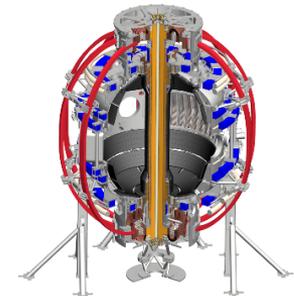


# Update on JRT 2017

V. A. Soukhanovskii

FY2017 Milestone status meeting  
PPPL  
25 May 2017



# JRT-2017: FES Multi-Facility Joint Research Target / Milestone (Led by DIII-D)

- Conduct research to examine the effect of configuration on operating space for dissipative divertors. Handling plasma power and particle exhaust in the divertor region is a critical issue for future burning plasma devices, including ITER. The very narrow edge power exhaust channel projected for tokamak devices that operate at high poloidal magnetic field is of particular concern. Increased and controlled divertor radiation, coupled with optimization of the divertor configuration, are envisioned as the leading approaches to reducing peak heat flux on the divertor targets and increasing the operating window for dissipative divertors. Data obtained from DIII-D and NSTX-U and archived from Alcator C-Mod will be used to assess the impact of edge magnetic configurations and divertor geometries on dissipative regimes, as well as their effect on the width of the power exhaust channel, thus providing essential data to test and validate leading boundary plasma models.

# JRT-2017 contribution from NSTX-U

- No divertor experimental data from NSTX-U
- Large experimental NSTX database, however, few divertor diagnostic measurements
  - XP605, XP708, XP814, XP816, XP826, XP1045, XP1050
- NSTX-U contributions to include
  - Summary of operating space and characteristics of a partially detached divertor in NSTX (0.8, 1.0, 1.2 MA; 4, 6 MW)
  - New analysis of NSTX divertor detachment onset as function of standard divertor geometry ( $I_{||}$ ,  $f_{exp}$ ,  $R_{SP}$ , etc)
    - XP 816 – 0.9 MA, 4 MW, no lithium, 6 configurations with a range of  $I_{||}$ ,  $f_{exp}$ ,  $R_{SP}$ , strong  $n_e$  ramp
    - UEDGE model for the 6 configurations with charge-state resolved carbon and  $n_e$  scans
  - New analysis of the radial detachment region extent as function of divertor scrape-off layer width and gas seeding (0.8, 1.0, 1.2 MA)
  - **New contribution: heat flux reduction in NSTX double-null discharges**



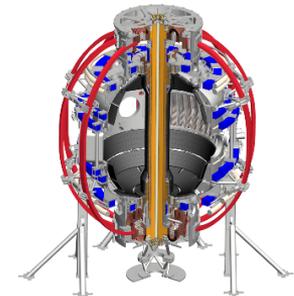
# Further comments on JRT-2017

- Aiming to complete JRT analysis by late July 2017
  - Prepare report and journal manuscript by September 2017
- NSTX-U campaign on DIII-D apparently approved
  - 1 run day MP on divertor detachment similarity to NSTX / NSTX-U
  - No commitment to include results in final JRT report
- FES emphasized that JRT effort must be “joint”
- Notes from March Status Meeting
  - JEM: Do UEDGE modelling of cases scoping out detachment vs.  $\lambda$ -q during next several months
  - JEM: Matt R – For workflows, identify bottlenecks that can be tangibly addressed that might benefit the wider NSTX-U team, such as web-based diagnostic geometry/info sharing... and Is OMFIT useful for all this workflow?

# Heat Flux Reduction in NSTX Double-Null Discharges

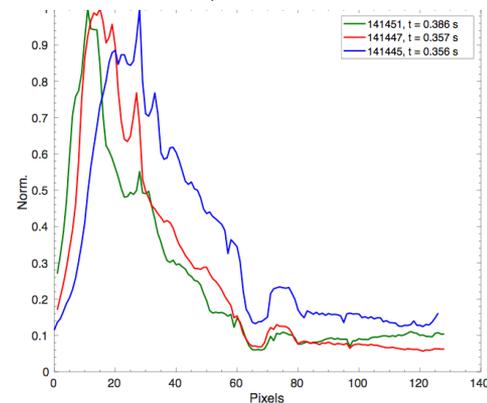
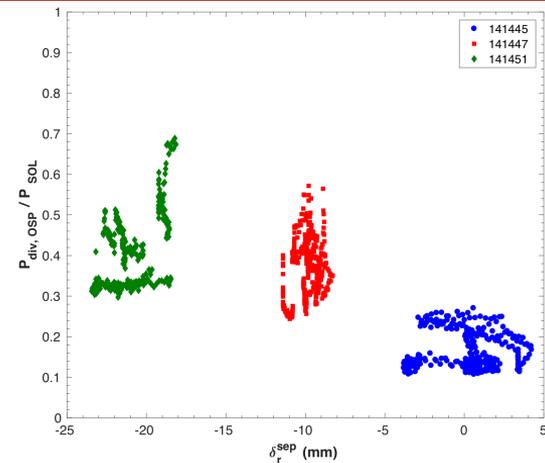
TK Gray, MA Jaworski, ML Reinke, J-W Ahn on behalf of  
the Div/SOL TSG

FY2017 Research Milestone Status Update  
May 25, 2017



# Inter-ELM Power to the lower, outer strike point is reduced as $\delta_r^{\text{sep}} \rightarrow 0$

- $\delta_r^{\text{sep}}$  scan as part of XP 1043
  - $I_p = 0.9$  MA,  $P_{\text{NBI}} = 4$  MW,  $\delta_L \sim 0.7$
  - Fast IR measurements to resolve ELMs
- Near double-null  $10 \leq P_{\text{div, OSP}}/P_{\text{SOL}} \leq 30\%$
- Density dependence observed
  - Filtering and data reduction is in progress
- $\lambda_q$  broadens as  $\delta_r^{\text{sep}} \rightarrow 0$ 
  - Needs to be quantified



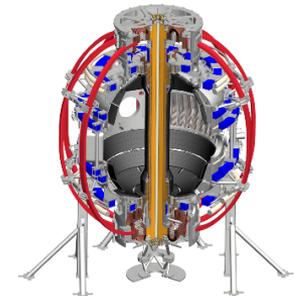
# Plans for Q4

- Use Langmuir probe data to estimate power deposition at other strike points
  - Fill-in the gaps in IR measurements at the other strike point locations
  - Probe interpretation of heat flux has known issues that will have to be resolved
- Quantify changes in  $\lambda_q$  with  $\delta_r^{\text{sep}}$
- Several other XP's explored Double-Null (DN) discharges during NSTX operation
  - Eg: XP's 413, 434, 530, and 609
  - Analysis of XP 609 was inconclusive ... more data mining is possible
- Additional data mining in XP1043
  - $\delta_r^{\text{sep}} = -5, -15$  mm

# Update on R(17-2) Milestone

V. A. Soukhanovskii

FY2017 Milestone status meeting  
PPPL  
25 May 2017



# R(17-2): Advanced divertor operating scenario modeling for NSTX-U

Divertor power exhaust is a critical issue for ITER and next-step tokamaks, and advanced magnetic divertor configurations are being developed and tested to provide candidate solutions for high heat flux and excessive material erosion expected in future facilities. NSTX-U will enable access to a number of advanced divertor configurations including snowflake and X-divertors thanks to a flexible set of divertor poloidal field coils. A range of scrape-off-layer (SOL) widths and high parallel heat fluxes expected in NSTX-U with  $I_p = 1\text{-}2$  MA,  $P_{\text{NBI}} = 6\text{-}12$  MW will enable critical tests of the underlying physics of advanced divertor configurations. To guide the experiments, modeling of advanced divertor scenarios and transport will be performed. Divertor radiation and heat fluxes as functions of current, input power, density, and seeded impurities will be studied. Predictive free-boundary codes including ISOLVER and CORSICA will be used to study the operational space of advanced divertor configurations under various solenoid and poloidal field coil current states. The recently developed GINGRED code will be utilized for numerical grid generation for divertor configurations with multiple X-points. Transport and radiation in these advanced divertor configurations will be modeled using SOLPS and UEDGE multi-fluid two-dimensional transport codes and will include studies of the effects of poloidal variation of transport coefficients. The impact of 3D fields on advanced divertor configurations will also be studied using M3D-C1 and EMC3-ERENE codes to understand how small non-axisymmetric perturbation fields may change plasma parameters inside the separatrix and in the divertor. This research will provide a significant step in advanced divertor concept development for NSTX-U and future conventional and spherical tokamaks.

# Summary of R(17-2) tasks

- Operational space of advanced divertor configurations under various solenoid and poloidal field coil current states
  - Snowflake divertor configurations with ISOLVER (PPPL, LLNL)
  - X-divertor configurations with CORSICA (UT-Austin)
- Transport and radiation in advanced divertor configurations
  - Snowflake modeling with UEDGE (LLNL)
  - X-divertor modeling with SOLPS (UT-Austin)
- Impact of 3D fields on advanced divertor configurations
  - Plasma response and RMP strength using M3D-C1 (General Atomics, PPPL)
    - G. Canal et.al., M3D-C1 simulations of the plasma response to non-axisymmetric magnetic perturbations in the NSTX-U snowflake divertor, NUCLEAR FUSION (2017)
  - Field line tracing, 3D multi-fluid and neutral transport using FLARE, EMC3-EIRENE (U. Wisconsin)
    - H. Frerichs et.al., Exploration of magnetic perturbation effects on advanced divertor configurations in NSTX-U, PHYS. PLASMAS (2016)
    - I. Waters, on-going PhD thesis work, APS 2016



# Further comments on R(17-2)

- Notes from March Status Meeting

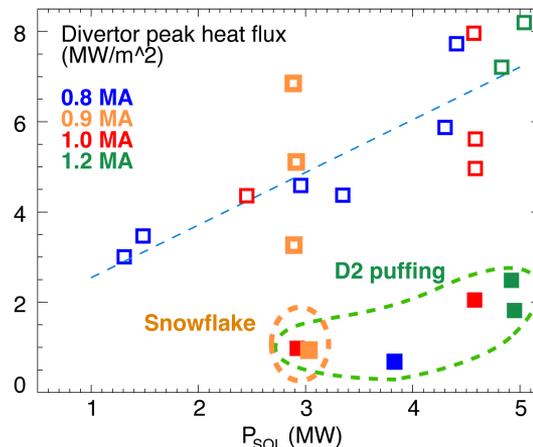
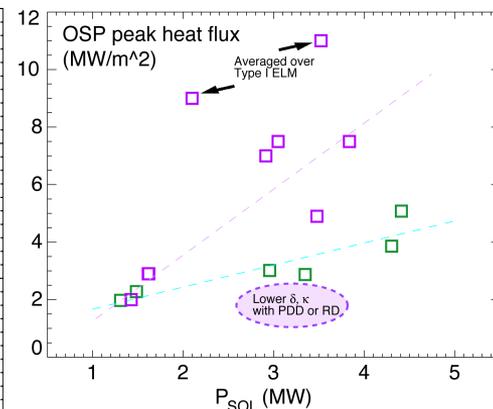
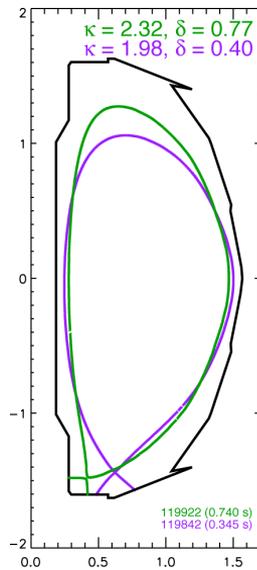
- Assess impact of control / coil current variations - should analyze impact of vertical control oscillation on DRSEP oscillation leading to heat flux oscillation... is this important?
- For comparison of standard and snowflake divertor with UEDGE, try using lower chi and D to simulate narrower up-stream with lambda-q closer to 2mm instead of 3mm.
- J. Menard – share/distribute GEQDSK files being used in divertor heat flux studies for use in boundary, AS, and MS/RMP studies
- G. Canal (?) – share GEQDSK files used for the planned XGC scans and runs for wider vetting before the XGC scans are carried out. Should share these files with boundary group for ELITE / ELM analysis.
- Vlad and/or Matt – U-Wisconsin – 3D physics work... should look at 2MA, 1T, scenarios.... What was power? What is peak heat flux? And what is asymmetry in heat loading? Should also work with BP and MS groups to identify realistic n-spectrum and amplitudes that will result from error field correction in NSTX-U.

# Backup

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# Partial detachment operating space in NSTX

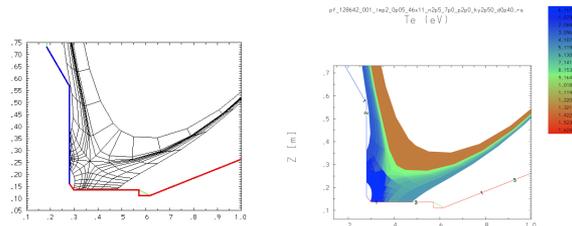
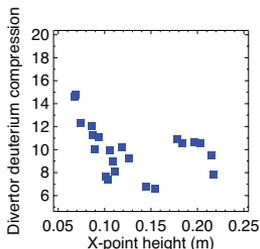
- Only no lithium data (2004-2008)
- Standard divertor configuration
  - Compact (small geometric area - ST)
  - High divertor power and peak heat flux
  - Never reaches detachment naturally at high  $n_e \sim 0.9 n_G$
  - Detachment onset strongly depend on
    - Magnetic flux expansion
    - Gas puffing location
    - Plasma current ( $B_p, \lambda_q$  ?)



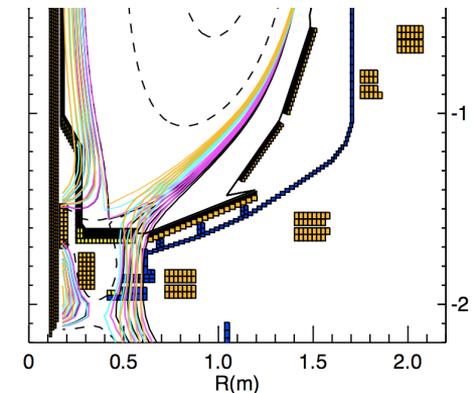
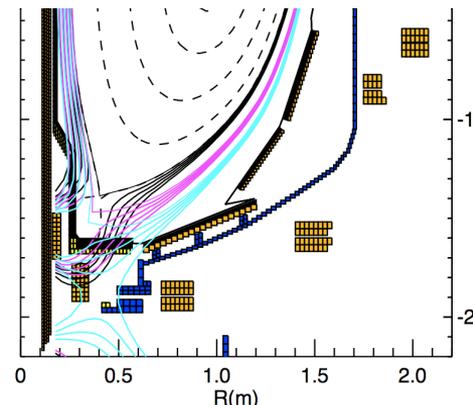
	NSTX high $\kappa, \delta$	Tokamak
Aspect ratio	1.3	2.7
In-out SOL area ratio	1:3	$\sim 2:3$
Parallel connection length $L_{\parallel}$ , midplane to target (m)	8-12	30-80
$L_{\parallel}$ , X-point to target (m)	5-8	10-20
Angle at target (deg)	5-15	1-2

# Detachment onset dependence on flux expansion investigated

- Only transient detachment with divertor gas puffing at low  $\delta$  (low  $f_{exp}$ )
  - High  $q_{||}$  concentrated in small physical volume
- At high- $\delta$ , dedicated XP to study transition to detachment as function of  $f_{exp}$  and  $R_{OSP}$  (area expansion)
  - Approached detachment at lower X-point height
  - High flux expansion provides higher “plasma plugging” efficiency and higher volumetric losses
    - Higher neutral compression
    - Higher impurity radiation
  - UEDGE modeling (O. Izacard)

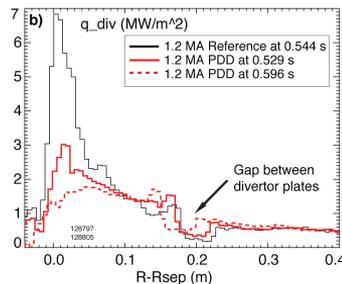
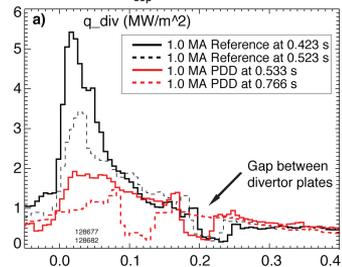
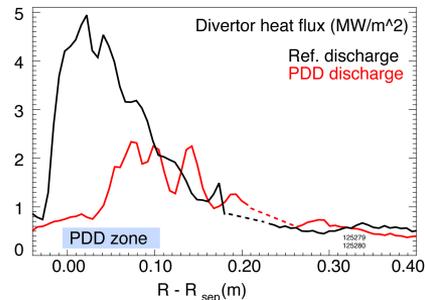
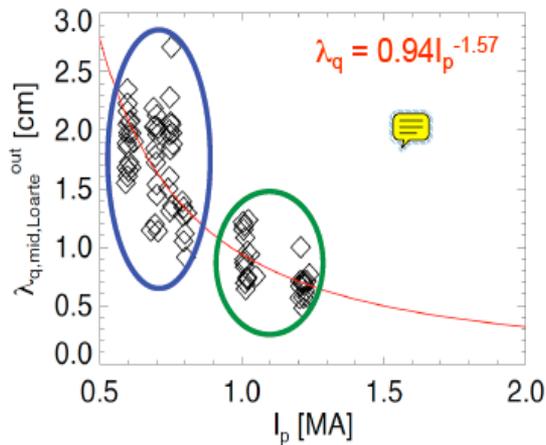


Experiment	Coils	X-pt height	OSP major radius	Flux expansion
# 1	PF1AL	6-23 cm	0.30-0.39 m	6-26
# 2	PF1AL & PF1B	4-11 cm	0.42-0.45 m	14-35



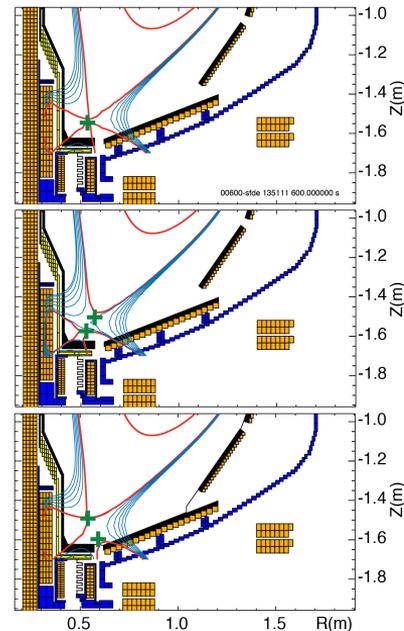
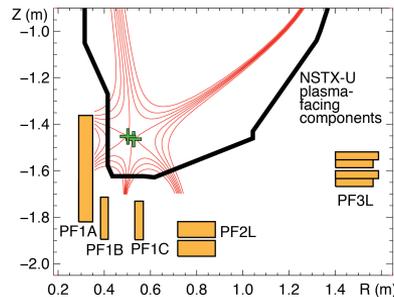
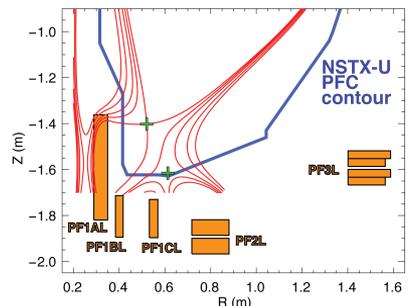
# Connection between partial detachment extent and SOL power width $\lambda_q$ investigated

- SOL power width is a function of  $1/I_p$  ( $B_p$ )
  - Balance between parallel and cross-field transport
- Can extent of detachment be linked to radial transport via  $\lambda_q$
- NSTX data at  $\delta \sim 0.5$  and  $\delta \sim 0.7$  in a range of  $I_p$  and  $P_{NBI}$ 
  - SOL width contracts with  $I_p$
  - Divertor peak heat flux varies directly with  $I_p$  and  $P_{NBI}$  and inversely with flux expansion
- Interpretive UEDGE modeling expected



# Advanced magnetic divertor configuration equilibria modeling

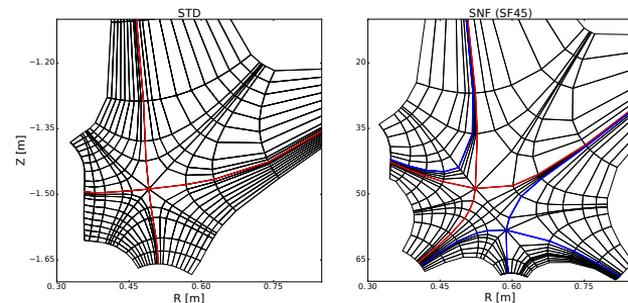
- Impact of partial divertor coil set, ohmic flux swing, cryo-pump geometry
  - Snowflake divertor configurations with ISOLVER (PPPL, LLNL)
  - X-divertor configurations with CORSICA (UT)
- Waiting for finalized (or near-final) divertor poloidal field coil layout



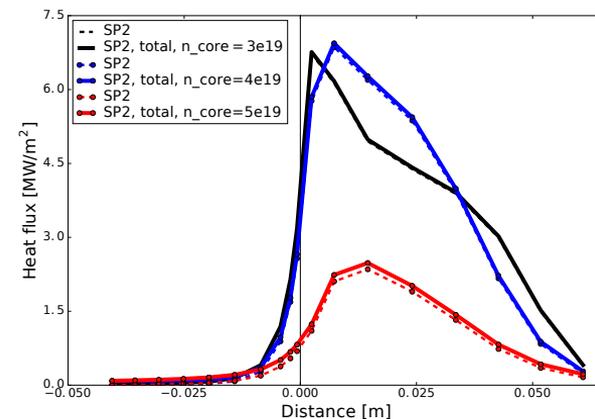
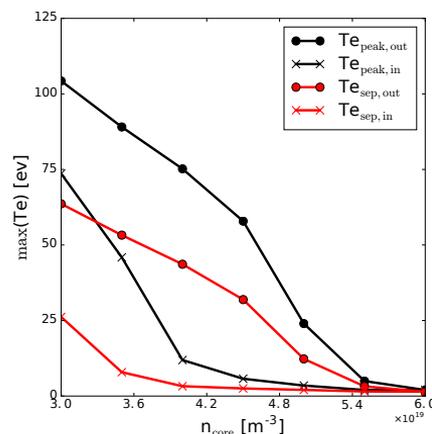
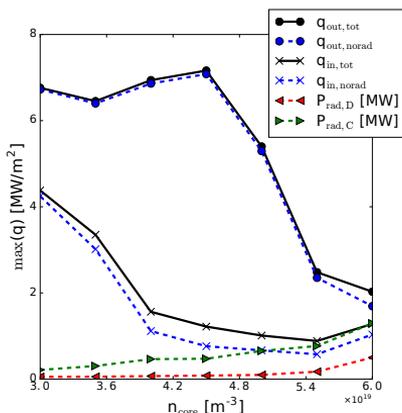
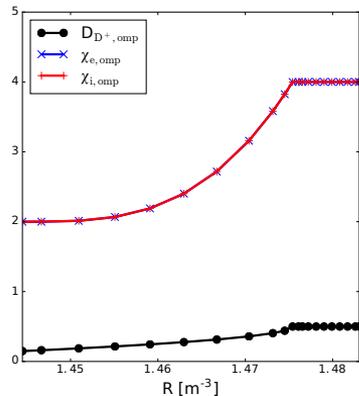
Snowflake divertor configurations for NSTX-U  
With PF1B                      Without PF1B

# Modeling of transport and radiation in advanced divertor configurations with 2D multi-fluid codes

- X-divertor with SOLPS (UT)
  - Preliminary results shown in NSTX-U Monday Meeting [01/23/2017](#)
- Standard and snowflake divertor with UEDGE (LLNL, O. Izacard)
  - 2 MA, 1 T,  $P_{\text{SOL}}=10$  MW
  - NSTX-like transport ( $D$ ,  $\chi$ ), electron/ion - 50/50
  - Charge-state resolved carbon, constant  $D$  for all ions
  - $R=0.99$



## Standard divertor



# Impact of 3D fields on advanced divertors

- Modeling of advanced divertor configurations with 3D fields
  - Plasma response and RMP strength using M3D-C1 (General Atomics, PPPL)
    - G. Canal et.al., M3D-C1 simulations of the plasma response to non-axisymmetric magnetic perturbations in the NSTX-U snowflake divertor, Submitted to NUCLEAR FUSION (2016)
  - Field line tracing, 3D multi-fluid and neutral transport using FLARE, EMC3-EIRENE (U. Wisconsin)
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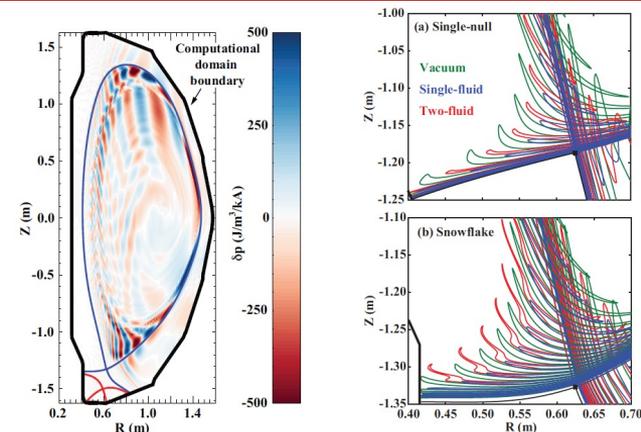


Figure 5. Perturbation of the total plasma pressure from the two-fluid plasma response to an externally applied  $n = 3$  magnetic perturbation.

Figure 10. Manifolds of (a) SN and (b) SF configurations calculated using the vacuum approach (no plasma response) and with the single- and two-fluid plasma responses.

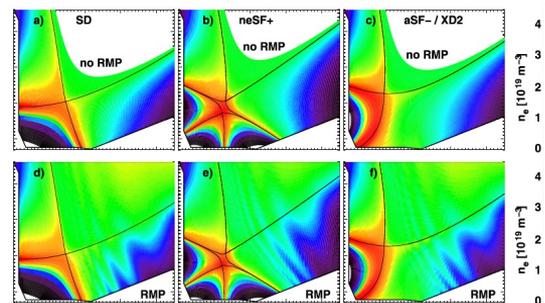


FIG. 8. Comparison of the edge plasma density with and without magnetic perturbations: (a) and (d) standard divertor configuration, (b) and (e) near exact snowflake configuration, and (c) and (f) asymmetric snowflake minus/X-divertor configuration. The position of the unperturbed separatrix is marked in black for reference.