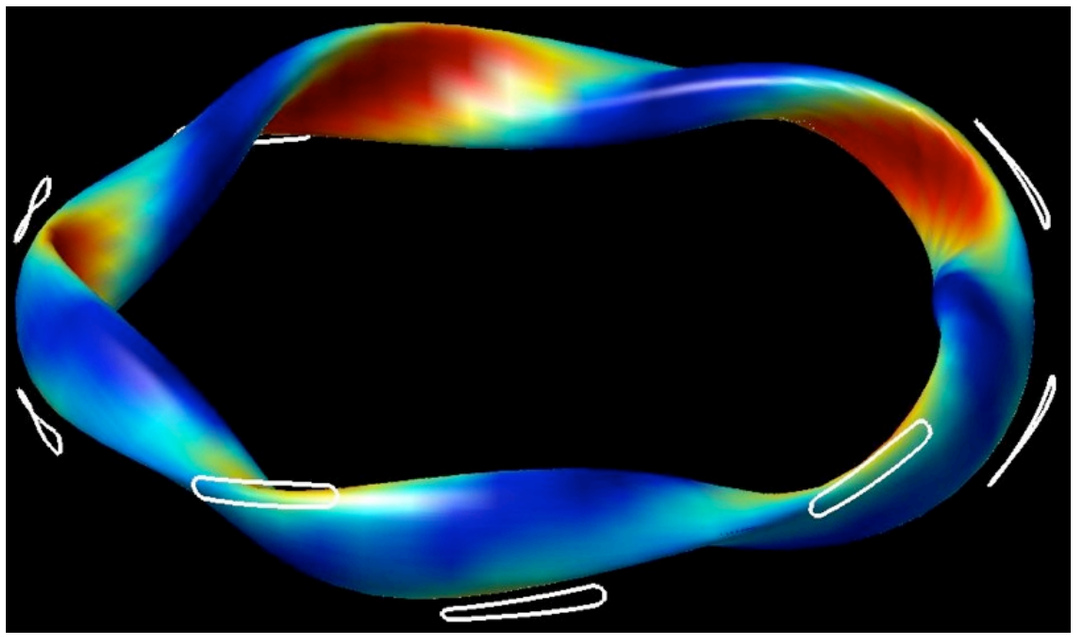
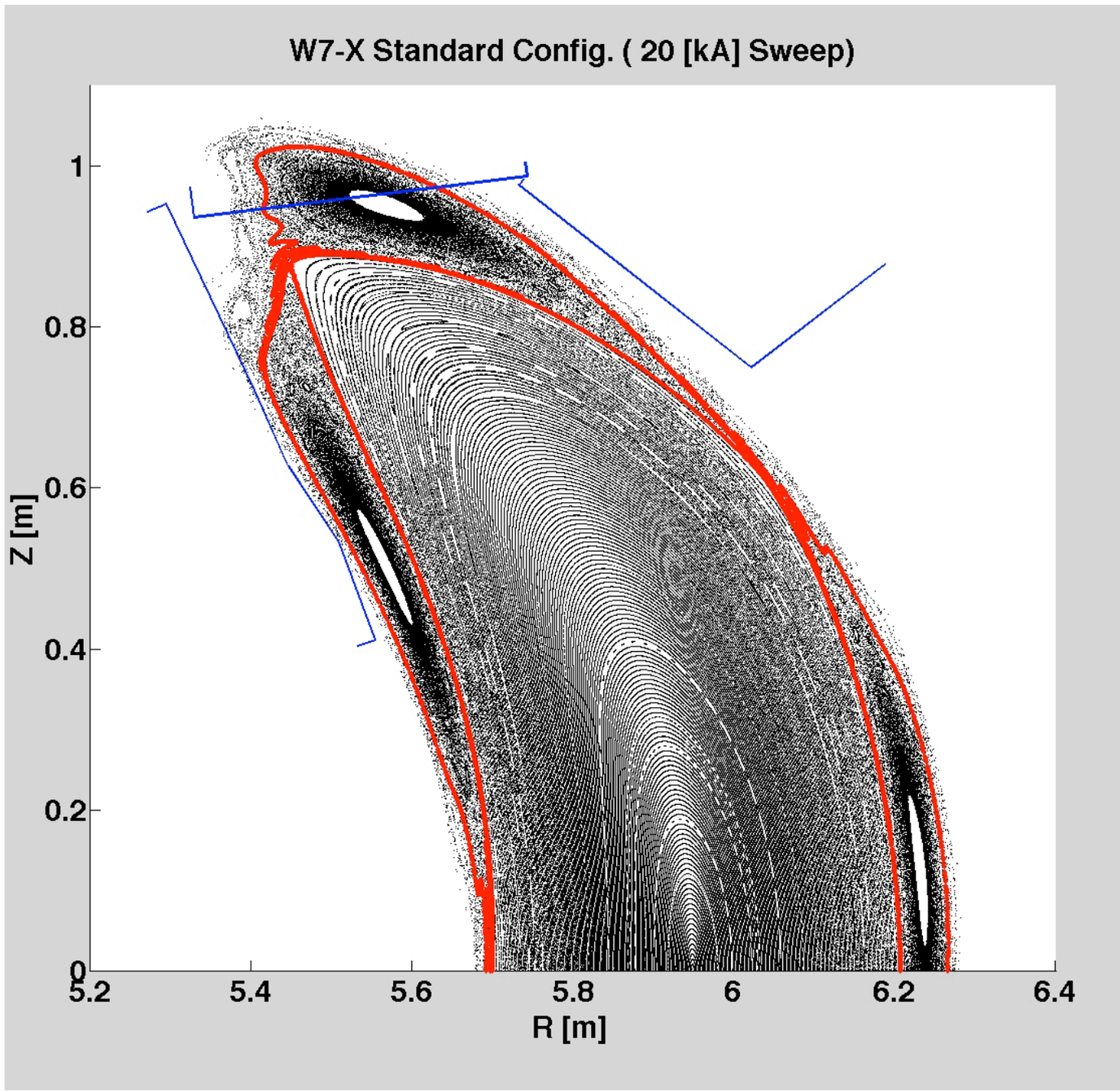
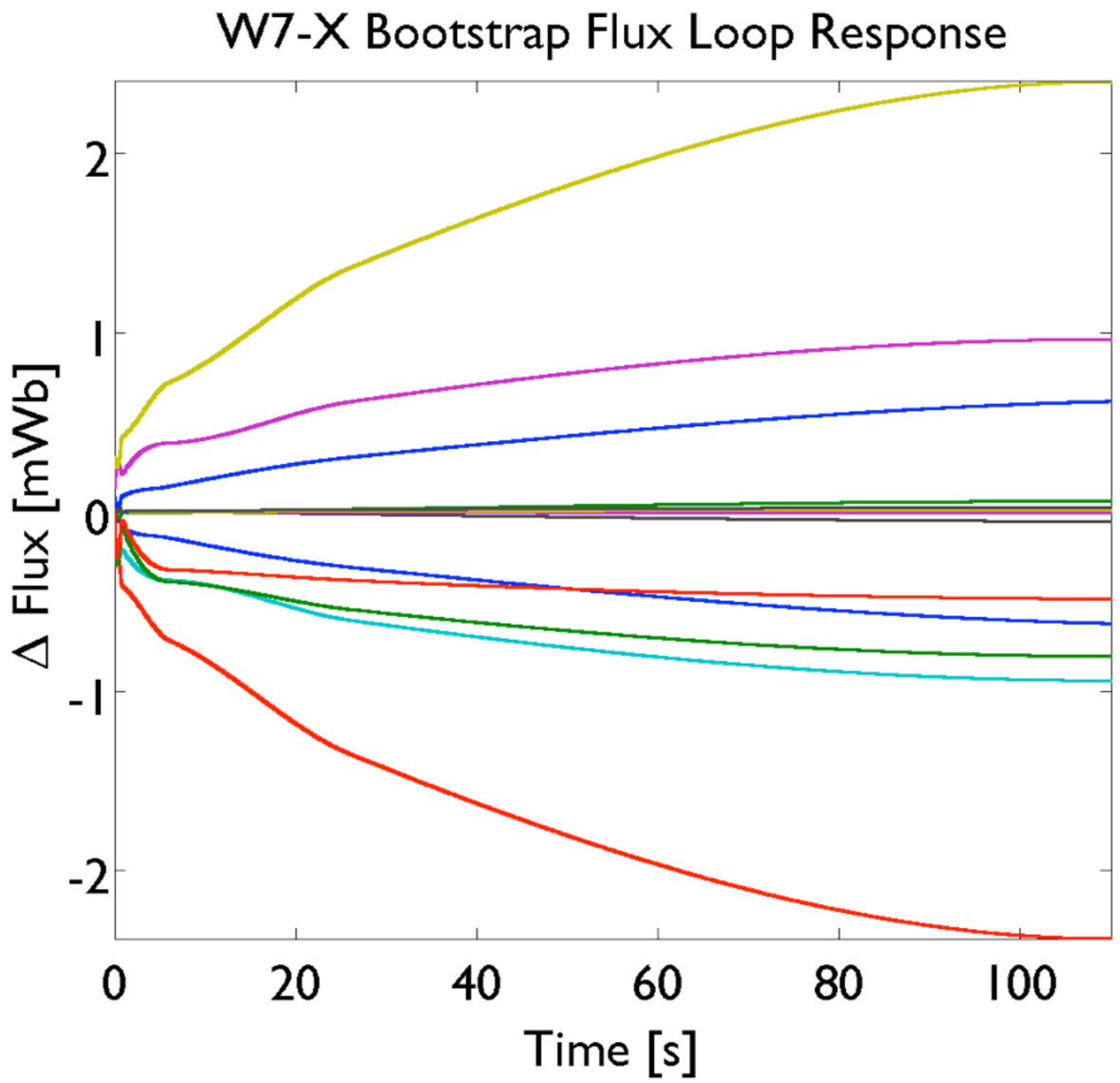




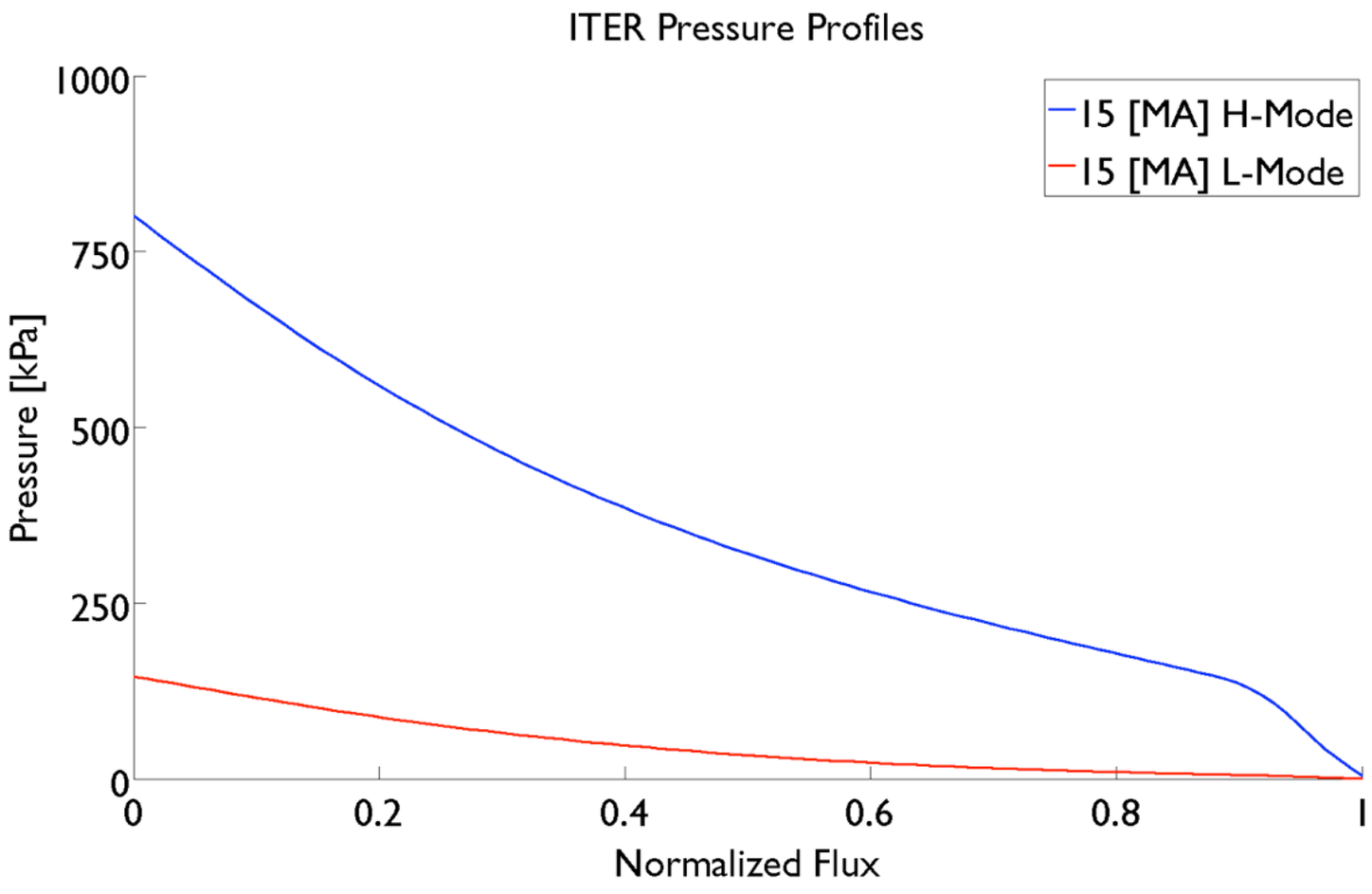
Magnetics detect scenario differences

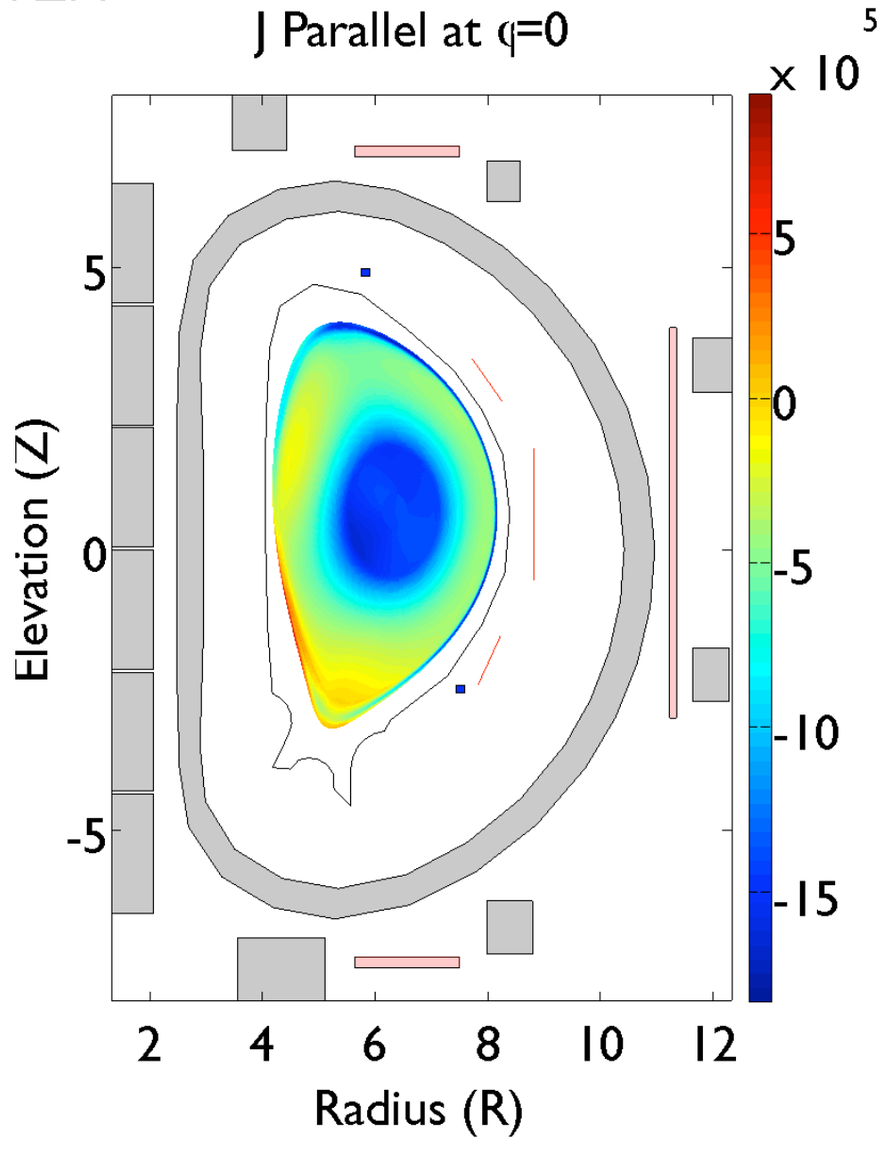
- Flux loop response for each scenario calculated
- Signal due to bootstrap current present
- Ability to constrain bootstrap current unknown
- Ability to detect strike point motion unknown
- Sensitivity analysis in progress



3D Effects in ITER

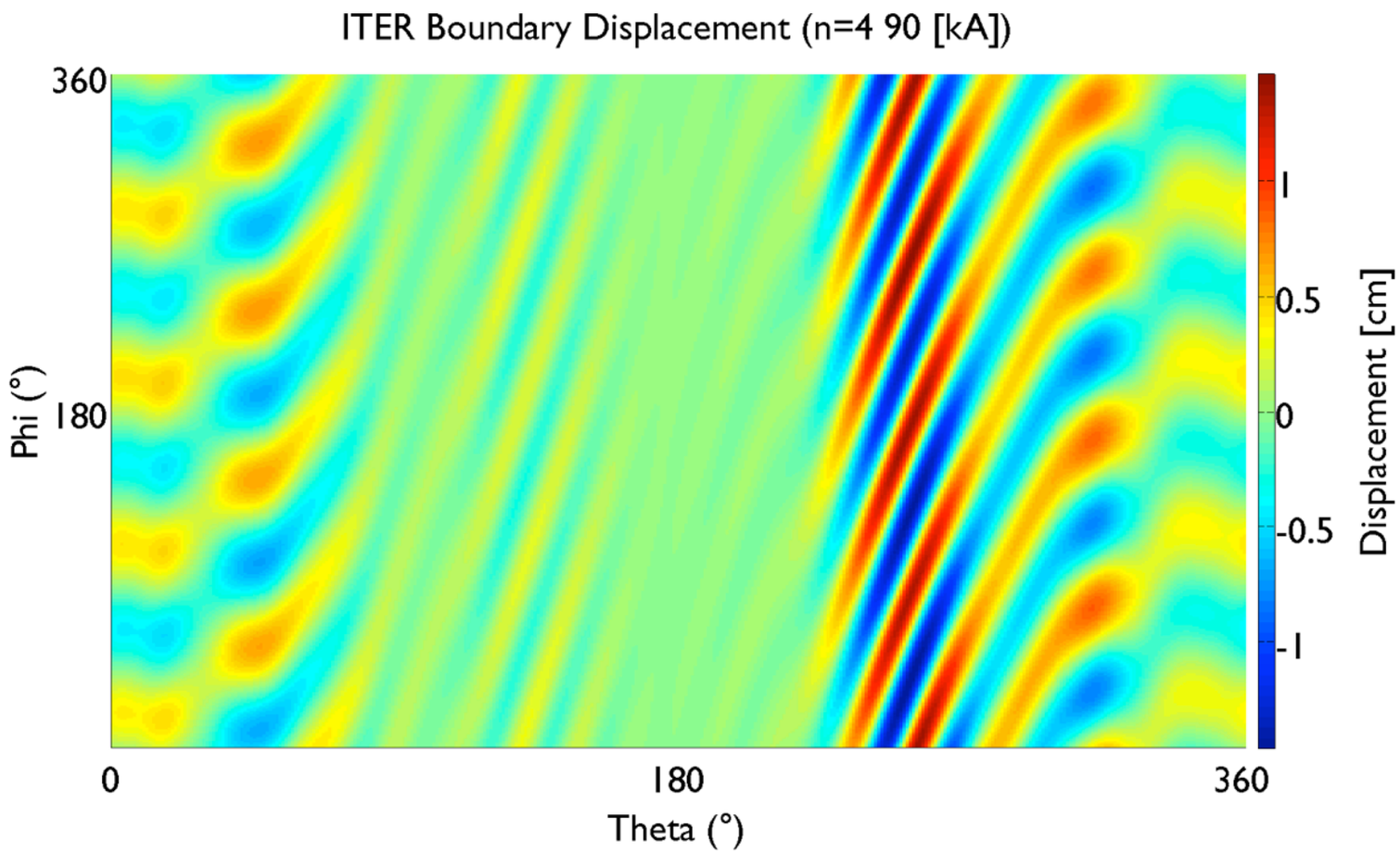
- VMEC utilized to calculate equilibrium response to RMP application
- DIAGNO2 utilized to calculate flux loop response in ITER





Boundary Displacements with ELM Coils (L-Mode)

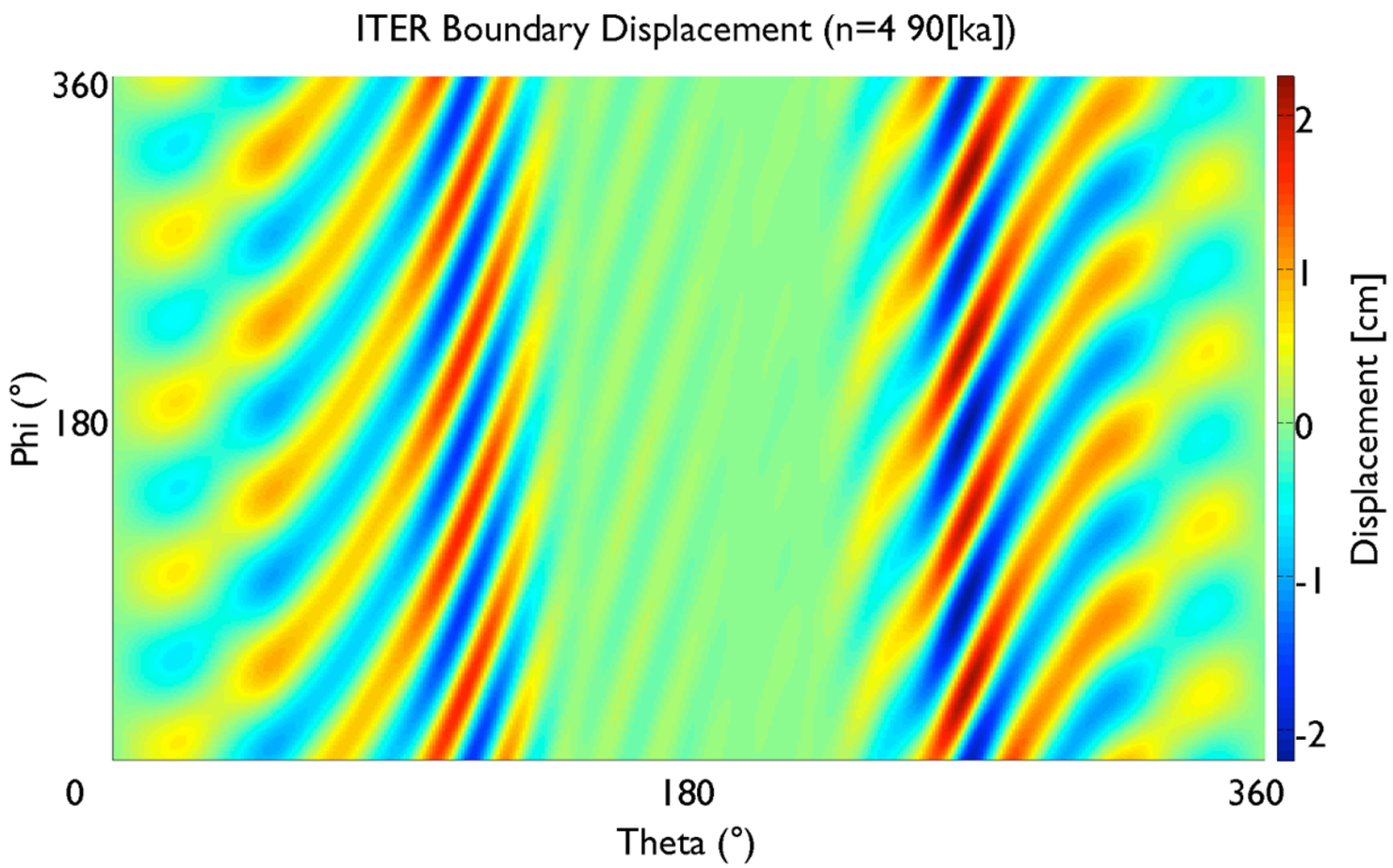
ELM Coil Current	Maximum Displacement
n=3 45 [kA]	0.70 [cm]
n=3 90 [kA]	1.88 [cm]
n=4 30 [kA]	0.54 [cm]
n=4 90 [kA]	1.46 [cm]



VMEC Resolution s=99,m=24,n=4

Boundary Displacements with ELM Coils (H-Mode)

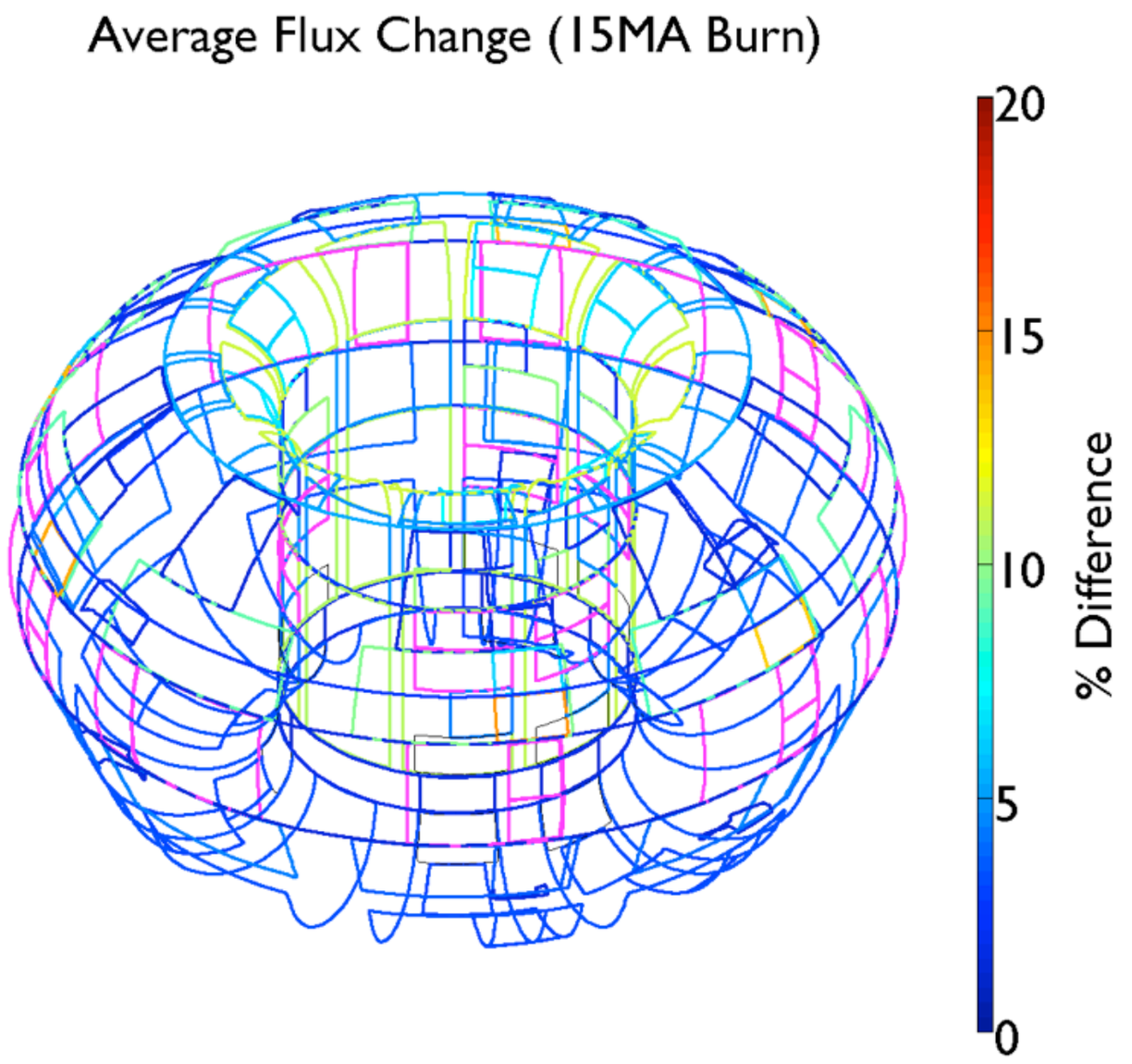
In-Vessel Coil Scenario	Maximum Displacement
n=3 45 [kA]	0.84 [cm]
n=3 90 [kA]	1.84 [cm]
n=4 30 [kA]	1.15 [cm]
n=4 90 [kA]	2.25 [cm]



VMEC Resolution s=99,m=24,n=4

Flux loops show a clear non-axisymmetric response

- Flux loop response to plasma calculated
- Compared to axisymmetric plasma signal
- Coil configurations averaged
- Nearly all loops indicate >1% signal change
- Pink loops indicate >20% change



Conclusions

- Magnetic diagnostic are sensitive to bootstrap current variations in W7-X allowing the development of island divertor control scenarios
- ITER Flux Loops are sensitive to changes in the 3D equilibria when RMP's are applied suggesting care should be taken in design of real-time control systems