NSTX-U   *Supported by*   U.S. DEPARTMENT OF ENERGY   Office of Science

NSTX-U 5 Year Plan for Pedestal, Scrape-off Layer and Divertor Physics

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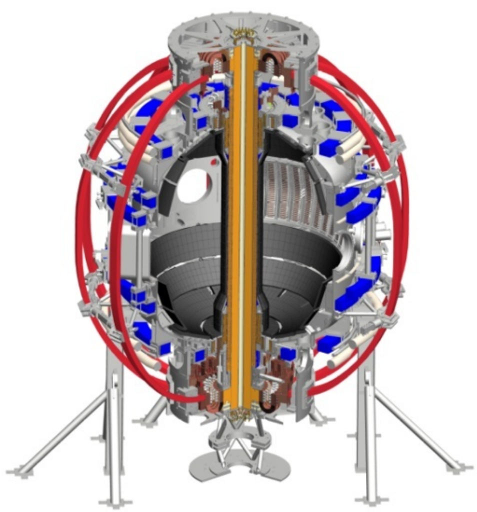
for the NSTX-U Research Team

NSTX-U PAC-33 Meeting
PPPL – B318
February 19-21, 2013



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Boundary Physics program in NSTX-U contributes to critical research areas for ITER/tokamaks and STs

High-level goals for NSTX-U 5 year plan

- Demonstrate stationary non-inductive operation
- Access reduced ν^* and high-β
- Develop and understand non-inductive start-up/ramp-up
- **Develop and utilize high-flux-expansion snowflake divertor and radiative detachment for mitigating very high heat fluxes**
- Begin to assess high-Z PFCs + liquid lithium

Boundary Physics program in NSTX-U contributes to critical research areas for ITER/tokamaks and STs

- Boundary Physics Thrusts (and outline of the talk)
  - BP-1: Assess and control pedestal structure, edge transport and stability
    - Pedestal structure, transport and turbulence studies
    - ELM characterization and control
  - BP-2: Assess and control divertor heat and particle fluxes
    - SOL transport and turbulence, impurity transport
    - Divertor heat flux mitigation with impurity seeding and divertor geometry
- This talk: Recent NSTX Boundary Physics progress, Goals and Plans for Pedestal, ELM, SOL and divertor research in 2014-2018

Planned NSTX-U facility upgrades enable access to new parameter space and unique capabilities

Planned upgrades (NSTX → NSTX-U)	Operations year available	Boundary Physics area
P_{NBI} = 5 → 12 MW (5 s) 7.5 →15 MW (1.5 s)	1-2	Pedestal structure and ELM stability, L-H, divertor heat flux (12 → 15-20 MW/m^2) P/R ~ 10 → 20 P/S ~ 0.2 → 0.4
I_p = 1.3 → 2 MA B_t = 0.5 → 1 T	1-2	L-H transition, pedestal structure and stability, SOL width, divertor heat flux
Pulse length 1.5 → 5-10 s	1-2	Steady-state divertor heat flux mitigation, density and impurity control
Axisymmetric PF (divertor) coils PF1A, 1B, 1C, 2L	1-3	Plasma shaping, L-H, divertor configuration control
Non-axisymmetric control coils	3	ELM control and pedestal transport
Divertor cryogenic panel	3	Pedestal stability, density control, radiative divertor with impurity seeding
Molybdenum plasma-facing components	2	Core and pedestal impurity density, divertor heat transport regimes

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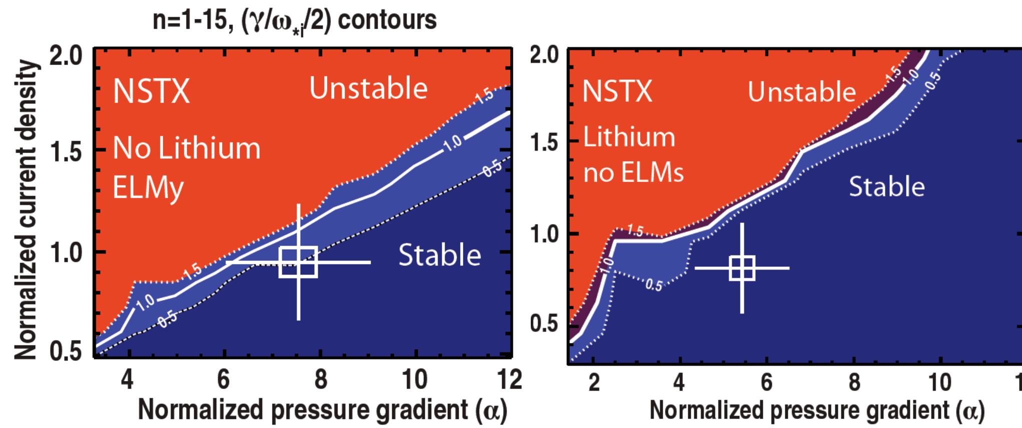
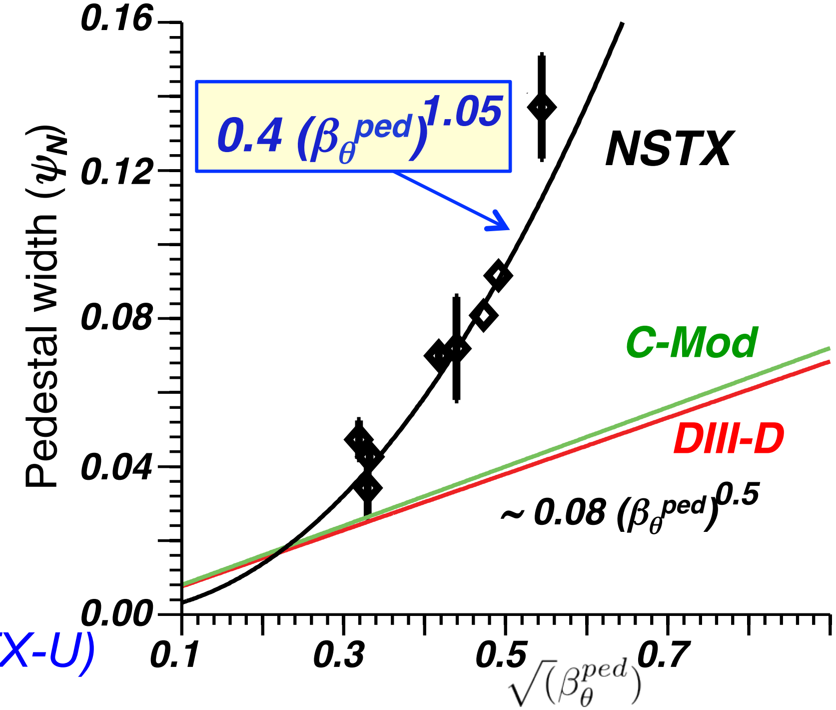
Pedestal studies focus on testing applicability of peeling ballooning and kinetic ballooning to limit pedestal heights widths, and gradients

BP-1

- Peeling ballooning limits on pedestal height consistent with ELMy/ELM-free operation
  - Challenge: applicability of diamagnetic stabilization
  - Lithium and 3-D fields used to manipulate profiles



- Kinetic ballooning being tested as a mechanism to limit width
  - Scaling with β_{pol}^{ped} stronger in STs than higher R/a
  - No evidence yet of KBM fluctuation

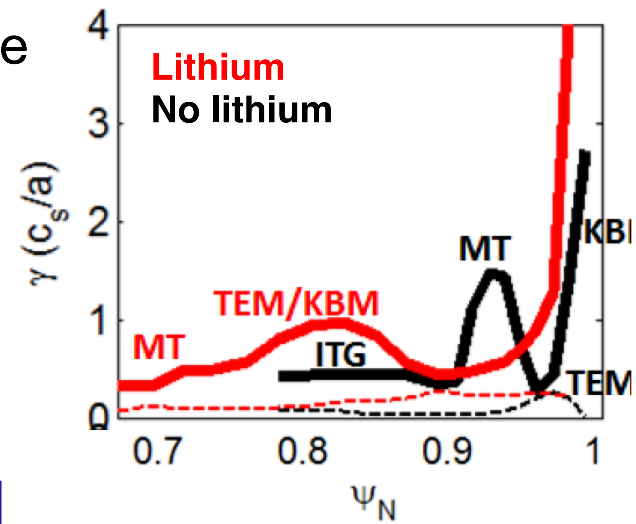


Diagnostics:

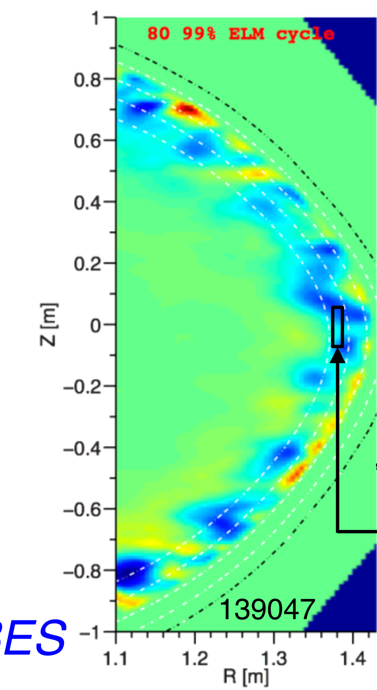
30 point MPTS (NSTX) → 42 point MPTS (NSTX-U)

Understand role of different microinstabilities for different transport channels for pedestal control

- TEM / KBM modes appear dominant in near-edge region of NSTX pedestal
  - GENE: ITG/KBM-TEM hybrid modes and microtearing
  - GS2: hybrid TEM/KBM dominant
    - No lithium: microtearing modes linearly unstable
    - Lithium: microtearing stable, TEM unstable, ETG unstable near separatrix



- Measured correlation lengths at pedestal top are consistent with theory (XGC1)
  - Spatial structure exhibits ion-scale microturbulence
  - Compatible with ITG modes and/or KBM



R = 1.38m

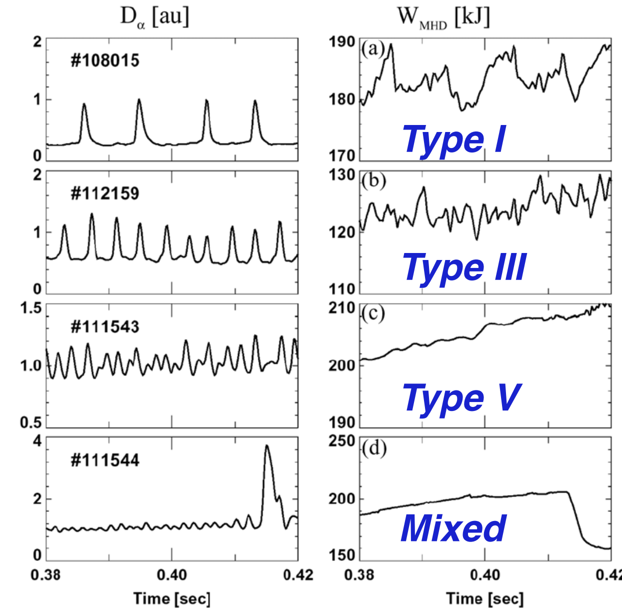
	Theory (non-linear XGC1 code)	***Experiment***
radial	3 cm	2 – 4 cm (reflectometry)
poloidal	11 cm	10 – 14 cm (BES)

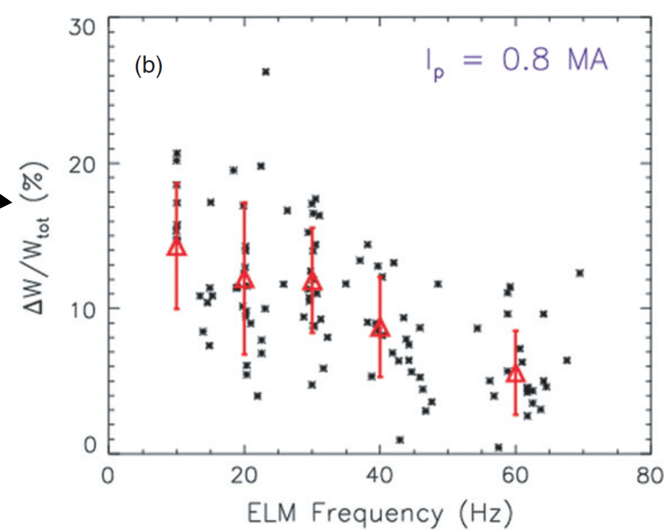
80% - 99% ELM cycle

Diagnostics (NSTX-U):
42 point MPTS, reflectometry, 48 point BES

ELM evolution and divertor/wall heat flux studies in NSTX-U to focus on acceptable ELM heat flux scenarios

- Many ELM regimes observed in NSTX: Type I, III, V, mixed, (and also Type II in narrow operational windows)
  - Phenomenology dependent on ν^*_{ped}, P_{SOL}, $I_{p,}$ shaping
- ELM control techniques
  - Lithium granule injector (tested at EAST)
  - Lithium evaporation
  - Enhanced Pedestal (ELM-free) H-mode
  - 3-D fields (n=3 RMP)
- Heat flux from Type I & III ELMs measured to be very high; small Type V ELMs have low heat flux
  - Type I ELMs triggered with 3-D fields can reduce per ELM energy loss and peak heat flux, but slower than $1/\nu_{ELM}$
  - Toroidal asymmetry increases with ELM peak heat flux





Plans for pedestal transport, turbulence and ELM control research

- Year 1 of 5 Year Plan
  - Continue cross-machine comparison of pedestal structure with DIII-D and Alcator C-Mod
  - Continue gyro-kinetic modeling of electromagnetic turbulence

- Years 2-3 of 5 Year Plan
  - Pedestal structure and turbulence vs engineering and physics parameters
  - ELM control with lithium coatings, lithium granule injector, and 3D fields
  - Access to new operational regimes (enhanced pedestal H-mode, I-mode)
  - Initiate assessment of SOL current generation and impact on ELM models and control
  - Re-establish parameter regime for observation of edge harmonic oscillations

- Years 4-5 of 5 Year Plan
  - ELM control with off-midplane non-axisymmetric control coils
  - Compare pedestal structure and turbulence with edge transport models, XGC0 and XGC1
  - Assess cryopump and molybdenum PFC impact on pedestal collisionality and control

Diagnostics: MPTS, CHERS, BES, reflectometry, GPI

Boundary Physics program in NSTX-U contributes to critical research areas for ITER/tokamaks and STs

- Boundary Physics Thrusts (and outline of the talk)
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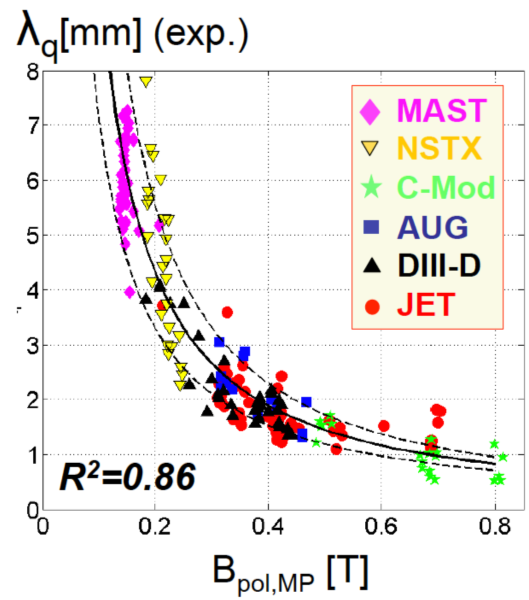
    - **SOL transport and turbulence, impurity transport**
    - **Divertor heat flux mitigation with impurity seeding and divertor geometry**

NSTX-U data will help reduce SOL width scaling uncertainties for ST-FNSF and ITER

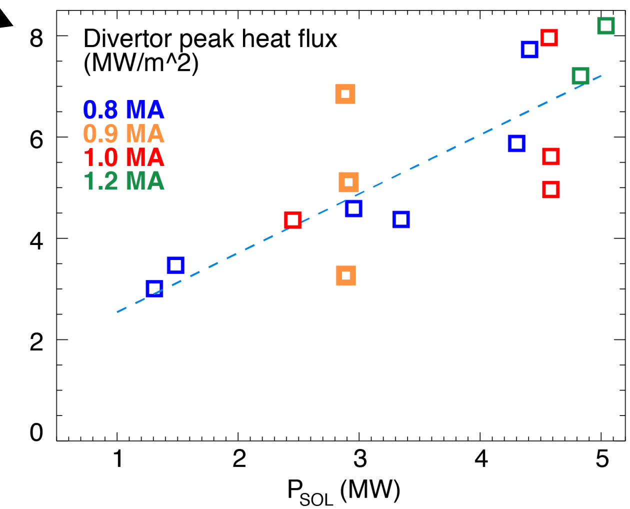
- SOL width scaling
  - In NSTX: $\lambda_q^{mid} \sim I_p^{-1.6}$, independent of P_{SOL} and B_t
    - For NSTX-U (2 MA): $\lambda_q^{mid} = 3\pm0.5$ mm
  - Multi-machine database (Eich IAEA FEC 2012): →

    λ_q^{mid} (mm) = $(0.63+/-0.08)\times B_{pol,MP}^{-1.19}$
    - For NSTX-U (B_p~0.55 T): $\lambda_q^{mid} \sim 1.3$ mm



- Divertor peak heat flux scaling
  - $q_{peak} \sim P_{SOL}$ and $q_{peak} \sim I_p$
  - For NSTX-U $q_{peak} \sim 20\text{-}30$ MW/m²

$$q_{pk} \simeq \frac{P_{heat}\,(1-f_{rad})f_{out/tot}f_{down/tot}(1-f_{pfr})\sin\alpha}{2\pi R_{SP}f_{exp}\lambda_{q_{||}}}$$



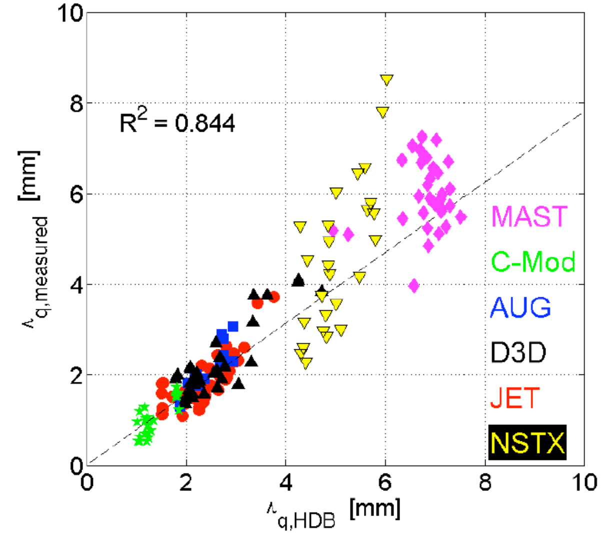
Diagnostics: IR cameras, MPTS, Langmuir probes

- ***Divertor Thomson scattering*** *(incremental) valuable for pressure/temperature balance between midplane, x-point, and divertor regions for heat transport studies*

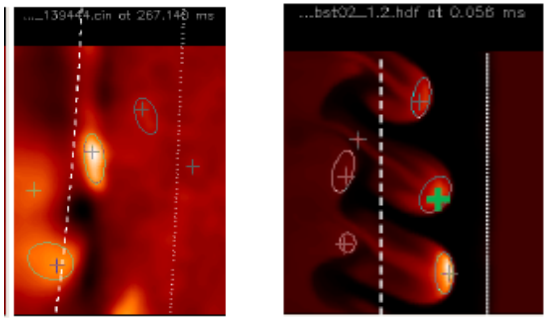
SOL turbulence studies will help assess relative importance of turbulent and drift-based transport

BP-2

- Comparison of λ_{SOL} with SOL models
  - Parallel transport: conductive/convective, cross-field : collisional / turbulent / drift
  - Goldston drift-based model
    - $\lambda_{SOL} \sim (2a/R)\,\rho_{\theta}$, for NSTX-U: $\lambda_q^{mid} \sim 6$ mm
  - Exploring mechanisms setting steep pressure gradient region and connection to SOL width
  - XGC0 (drift-kinetic): $\lambda_q^{mid} \sim I_p^{-1.0}$
  - SOLT (fluid turbulence): I_p scaling is weaker than observed



- Comparison of GPI, BES data and simulations elucidate on SOL transport and L-H transition
  - Blob formation, motion, interaction with sheared flows
  - Role of magnetic X-point geometry
  - Effects of 3-D fields on turbulence
  - Role of atomic physics

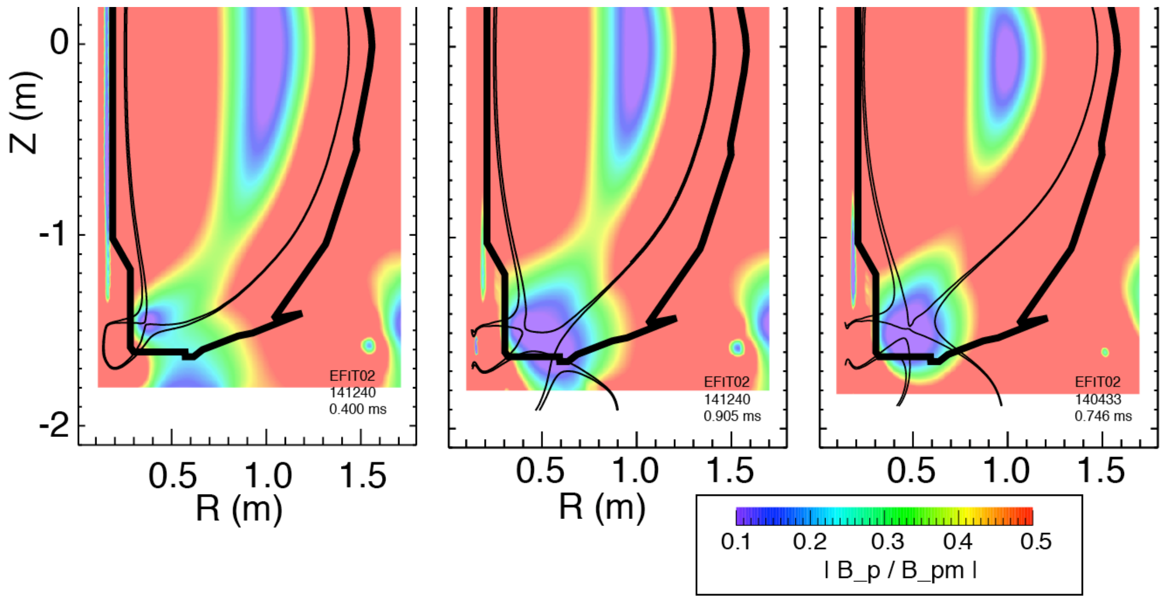


Diagnostics: MPTS, GPI – multiple views, BES, reflectometry, Langmuir probes

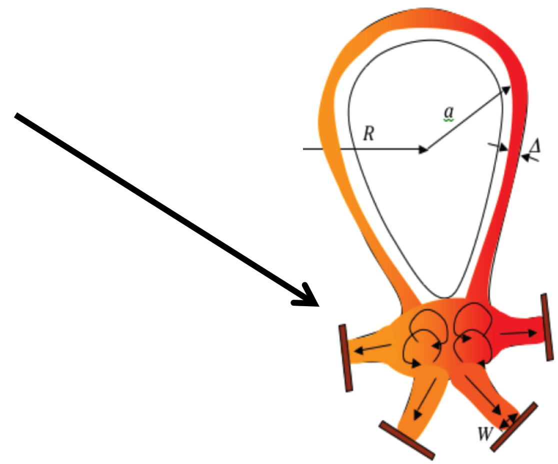
Snowflake divertor geometry has benefits over standard divertor

BP-2

- Second-order null
  - $B_p \sim 0$ and grad $B_p \sim 0$
- Significant divertor heat flux reduction due to geometry confirmed in NSTX and DIII-D

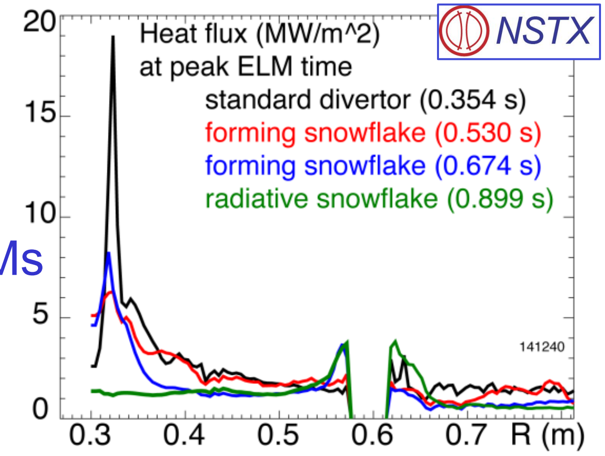


- Outstanding questions
  - Magnetic control of up-down symmetric snowflake
  - Effect on pedestal and ELMs
  - ELM convective heat transport in null point region
  - SOL and divertor turbulence disconnection
  - X-point transport and drifts
  - Compatibility with cryopumping

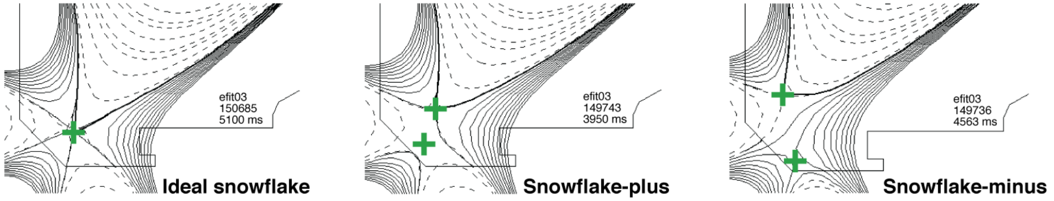


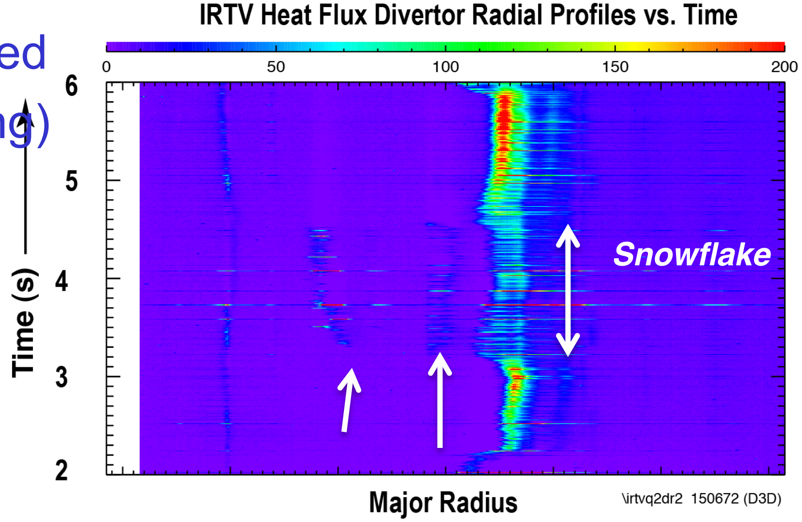
Multi-machine snowflake divertor studies validate the snowflake divertor concept for NSTX-U and ST-FNSF

- Snowflake divertor in NSTX (2009-2010)
  - High confinement, core impurity reduction
  - Destabilized ELMs suppressed by lithium
  - Reduced heat flux by x 2-5 between and during ELMs
  - Outer strike point radiatively detached



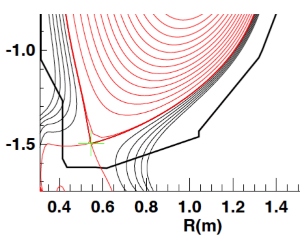
- Initial DIII-D experiments (2012)
  - Used NSTX-style snowflake control scenario
  - Long pulse (3s) snowflake, high τ_E, H(89P) ≥ 2
  - Heat flux reduced x 2-3, strike point attached
  - Reduced ΔW_{ELM} and q^{ELM}_{pk} (with D_2 seeding)

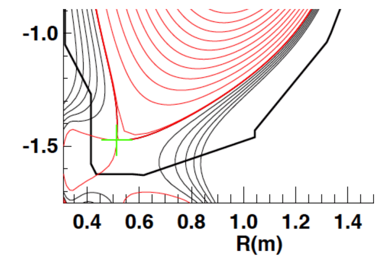




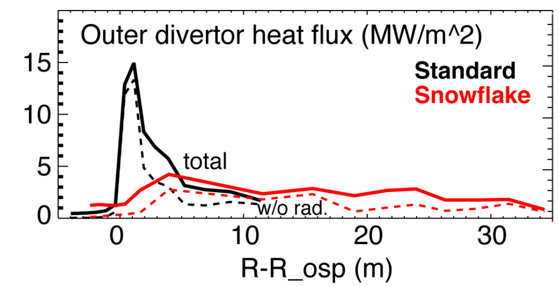
Simulations of snowflake divertor configuration for NSTX-U yield optimistic projections

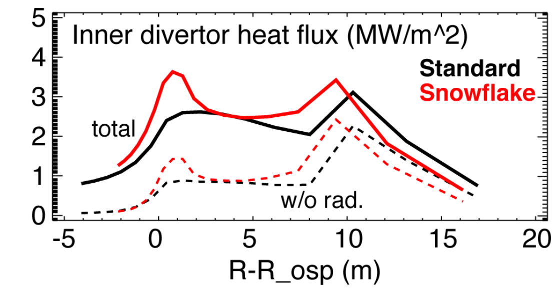
- Significant geometry effects
- Multi-fluid edge transport model (UEDGE)
  - Heat flux reduction with 4% carbon by geometry and radiation in outer strike point
    - for 12 MW NBI case from 15 MW/m^2 to 2-3 MW/m^2
  - Inner divertor detached
  - Particle removal by cryopump results in reduced radiation
    - But still significant heat flux reduction due to geometry





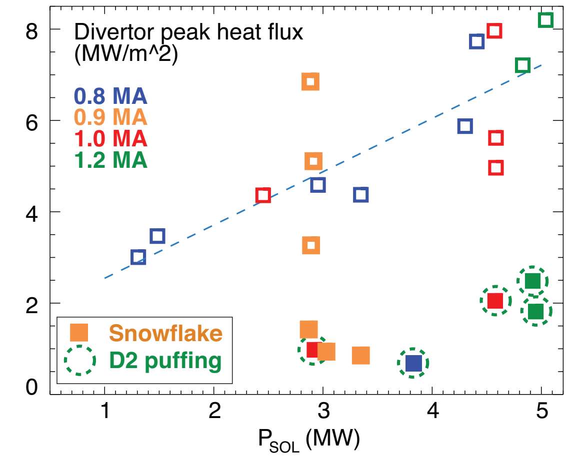
	Standard	Snowflake
L_X (m)	5	17
f_{exp}	20	60-100
V_{div} (m^3)	0.070	0.128

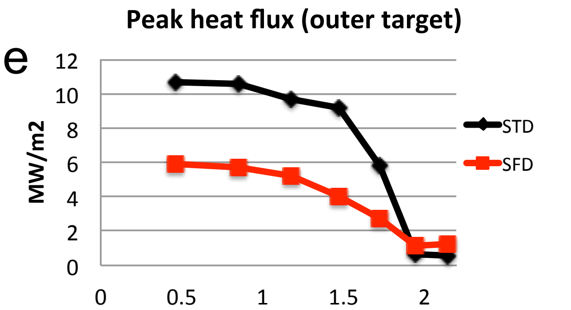


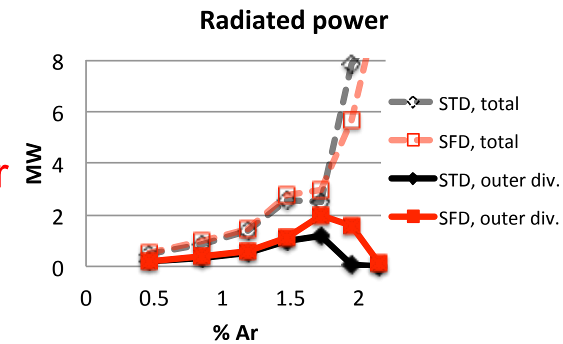


Impurity-seeded radiative divertor with feedback control is planned for NSTX-U

- In NSTX, heat flux reduction in radiative divertor compatible with H-mode confinement was demonstrated with D_2 or CD_4 puffing
- Seeded impurity choice dictated by Z_{imp} and PFC
  - Li/C PFCs compatible with D_2, CD_4, Ne, Ar seeding
  - UEDGE simulations show Ar most effective
    - Too much argon causes radiation collapse of pedestal
- Feedback control of divertor radiation via impurity particle balance control
  - Cryopump for particle removal + divertor gas injectors
  - Real-time control signal diagnostics identified for NSTX-U
    - PFC temperature via IR thermography or thermocouple
    - Thermoelectric current between inner and outer divertor
    - Impurity VUV spectroscopy or bolometry
    - Neutral gas pressure or electron-ion recombination rate







Plan for SOL and divertor research

- Year 1 of 5 Year Plan
  - Continue analysis of SOL width database and comparison with models
  - Collaboration with DIII-D on snowflake and radiative divertor experiments
- Years 2-3 of 5 Year Plan
  - Establish SOL width and divertor database vs. engineering and physics parameters
  - Re-establish edge turbulence measurements (GPI, BES, cameras, probes)
  - Initial radiative divertor experiments with D_2, CD_4 and Ar seeding and lithium
  - Develop snowflake divertor magnetic control and assess pedestal stability, divertor power balance, turbulence, 3D fields as functions of engineering parameters
  - Comparison with multi-fluid and gyro-kinetic models
- Years 4-5 of 5 Year Plan
  - 3D edge/SOL turbulence structure *vs.* edge plasma parameters, magnetic divertor geometry, and 3D fields and comparison with 3-D turbulence models
  - Snowflake divertor with cryopumping and molybdenum PFCs in H-mode scenarios
  - Radiative divertor with feedback control of impurity seeding and cryo-pumping

Diagnostics: MPTS, CHERS, BES, GPI, IR cameras, Langmuir probes, spectroscopy

- *Divertor Thomson scattering (incremental) highly beneficial for model validation*

Boundary program focuses on advancing pedestal physics, power and particle handling with new NSTX-U capabilities

- Pedestal physics: confirm consistency with peeling ballooning, and test applicability of kinetic ballooning
  - Use lithium conditioning and 3-D fields as a way to manipulate the density and pressure profile
- Power and particle handling: further develop snowflake and radiative divertors
  - Test key predictions of snowflake configuration, and evaluate synergy with radiative divertors, graphite and molybdenum plasma facing components
  - Evaluate compatibility with cryopumping
- Planned research aims at providing pedestal and divertor physics basis for ST-FNSF

Backup

Thrust BP-1: Assess, optimize, and control pedestal structure, edge transport and stability

- Characterize pedestal structure using the extended parameter range of NSTX-U
  - Measure turbulence and zonal flow dynamics with beam emission spectroscopy, reflectometry, and gas-puff imaging diagnostics
  - Assess maximum achievable pedestal height, variation in pedestal structure with increased field, current, power and shaping

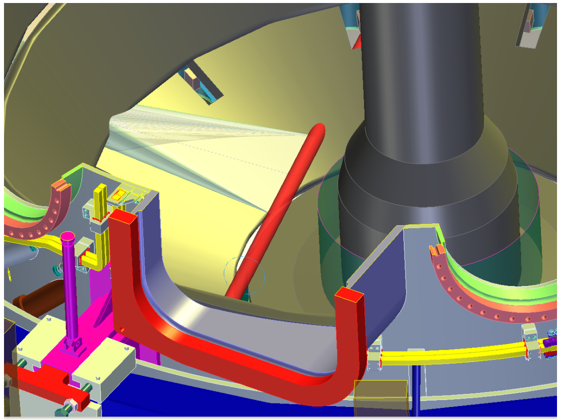
- Increase control of pedestal transport and stability
  - Density profile modification with improved impurity and density control
  - ELM triggering/suppression with 3D fields from mid-plane and off-midplane partial-NCC coil-sets and triggering with Li granule injection
  - Optimize enhanced-pedestal H-modes with above tools
  - Excite edge harmonic oscillations to increase particle x-port (increm.)

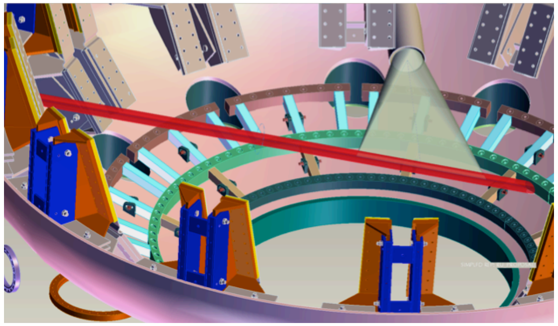
Thrust BP-2: Assess and control divertor heat and particle fluxes

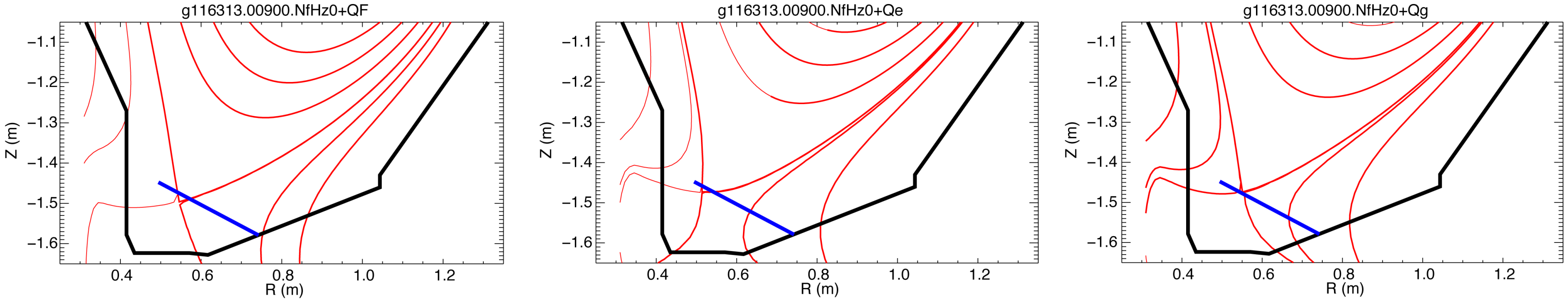
- Investigate SOL heat and particle transport and turbulence
  - Extend heat flux width studies to lower ν, higher B_T, I_P, and P_{SOL}
  - Compare data to multi-fluid turbulence and gyro-kinetic models
- Investigate the snowflake divertor for power and particle control
  - Develop magnetic control of conventional and snowflake divertors
  - Study steady-state & transient heat & particle transport, divertor loads
    - Vary magnetic balance, feedback-controlled impurity seeding rate
- Develop highly-radiating boundary solutions with feedback control, determine divertor detachment operating window
- Validate cryo-pump physics assumptions, perform initial density control studies, determine range of accessible density
- Assess impact of high-Z metal divertor PFCs on H-mode confinement, impurity accumulation, power exhaust

Divertor Thomson Scattering system would significantly enhance NSTX-U Boundary research capabilities

- Physics contributions
  - ELM and inter-ELM divertor transport
  - SOL width scaling, role of X-point heat transport
  - Radiative detachment model validation
  - Snowflake divertor properties, incl. X-pt β_p measurements
  - Divertor plasma-surface interaction and impurity transport studies, erosion rates via spectroscopy
- A conceptual geometry identified for NSTX-U
- Conceptual system design underway



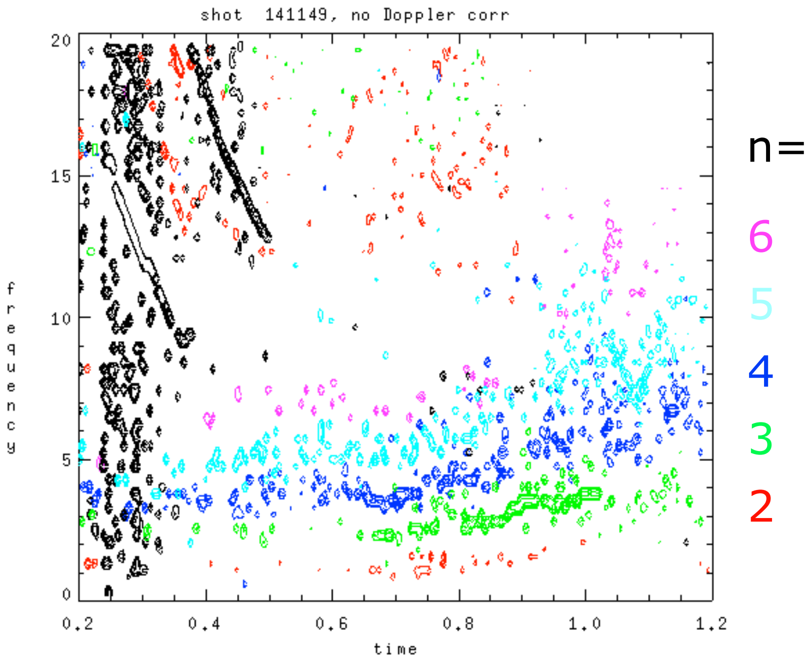




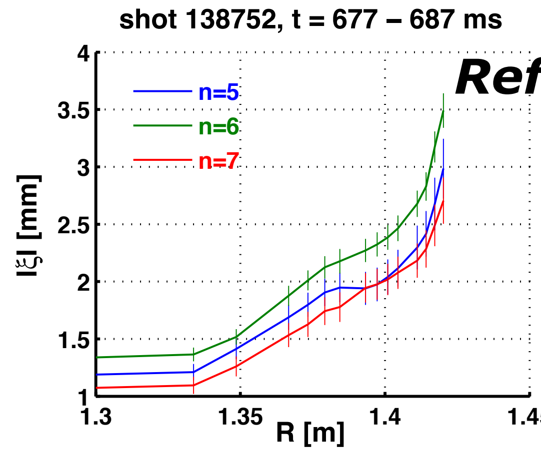
Edge Harmonic Oscillations

Rob Goldston, Eric Fredrickson, Neal Crocker, Mike Jaworski

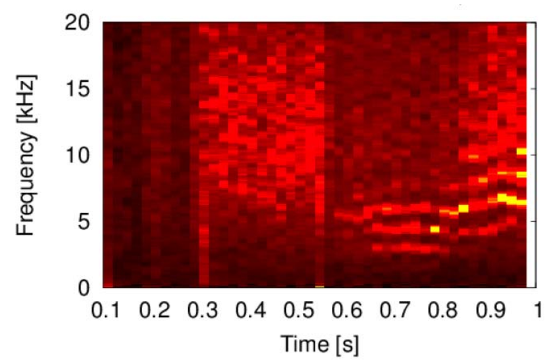
Mirnov



Reflectometry



Langmuir Probes

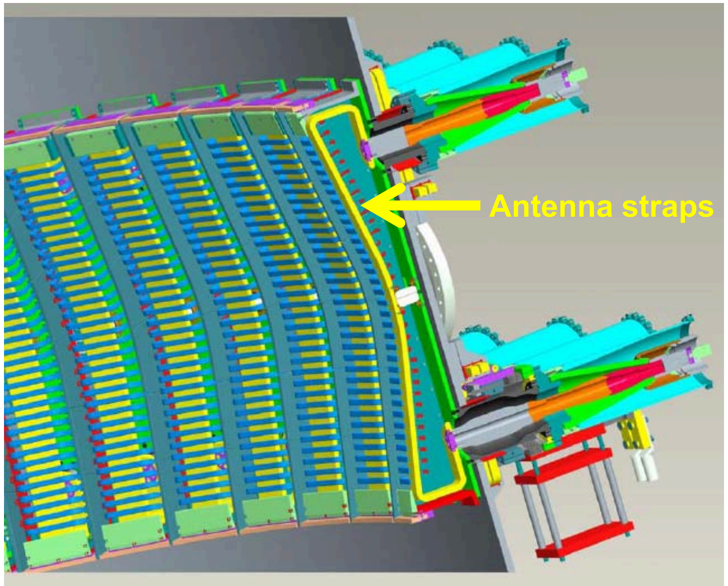


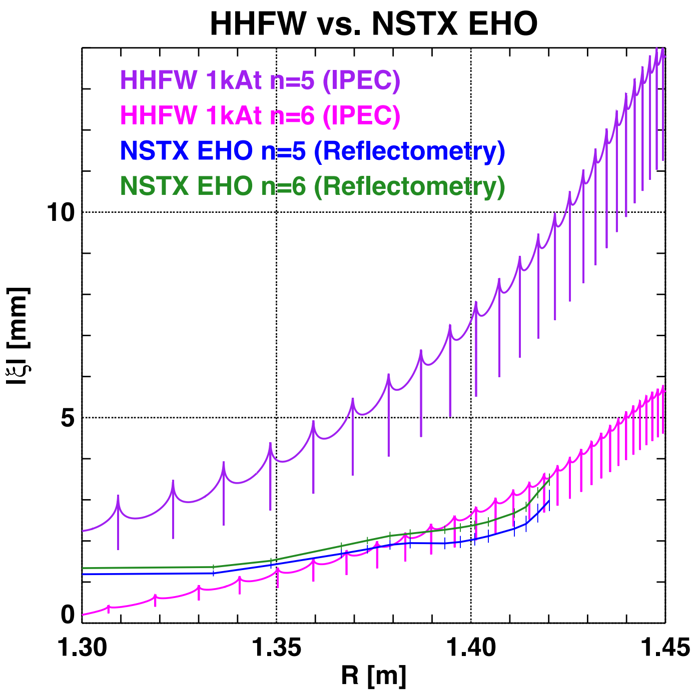
EHO's limit density rise in QH modes on DIII-D. They are observed on NSTX with Li, but don't seem to limit density.

However EHOs do affect the edge and SOL strongly.

Driving Edge Harmonic Oscillations
Key to Active Edge Control?

Jong-Kyu Park





MHD calculations indicate we can amplify edge kinks by driving HHFW antenna straps at audio frequencies.

Can this give us external control over edge pressure gradient (and so ELMs) and/or the SOL width?

Snowflake divertor geometry has benefits over standard X-point divertor geometry

- Predicted geometry properties in snowflake divertor (cf. standard divertor)
  - Increased edge shear :ped. stability
  - Add'l null: H-mode power threshold, ion loss
  - Larger plasma wetted-area A_{wet} : reduce q_{div}
  - Four strike points : share $q_{||}$
  - Larger X-point connection length L_x : reduce $q_{||}$
  - Larger effective divertor volume V_{div} : incr. P_{rad} , P_{CX}

$$q_{pk} \simeq \frac{P_{heat}\,(1-f_{rad}) f_{out/tot} f_{down/tot} (1-f_{pfr}) \sin\alpha}{2\pi R_{SP} f_{exp} \lambda_{q_{||}}}$$

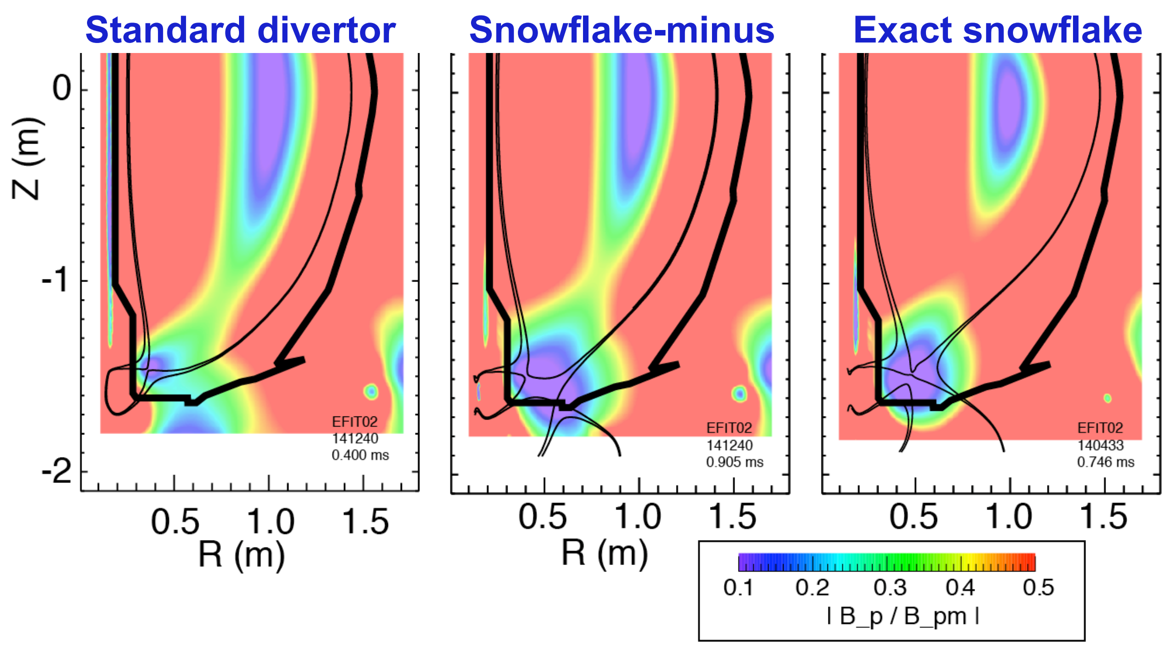
$$f_{exp} = \frac{(B_p/B_{tot})_{MP}}{(B_p/B_{tot})_{OSP}}$$

D. D. Ryutov, PoP 14, 064502 2007

$$A_{wet} = 2\pi R\, f_{exp}\, \lambda_{q_{||}}$$

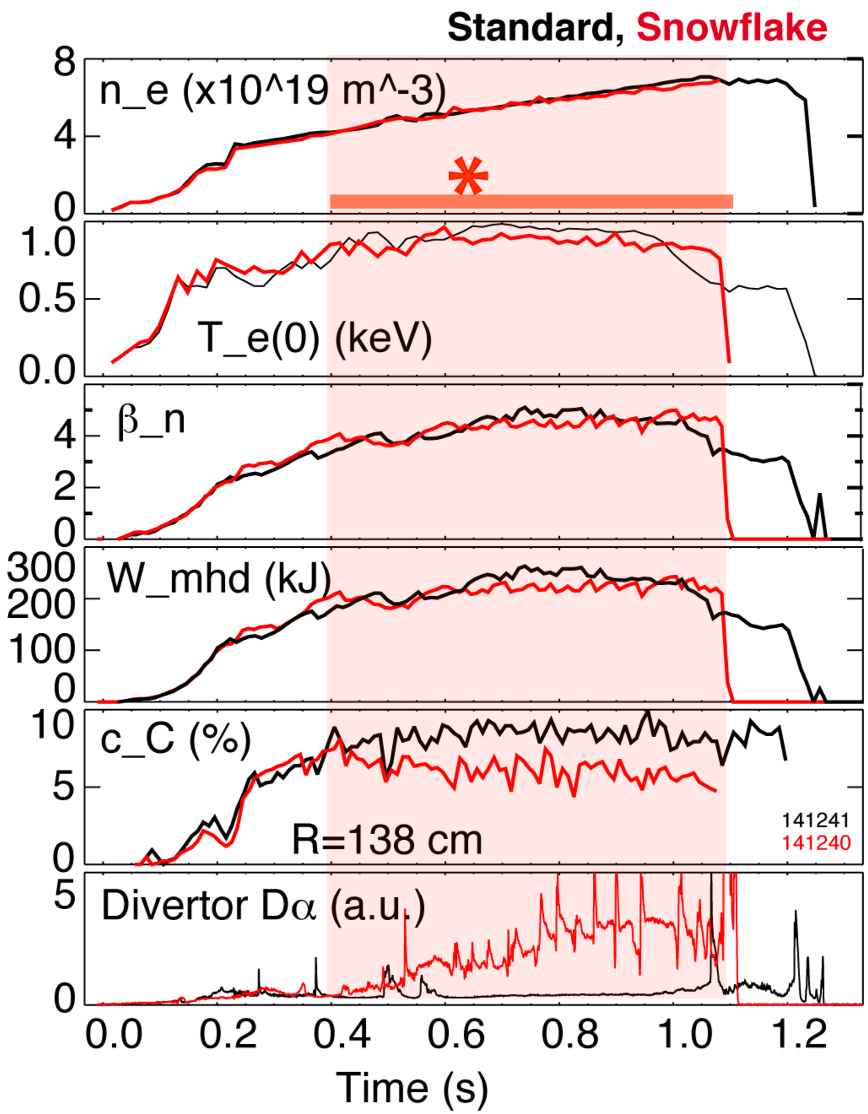
Snowflake divertor geometry takes advantage of second-order poloidal field null properties

- Second-order null
  - $B_p \sim 0$ and grad $B_p \sim 0$ (Cf. first-order null: $B_p \sim 0$)
- Obtained with existing divertor coils (min. 2)
- Exact snowflake topologically unstable



- Predicted geometry properties in snowflake divertor (cf. standard divertor)
  - Increased edge shear :ped. stability
  - Add'l null: H-mode power threshold, ion loss
  - Larger plasma wetted-area A_{wet} : reduce q_{div}
  - Four strike points : share $q_{//}$
  - Larger X-point connection length L_x : reduce $q_{//}$
  - Larger effective divertor volume V_{div} : incr. P_{rad} , P_{CX}

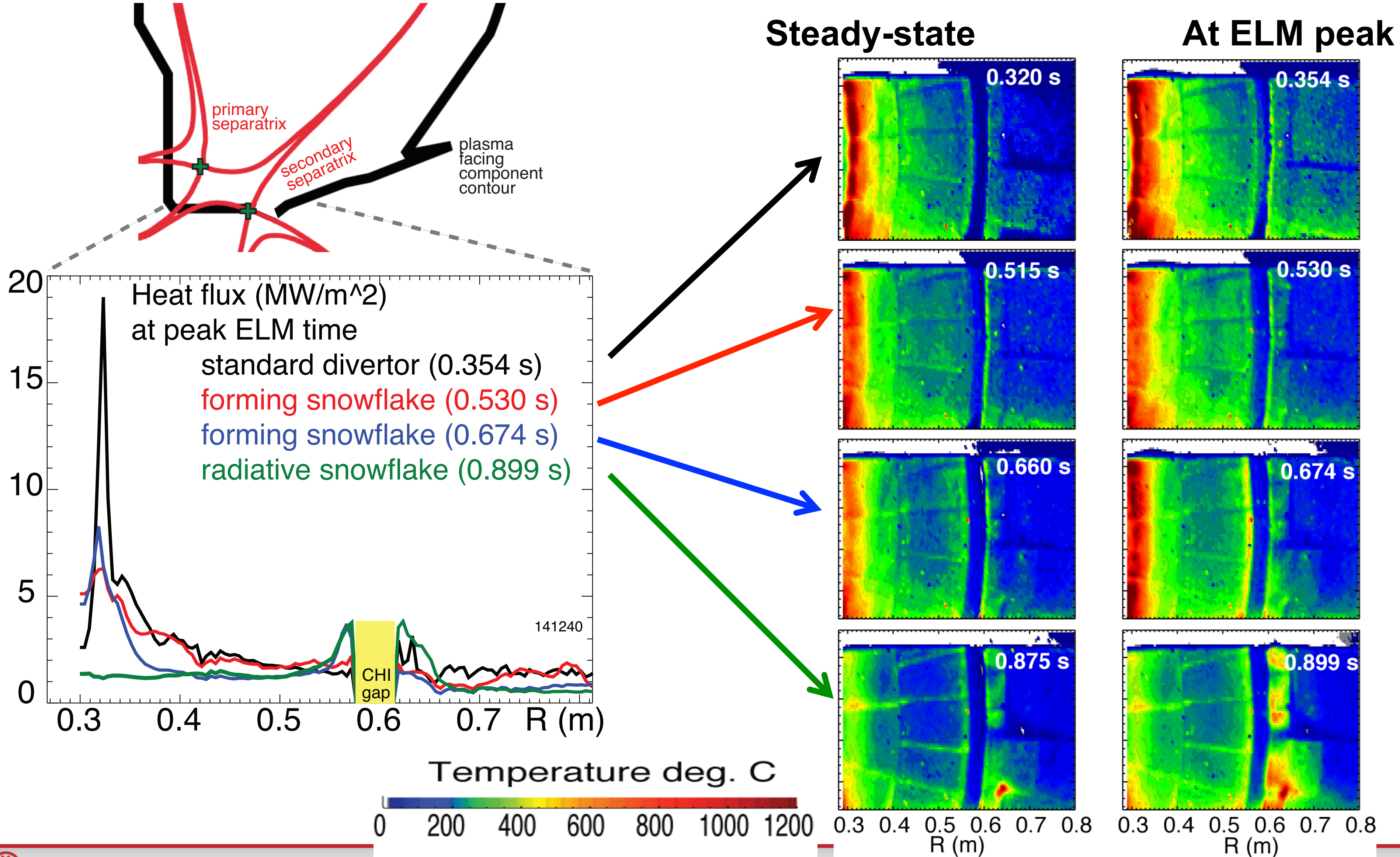
NSTX: good H-mode confinement properties and core impurity reduction obtained with snowflake divertor



NSTX

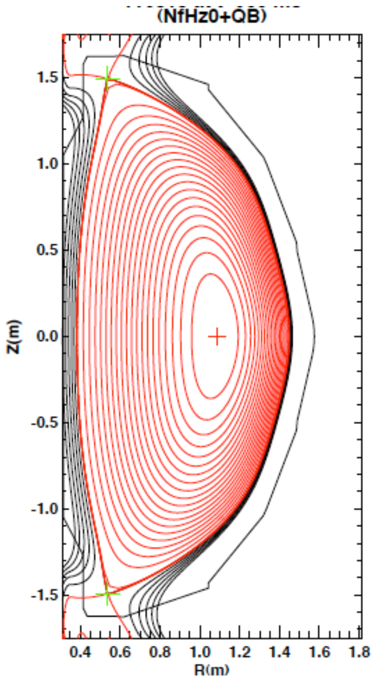
- 0.8 MA, 4 MW H-mode
- κ=2.1, δ=0.8
- Core T_e ~ 0.8-1 keV, T_i ~ 1 keV
- β_N ~ 4-5
- Plasma stored energy ~ 250 kJ
- H98(y,2) ~ 1 (from TRANSP)
- ELMs
  - Suppressed in standard divertor H-mode via lithium conditioning
  - Re-appeared in snowflake H-mode
- Core carbon reduction due to
  - Type I ELMs
  - Edge source reduction
    - Divertor sputtering rates reduced due to partial detachment

Impulsive heat loads due to Type I ELMs are mitigated in snowflake divertor

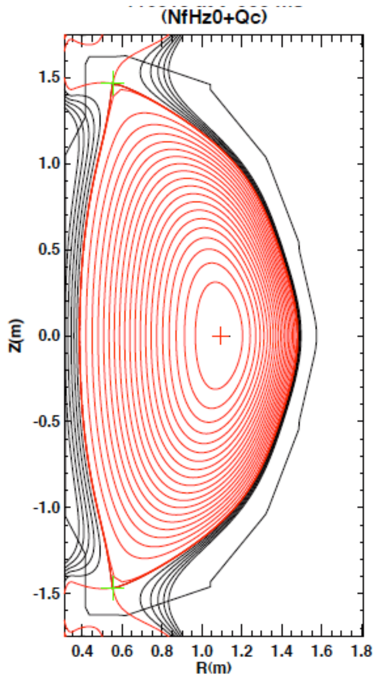


Snowflake divertor is a leading heat flux mitigation candidate for NSTX-U

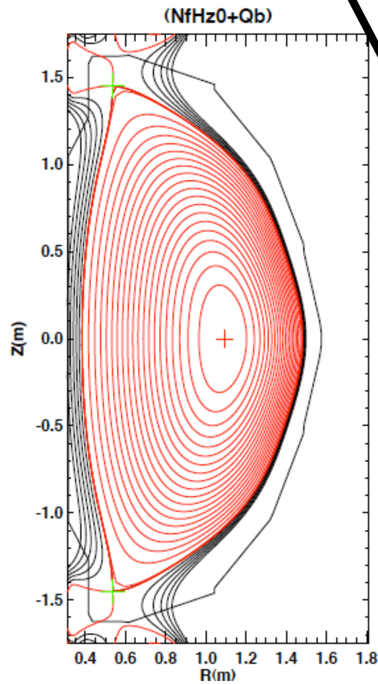
- Single and double-null radiative divertors and upper-lower snowflake configurations considered
  - Supported by NSTX-U divertor coils and compatible with coil current limits
  - ISOLVER modeling shows many possible equilibria
    - Impact of changing I_{OH} on snowflake minimal
    - Reduced divertor coil set can be used for snowflakes



NSTX-U double-null

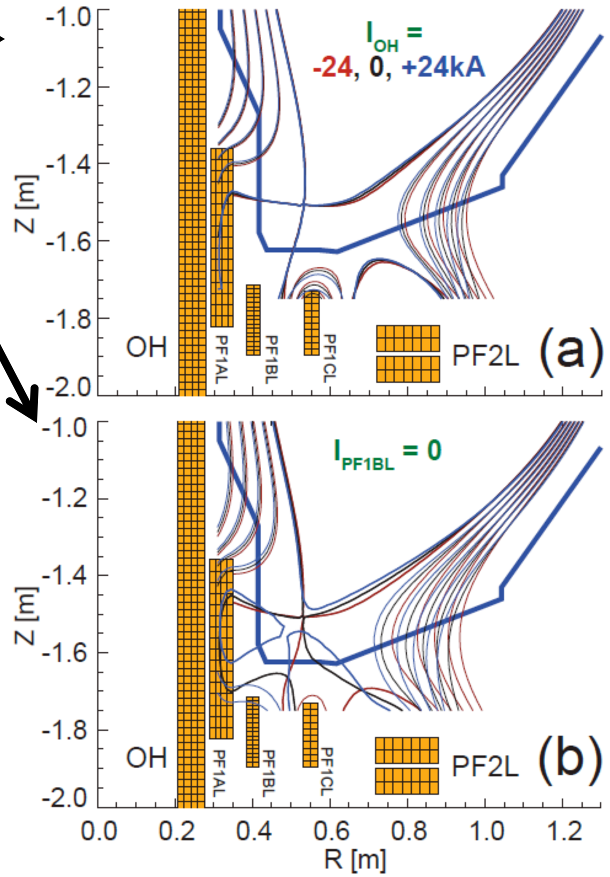


NSTX-U double-snowflake-plus



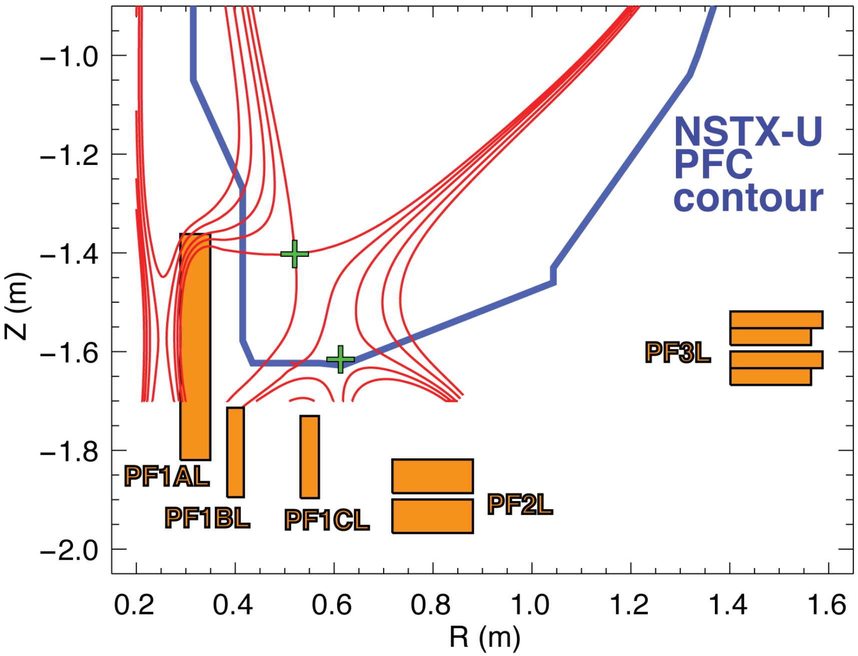
NSTX-U double-snowflake-minus

NSTX-U simulation



Four divertor coils should enable flexibility in boundary shaping and control in NSTX-U

- A variety of lower and both lower and upper divertor snowflake configurations are possible in NSTX-U with four coils per divertor
  - ISOLVER free-boundary Grad-Shafranov solver used
  - Four coils can be used to control up to four parameters (X-pts, OSP, etc)

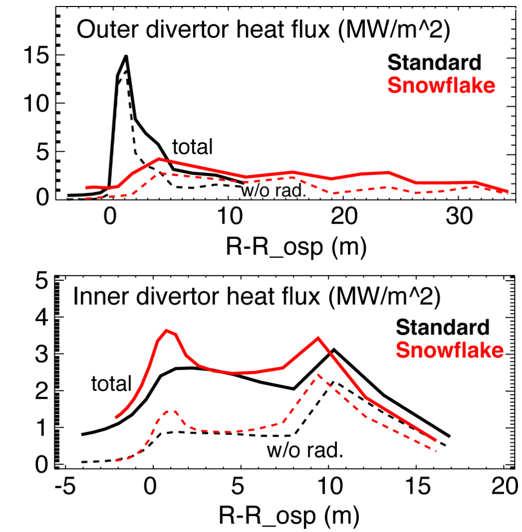


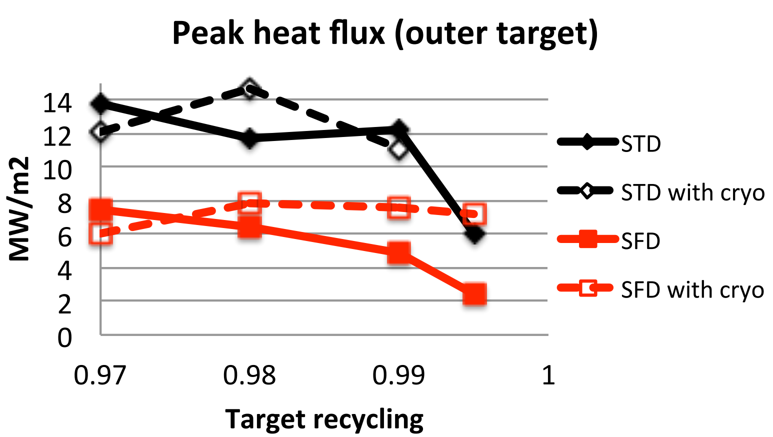
Midplane flux surface	0.0	1.5 mm	3.0 mm	6.0 mm	9.0 mm
L_{tot} (m)	38.3	20.4	13.9	9.9	8.3
L_X (m)	16.5	4.0	2.2	1.6	1.5
Angle (deg.)	1.6	0.8	0.99	3.0	3.9

- X 2-3 in plasma wetted surface area and connection length vs standard divertor

Simulations of snowflake divertor configuration inform heat flux mitigation scenarios in NSTX-U

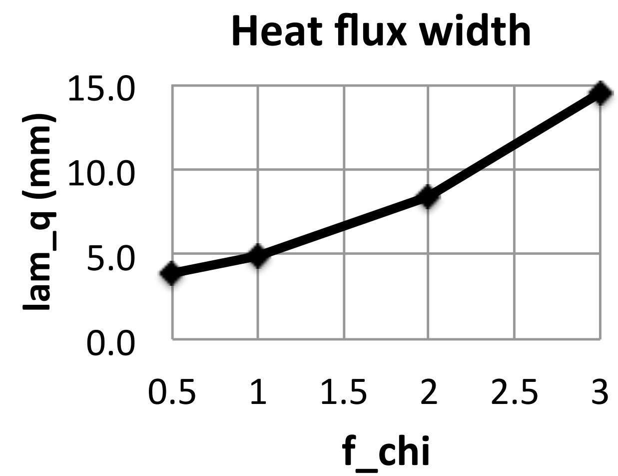
- ISOLVER modeling shows a variety of up-down symmetric snowflake (+/-) configurations possible
  - Impact of changing I_{OH} on snowflake minimal
  - Reduced divertor coil set can be used for snowflakes
- UEDGE simulations predict heat flux reduction with carbon by geometry and radiation
- Particle removal by cryopump results in reduced radiation in snowflake

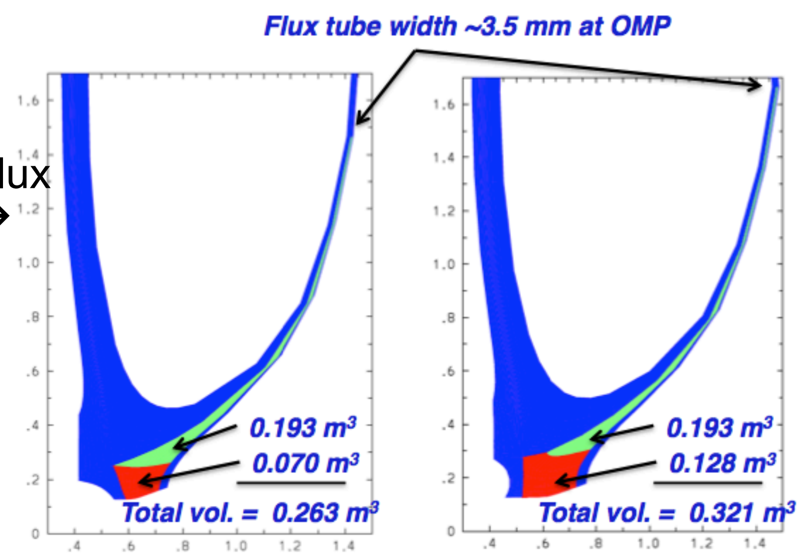




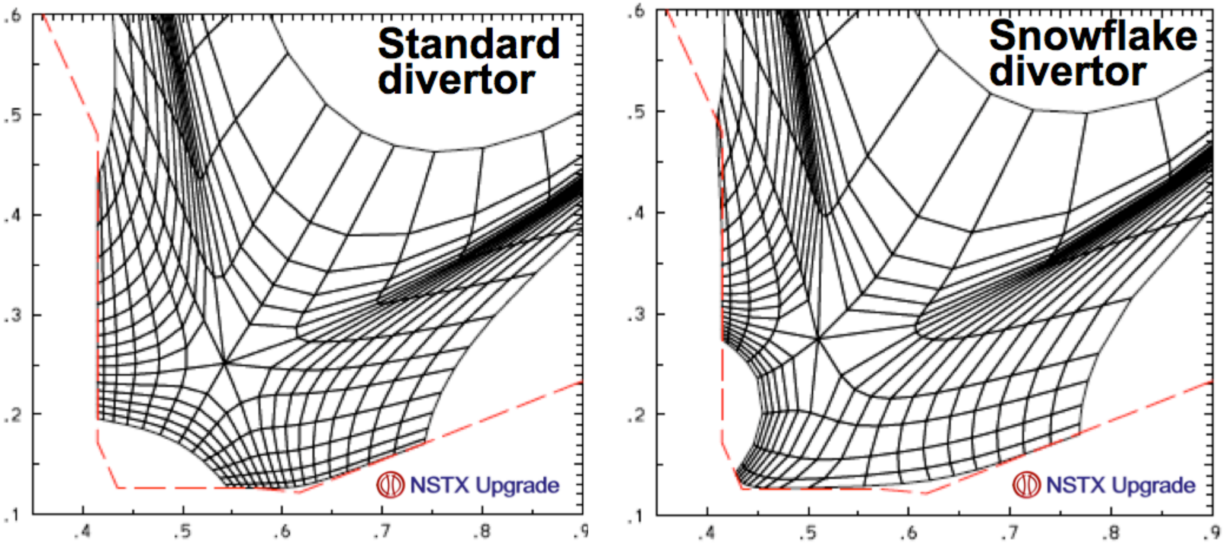
UEDGE settings

- Single null grid based on LRDFIT equilibria (129x129)
- Inertial neutral model is used with recycm=-.5
- Fixed fraction Argon is varied from 0.5 to 3.5%
- Fixed fraction Neon is varied from 0.5 to 6%
- $0.9 < \psi < 1.055$
- D_{perp} = .1 (in core) → 0.5 (in SOL) m^2/s
  - Cubic rise from core boundary to separatrix
- Thermal diffusivity $\chi_{i,e}$ = 1 (in core) → 3 (in SOL) m^2/s
  - Cubic rise from core boundary to separatrix
- Recycling = 0.99
- Power across ψ=0.9 surface P_{90} = 9 MW
- Zero flux BC for neutral D at core
- Psi=0.9 density value determined by fixing particle flux through core; based on 60 A for 4 MW NBI power → 180 A at P_{90}=9 MW
- 300 A centerstack puff at inner midplane.
- No drift effects
- Heat flux width analyzed for STD divertor only.
  - ~3 mm heat flux width expected; f_χ=1.0 (5 mm) is not unrealistic





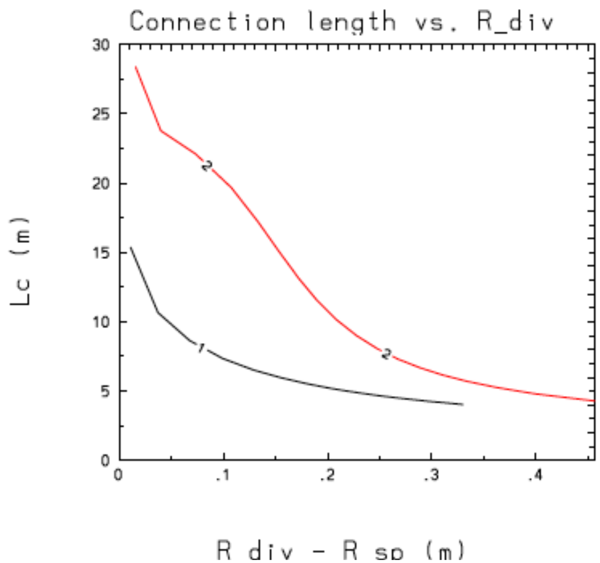
Projections with UEDGE edge multi-fluid model for NSTX-U are optimistic

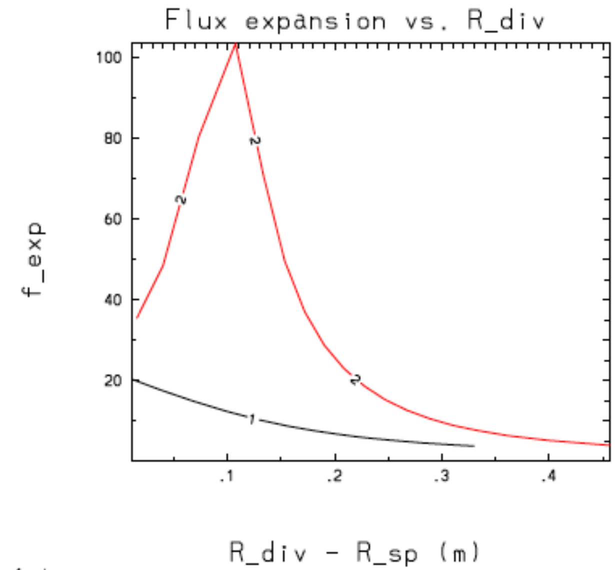


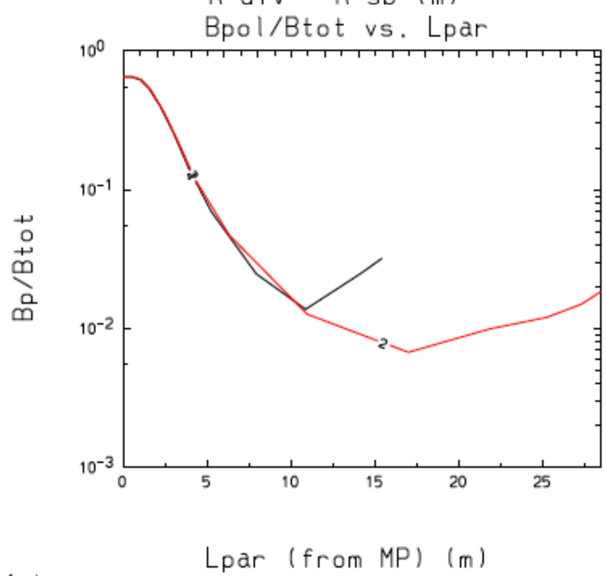
- Fluid (Braginskii) model for ions and electrons
- Fluid for neutrals
- Classical parallel transport, anomalous radial transport
- Core interface:
  - P_{SOL90} = 5; 7; 9 MW
- D = 0.1-0.5 m^2/s
- $\chi_{e,i}$ = 1-2 m^2/s
- R_{recy} = 0.99
- Carbon 5 %

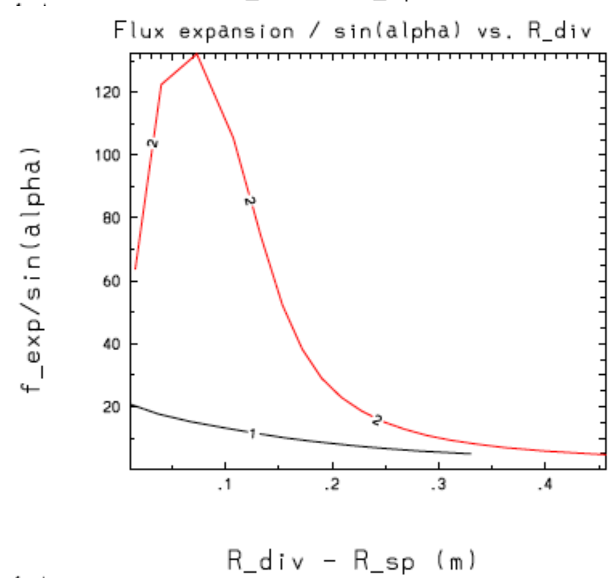
- Grids extend from psi=0.9 to psi=1.2
- STD grid covers 3.1 cm outside the separatrix at the outer MP
- SNF grid covers 3.4 cm outside the separatrix at the outer MP.

In modeled NSTX-U snowflake configuration magnetic geometry shows clear benefits (cf. standard divertor)





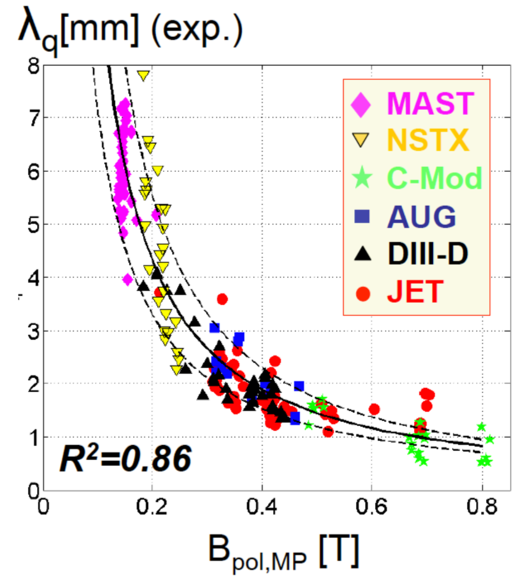


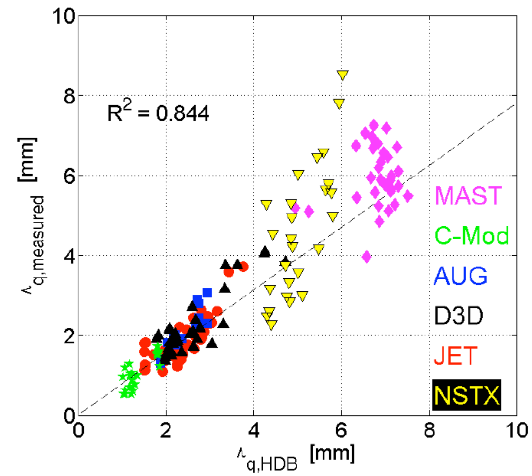


SOL width studies elucidate on heat flux scaling projections for NSTX-U, ST-FNSF and ITER

- Goal: compare SOL width scalings with models
- SOL width scaling
  - In NSTX: $\lambda_q^{mid} \sim I_p^{-1.6}$
    - For NSTX-U (2 MA): $\lambda_q^{mid} = 3\pm0.5$ mm
  - Multi-machine database (Eich IAEA FEC 2012):

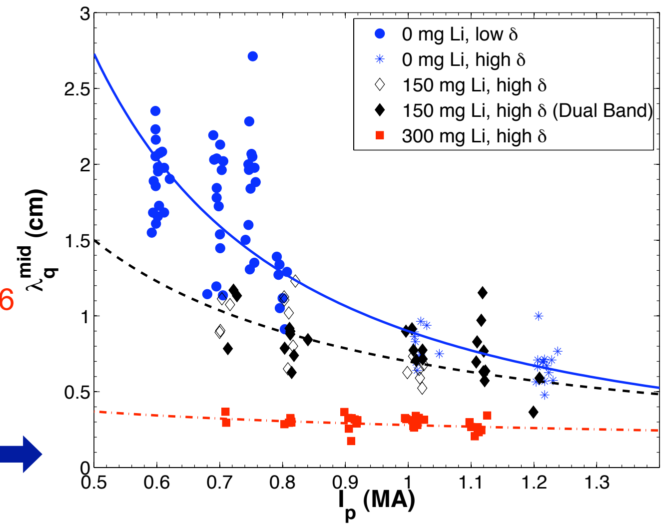
    λ_q^{mid} (mm) $(0.63+/-0.08)\text{x } B_{pol,MP}^{-1.19}$
    - For NSTX-U (B_p~0.55 T): $\lambda_q^{mid} \sim 1.3$ mm
  - Comparison with SOL models
    - Parallel transport: conductive/convective, cross-field : collisional / turbulent / drift
    - Goldston heuristic model: ∇B and curvature drift motion sets SOL width $\lambda_{SOL} \sim (2a/R)\,\rho_i$, Spitzer thermal conduction sets T_{sep}
      - For NSTX-U: $\lambda_q^{mid} \sim 6$ mm
- *Diagnostics: IR cameras, MPTS, Langmuir probes*
  - *Divertor Thomson scattering (incremental) desirable*



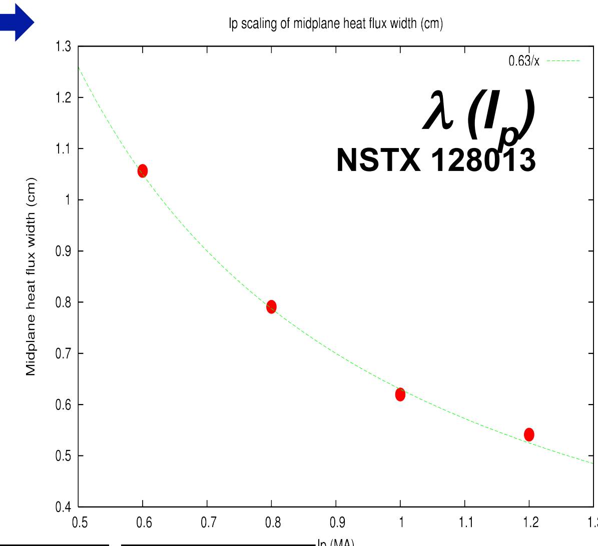


SOL width and divertor heat flux studies in NSTX inform NSTX-U and ITER divertor projections

- Completed FY 2010 DOE JRT
  - λ_q^{mid} characterized in experiment
    - independent of P_{SOL} and B_t
    - constant with increasing f_{exp}
    - contracts with increasing *drsep*; and I_p: $\lambda_q^{mid} \sim I_p^{-1.6}$ (DIII-D: $\lambda_q^{mid} \sim I_p^{-1.2}$; Alcator C-Mod: $\lambda_q^{mid} \sim I_p^{-1.0}$)
    - λ_q contracts with increasing lithium deposition



  - and modeled
    - XGC0 modeling reproduced I_p dependence (NSTX: $\lambda_q^{mid} \sim I_p^{-1.0}$; DIII-D: $\sim I_p^{-0.8}$; C-Mod: $\sim I_p^{-0.3}$)
    - SOLT modeling: weak λ_q scaling with P_{in}; I_p scaling is weaker than observed

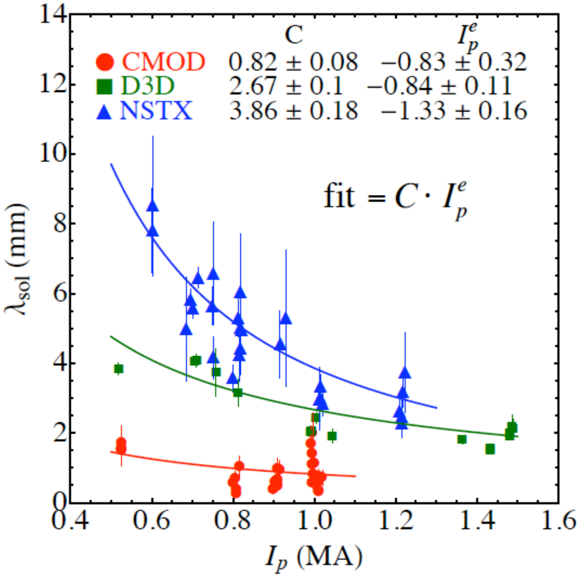


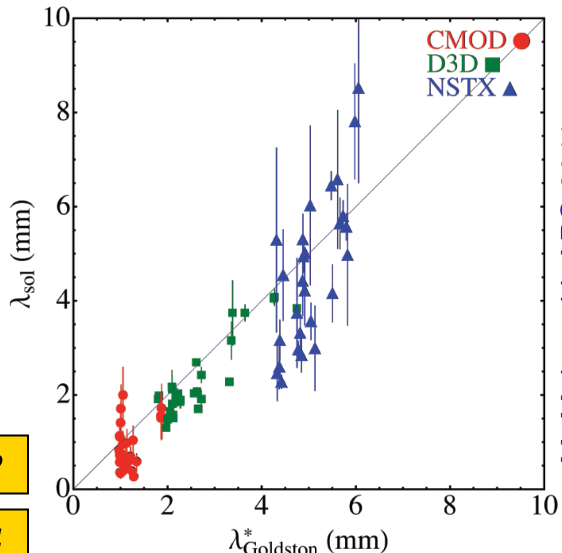
- Further studies
  - Connect λ_q^{mid} to pedestal width and edge turbulence
  - λ_q^{mid} data analysis for ITER / future STs
    - For NSTX-U parameters, λ_q^{mid} = 3±0.5 mm

PAC27-10 **PAC27-11**

SOL width studies in NSTX elucidate on divertor projections for NSTX-U, ST-FNSF and ITER

- JRT 2010 on heat transport
  - λ_q^{mid} contracts with increasing I_p: $\lambda_q^{mid} \sim I_p^{-1.6}$
- Comparison with SOL models
  - Parallel transport: conductive/convective, cross-field : collisional / turbulent / drift
  - XGC0 reproduced I_p dependence $\lambda_q^{mid} \sim I_p^{-1.0}$
  - SOLT: I_p scaling is weaker than observed
    - P_{SOL}, collisionality, L_{II}/R set cross-field transport and turbulence structure that affect λ_q
  - Goldston drift-based model of SOL flows
    - Attached H-mode regimes
    - ∇B and curvature drift motion sets SOL width $\lambda_{SOL} \sim (2a/R)\ \rho_i$, Spitzer thermal conduction sets T_{sep}
  - Exploring mechanisms setting steep pressure gradient region and connection to SOL width
- Projections to NSTX-U
  - λ_q^{mid} = 3±0.5 mm
  - As $q_{peak} \sim I_p$ and $q_{peak} \sim P_{SOL}$, q_{peak} ~ 20-30 MW/m^2





M. Makowski, APS 2011

PAC29-12

PAC29-14