NSTX-U

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Overview of Results and Analysis from the National Spherical Torus Experiment

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X Science LLC

S. A. Sabbagh

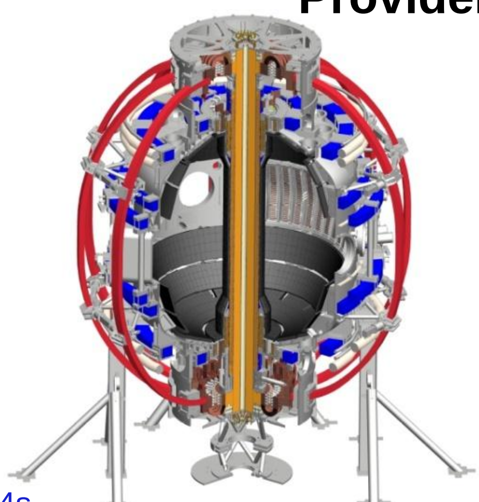
Columbia University

for the NSTX-U Research Team

54th Meeting of the APS Division of Plasma Physics

October 30th, 2012

Providence, Rhode Island



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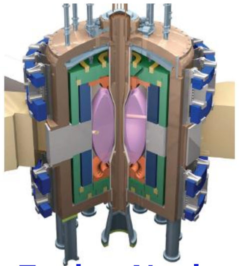
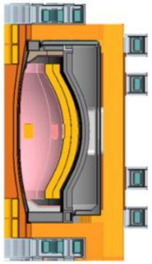
V1.4s

NSTX research targets predictive physics understanding needed for fusion energy development facilities

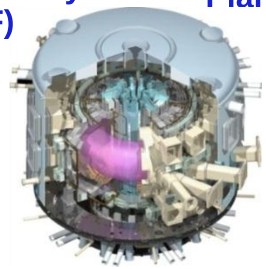
- Enable devices: ST-FNSF, ST-Pilot/DEMO, ITER
  - Leveraging unique ST plasmas provides new understanding for tokamaks, challenges theory



Fusion Nuclear Science Facility (FNSF)



ST Pilot Plant

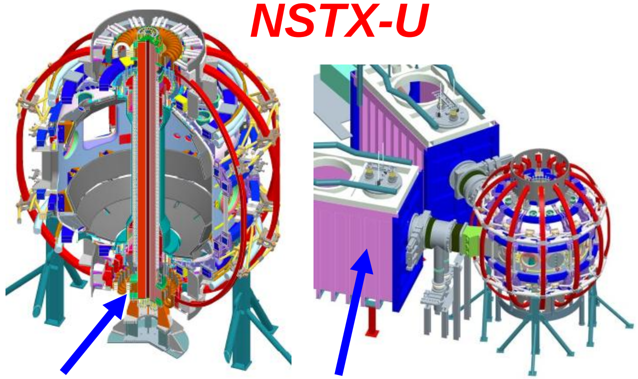


ITER

Outline

- Develop key physics understanding to be tested in unexplored, hotter ST plasmas
  - Study high beta plasma transport and stability at reduced collisionality, for extended pulse
  - Prototype methods to mitigate very high heat/particle flux
  - Move toward fully non-inductive operation

NSTX-U



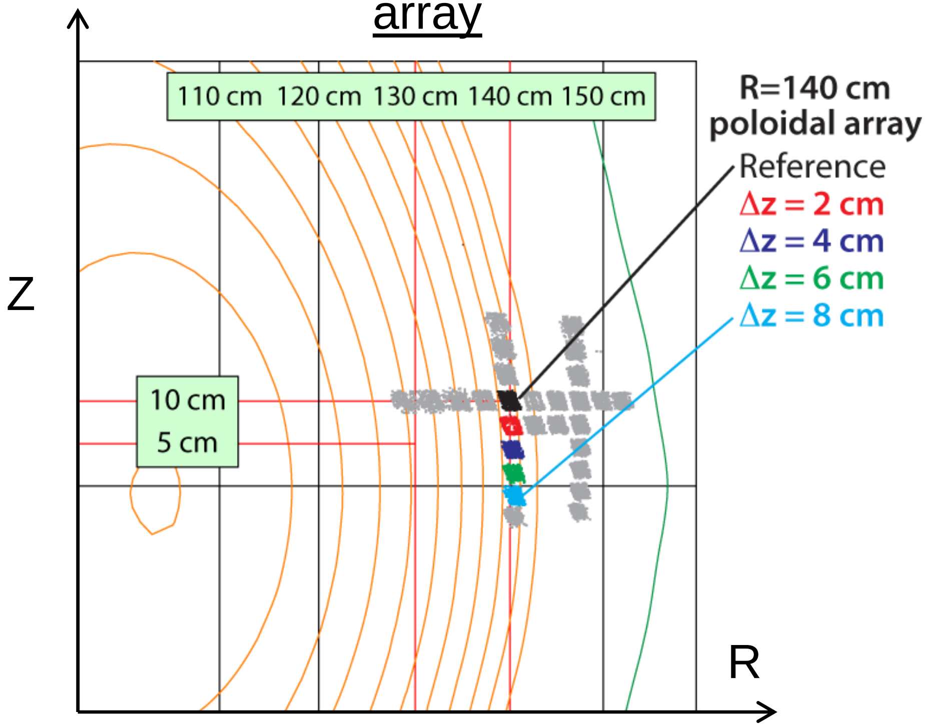
New center-stack

2nd neutral beam

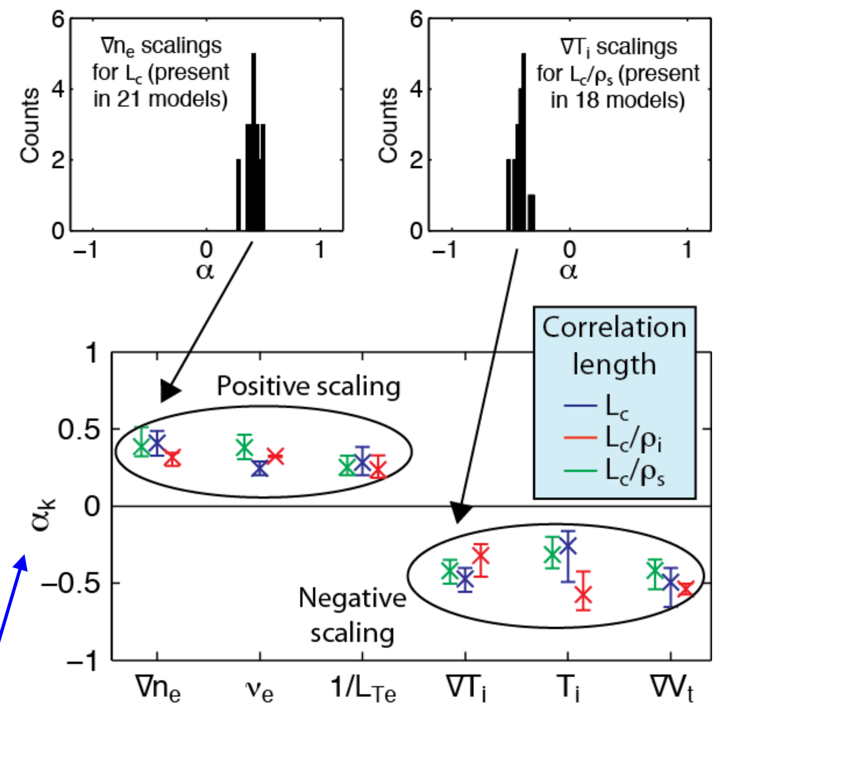
B_T	0.5 → 1 T	P_{NBI}	6 → 12 MW
I_p	1 → 2 MA	pulse	1 → 5 s

BES measured low-*k* turbulence in ELM-free H-mode pedestal steep gradient region is most consistent with TEMs

Beam emission spectroscopy (BES) array



Poloidal Correlation Length vs. Parameters

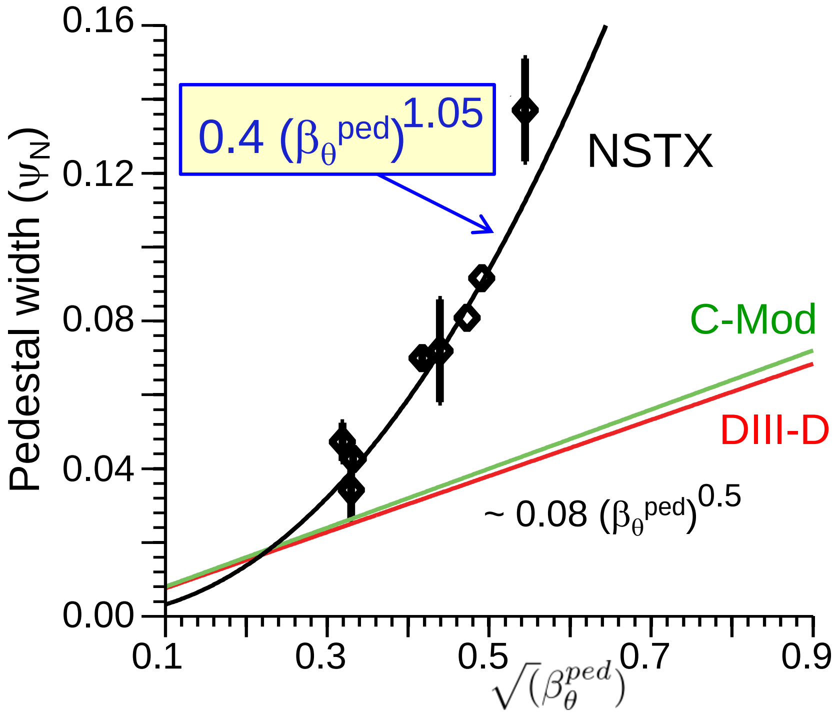


- Measurements during MHD quiet periods, in steep gradient region
  - $k_\theta \approx 0.2\text{-}0.4\ \mathrm{cm}^{-1}$ and $k_\theta \rho_i \approx 0.2$
- Large poloidal correlation lengths
  - $L_c \approx 10\ \rho_i$
- Multivariate linear scaling coefficients α_k
  - Fitting results are robust
  - Scalings are most consistent with Trapped Electron Modes

Smith YI3.04 (Invited – Friday)

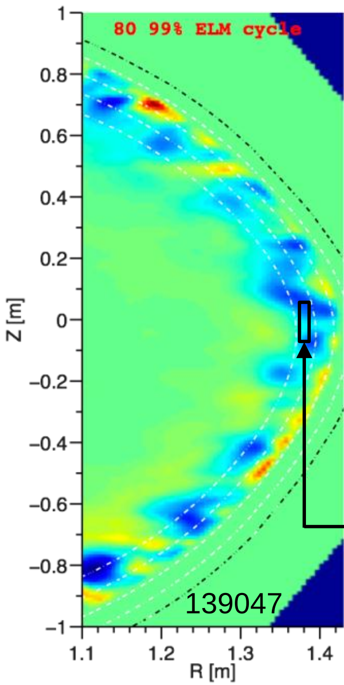
Pedestal width scaling differs from other devices; turbulence correlation measurements consistent with theory

Pedestal width scaling



Turbulence correlation lengths

(During inter-ELM period, at pedestal top)



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

80% - 99% ELM cycle

- Pedestal width scaling β_θ^{α} applies to multiple machines
- In NSTX, observed ped. width is larger
  - Data indicates stronger scaling: β_θ vs. $\beta_\theta^{0.5}$
  - Initial ballooning critical pedestal analysis indicates scaling ~ $\beta_\theta^{0.8}$ for NSTX

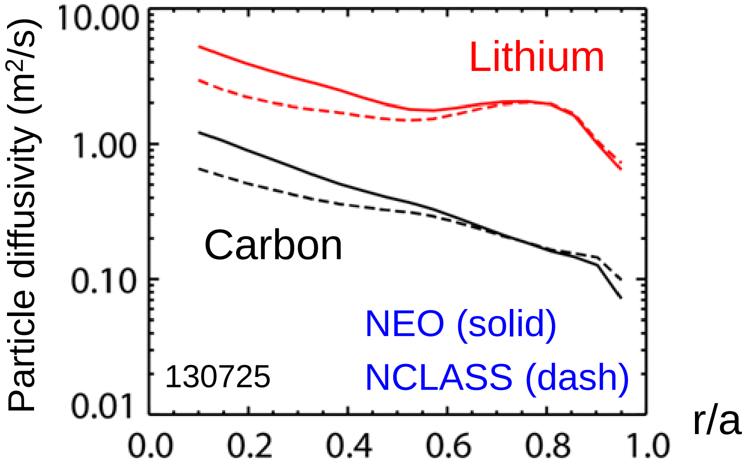
P. Snyder, IAEA 2012

- Measured correlation lengths at pedestal top are consistent with theory
  - spatial structure exhibits ion-scale microturbulence ($k_\perp \rho_i$ ~ 0.2 - 0.7)
  - Compatible with ITG modes and/or KBM

Diallo PP8.010 (We)

Investigations underway to understand positive aspects of lithium wall coating; plasmas reach kink/peeling limit

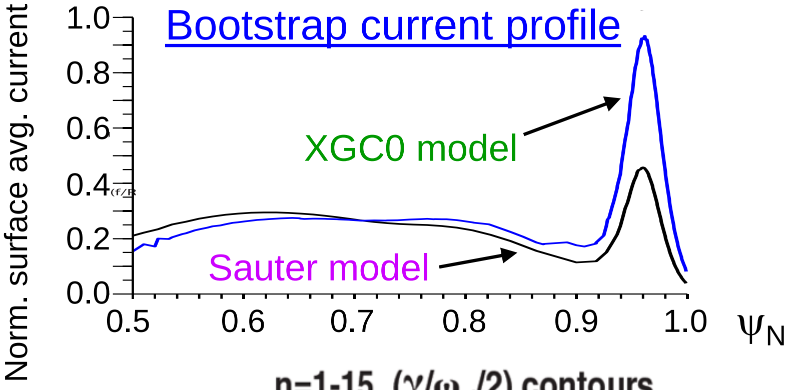
- Energy confinement improves, ELMs stabilize - with no core Li accumulation
  - Partially due to high neoclassical particle diffusivity

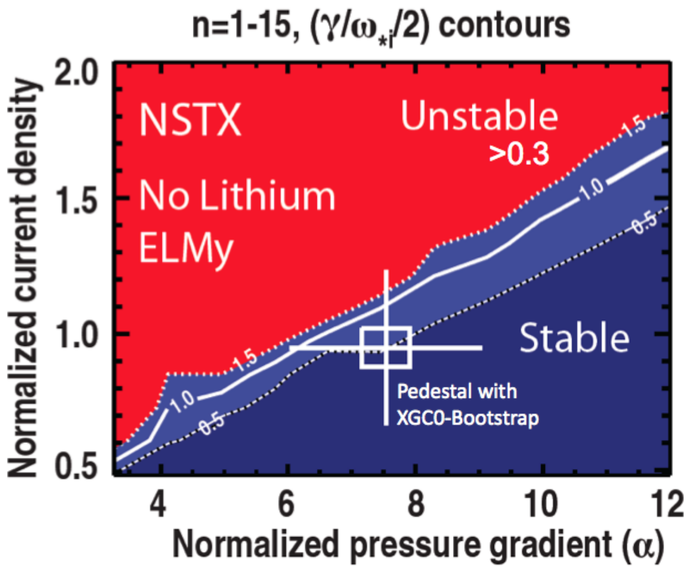


Scotti GI2.05 (Invited – Tu 11:30 AM)

- Surface analysis experiments show oxide coverage of Li plasma facing components (PFCs) expected in 20 – 200s
  - Short reaction times motivate flowing Li PFCs
  - Oxygen plays important role in D retention

Jaworski PP8.032 (We) | **Capece GO6.08 (Tu)**

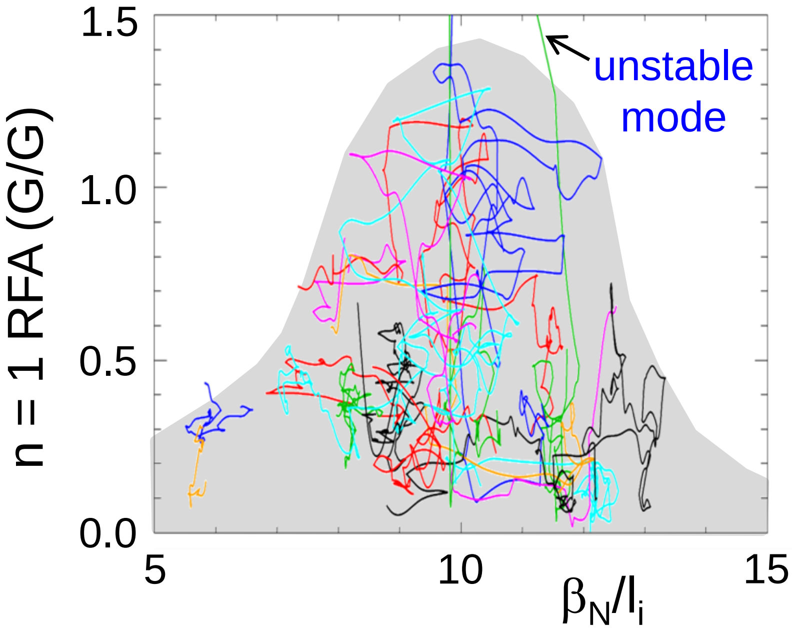




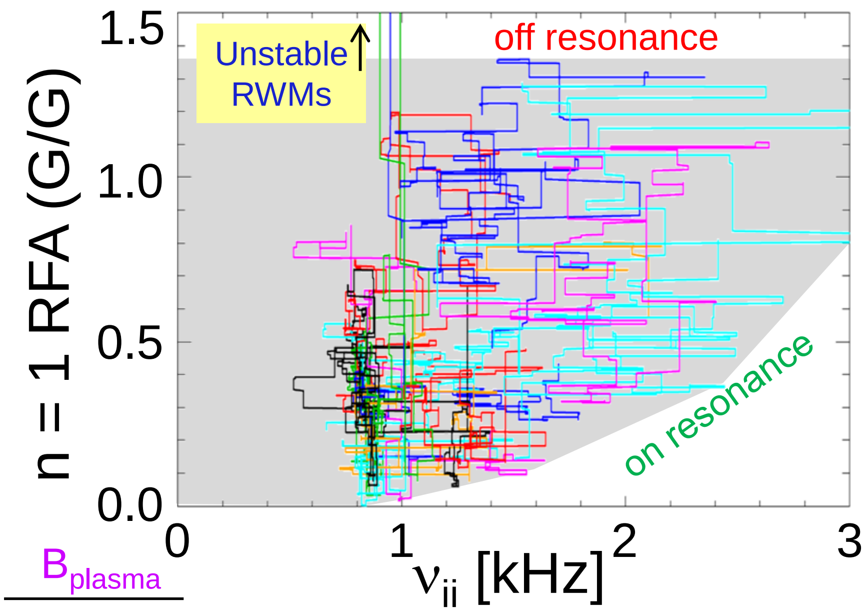
- New bootstrap current calculation (XGC0 code) agrees with profile reaching kink/peeling limit before ELM

Chang PO7.07 (We) | **Maingi PP8.007 (We)**

Experiments measuring global stability further support kinetic RWM stability theory, provide guidance for NSTX-U



(trajectories of 20 experimental plasmas)



$$\text{RFA} = \frac{B_{plasma}}{B_{applied}}$$

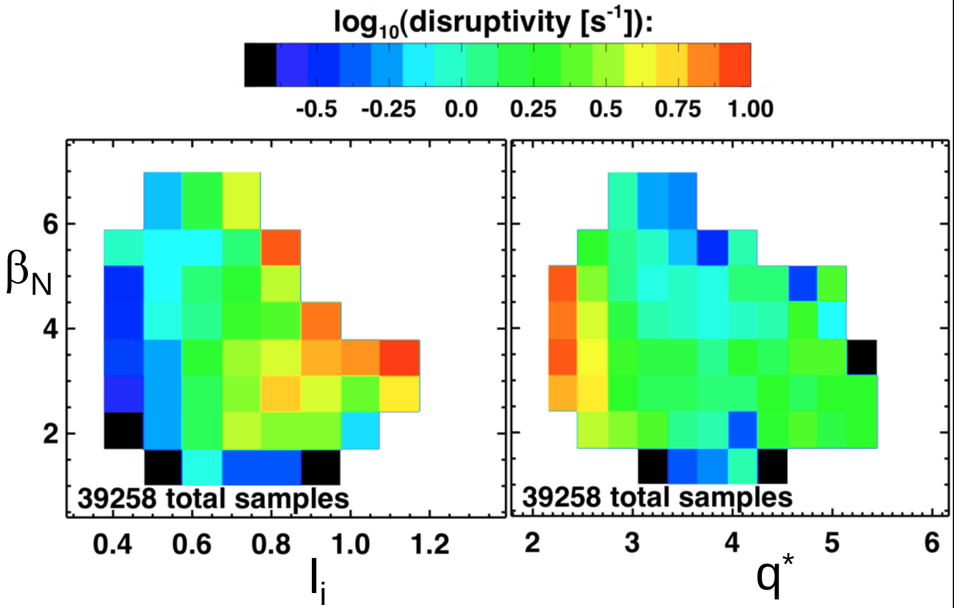
- Mode stability directly measured in experiments using MHD spectroscopy
  - Stability decreases up to $\beta_N/l_i = 10$, increases at higher β_N/l_i
  - Consistent with kinetic resonance stabilization
- Two competing effects at lower ν
  - Collisional dissipation reduced
  - Stabilizing resonant kinetic effects enhanced (contrasts early theory)
- Expectations at lower ν
  - More stabilization near ω_φ resonances; almost no effect off-resonance

Berkery GO6.09 (Tu)

Bialek PP8.013 (We)

Disruptivity studies and warning analysis of NSTX database are being conducted for disruption avoidance in NSTX-U

Disruptivity

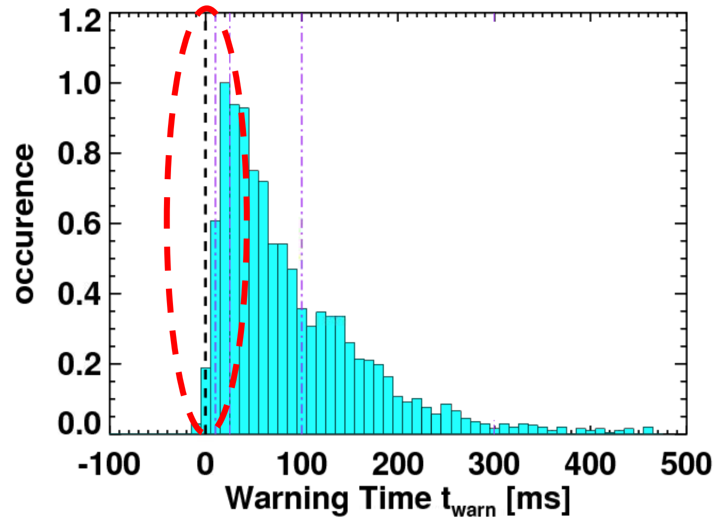


All discharges since 2006

- Physics results
  - Low disruptivity at relatively high $\beta_N \sim 6$; $\beta_N / \beta_N^{\text{no-wall}(n=1)} \sim 1.3\text{-}1.5$
    - Consistent with specific disruption control experiments, RFA analysis
  - Strong disruptivity increase for $q^* < 2.5$, and at very low rotation

Warning Algorithms

- Disruption warning algorithm shows high probability of success
  - Based on combinations of single threshold based tests

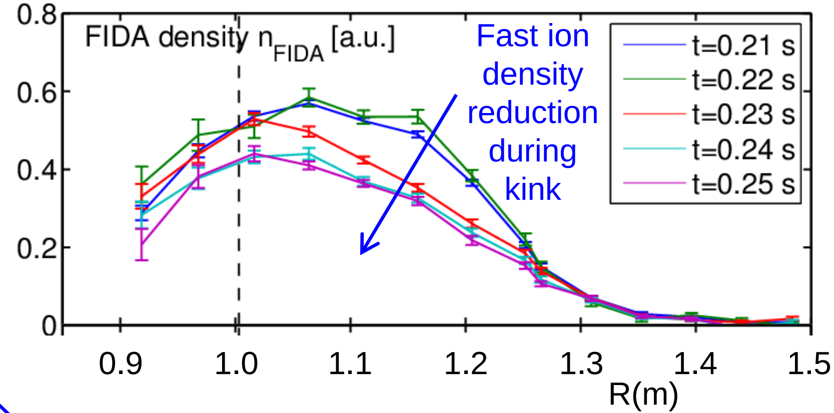


- Results
  - ~ 98% disruptions flagged with at least 10ms warning, ~ 4% false positives
  - False positive count dominated by near-disruptive events

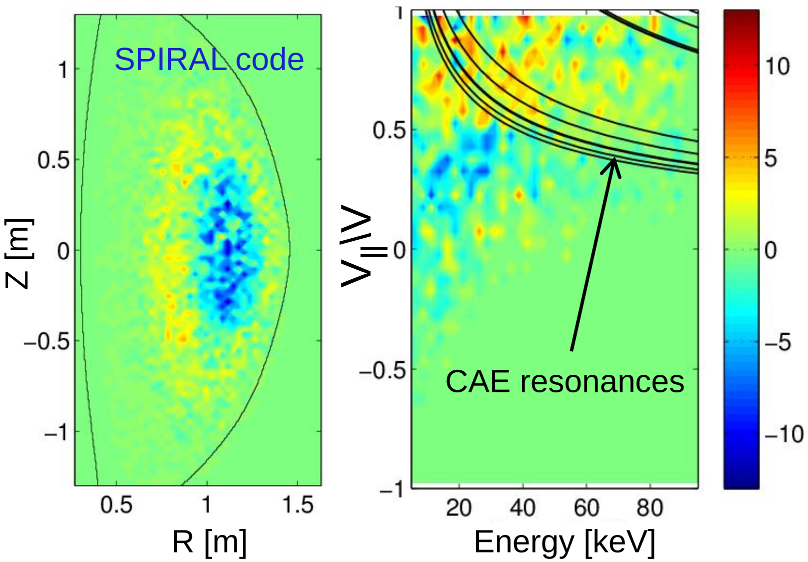
S.P. Gerhardt

Fast ion redistribution associated with low frequency MHD measured by fast ion D_α (FIDA) diagnostic

- Caused by n = 1 global kink instabilities
- Redistribution can affect stability of *AE, RWMs, other MHD
- Full-orbit code (SPIRAL) shows redistribution in real and velocity space
  - Radial redistribution from core plasma
  - Particles shift towards $V_{||}/V = 1$



Change in distribution due to kink mode

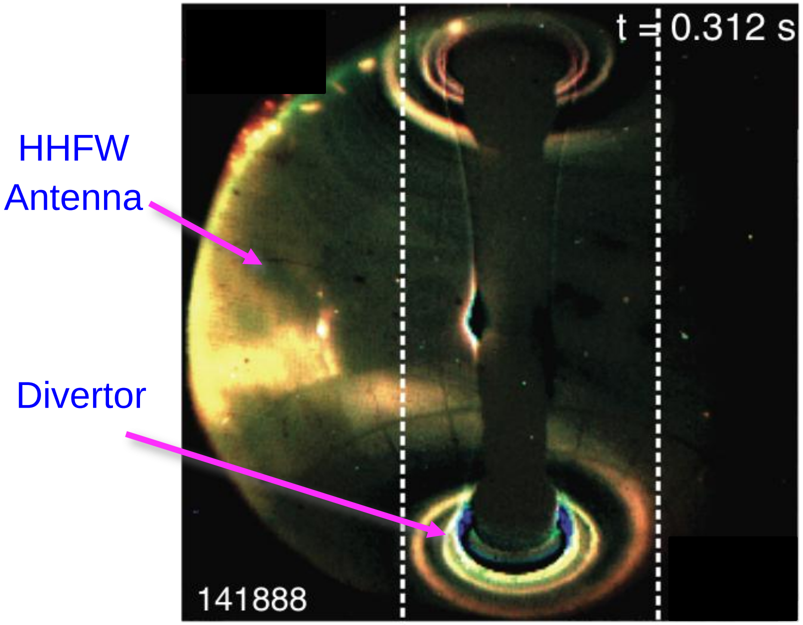


- Core localized CAE/GAEs measured in H-mode plasmas **Crocker GO6.03 (Tu)**
- CAE/GAE-simulated core electron thermal transport matches experiment **Tritz GO6.04 (Tu)**
- Simulations of NBI-driven CAEs show coupling to KAWs **Belova PP8.022 (We)**

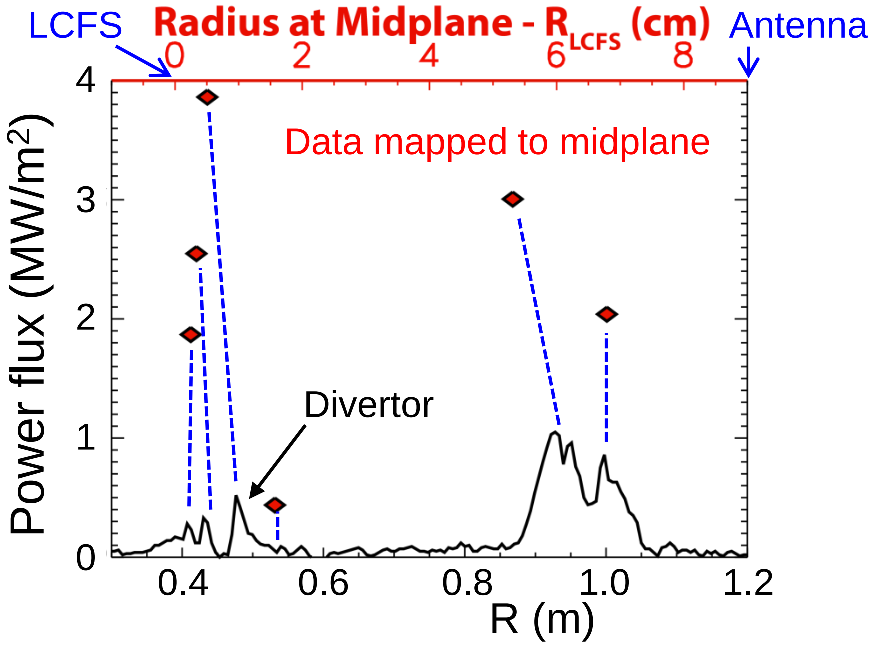
Bortolon JI2.02 (Invited – Tuesday PM)

Significant HHFW power deposited in the SOL in front of the antenna flows to divertor region

Visible camera image of edge RF power flow to divertor



RF power loss profile (divertor, and mapped to midplane)



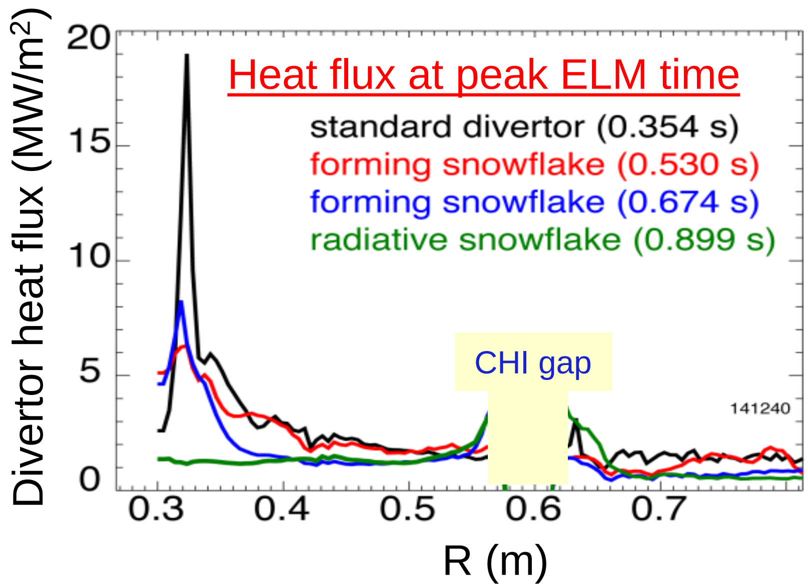
- RF power couples to field lines across entire scrape-off layer (SOL) width, not just to field lines connected to antenna components
  - Midplane mapping shows strong losses close to antenna and separatrix
- Shows importance of quantitatively understanding RF power coupling to the SOL for prediction to future devices

R. Perkins, et al., PRL **109** (2012) 045001

Perkins GO6.012 (Tu)

Radiative snowflake divertor greatly reduces heat flux during ELMs; toroidal asymmetry of 2D heat flux studied

Snowflake divertor in NSTX

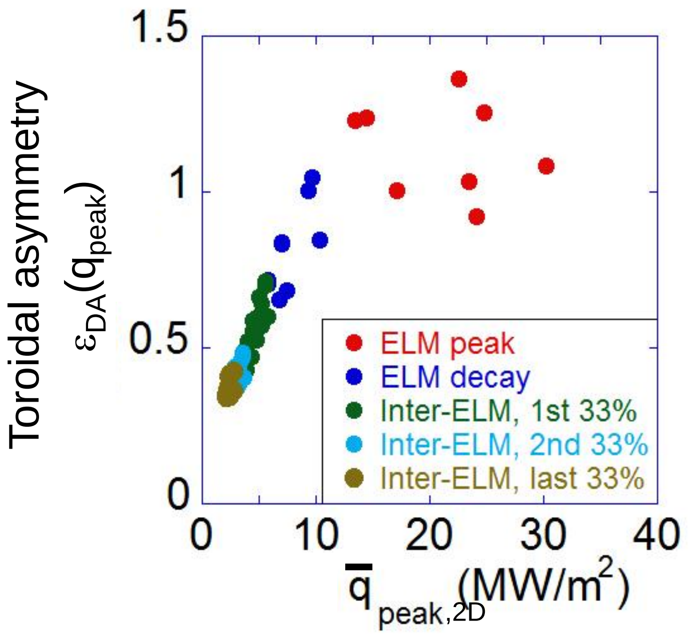


- Divertor heat flux significantly reduced both during and between ELMs
  - during ELMs: 19 to ~ 1.5 MW/m^2
  - steady-state: 5-7 to ~ 1 MW/m^2
- Achieved by a synergistic combination of detachment + radiative snowflake

Soukhanovskii PP8.027 (We)

Meier PP8.028 (We)

Toroidal asymmetry of 2D heat flux



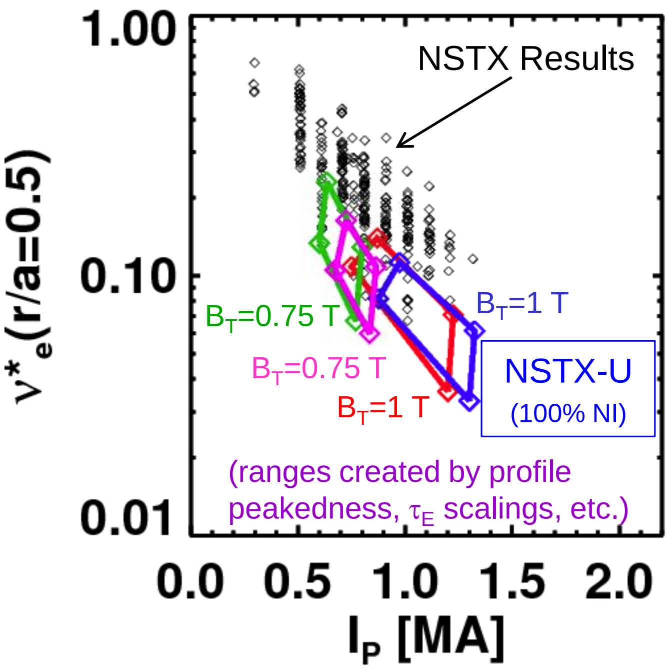
$$\varepsilon_{DA}(q_{peak}) = \sigma_{qpeak} / \bar{q}_{peak,2D}$$

- 2D fast IR camera measurement (6.3kHz)
- Toroidal asymmetry becomes largest at the peak heat flux for usual Type-I ELMs

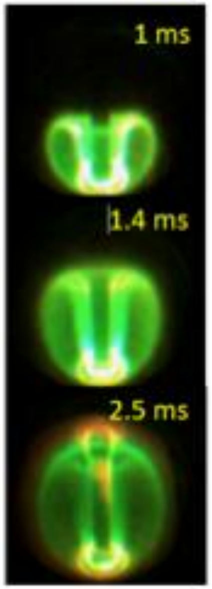
Ahn GO6.06 (Tu)

100% non-inductive scenarios projected over wide range of NSTX-U operation; coaxial helicity injection (CHI) scales well

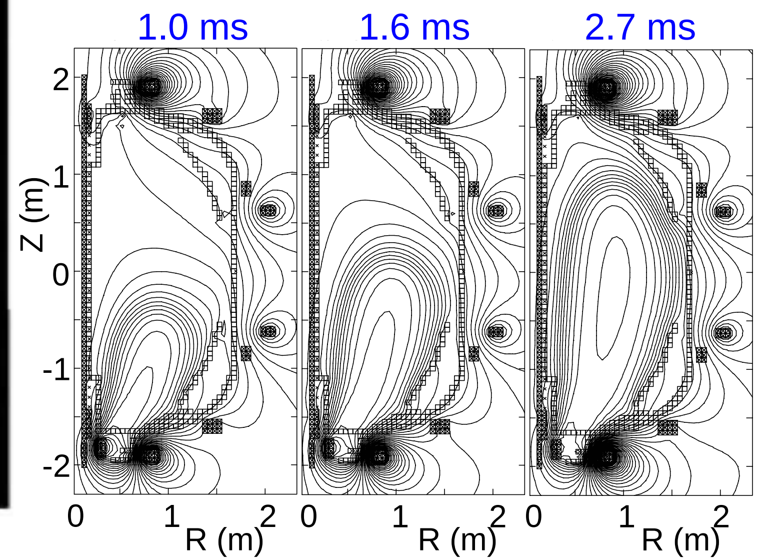
NSTX-U projected scenarios



- In NSTX
  - Sustained non-inductive fraction of 65% with NBI at I_P = 0.7 MA
  - 70 - 100% non-inductive reached using HHFW current drive (I_P = 0.3 MA)



TSC simulation of CHI startup



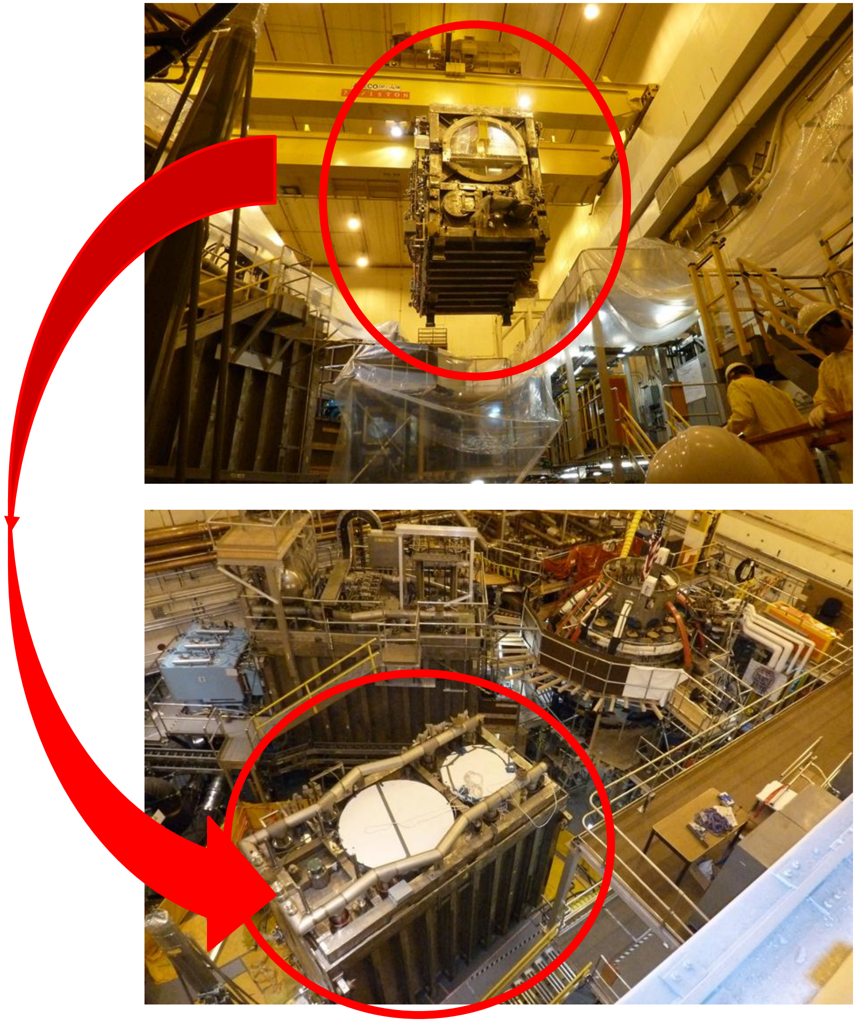
- In NSTX, I_p ramp to 1 MA requires 35% less inductive flux when CHI is used
  - Plasmas with favorable high κ, low l_i, n_e
- TSC modeling predicts a doubling of closed flux current > 400kA in NSTX-U
  - Suitable for hand-off to NBI heating/current drive

Ono PP8.06 (We)

S. Gerhardt, et al., Nucl. Fusion **52** (2012) 083020

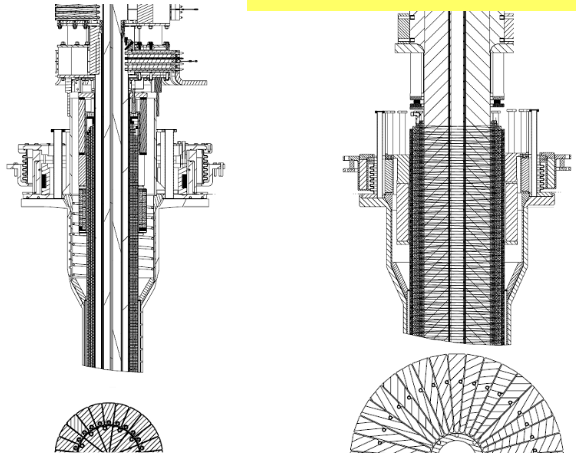
Raman GO6.011 (Tu)

Rapid Progress is Being Made on NSTX Upgrade



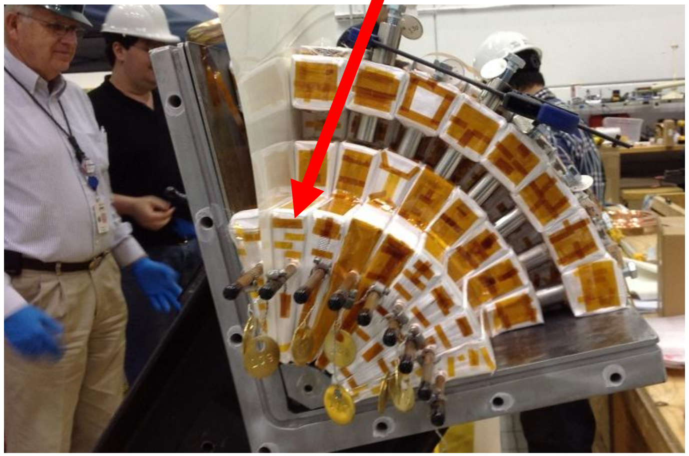
Old center stack

NEW Center Stack



TF OD = 20cm

TF OD = 40cm



- 2nd neutral beam moved into place
- TF quadrant assembled

(first plasma anticipated Summer 2014)

Ono PP8.06 (We)

NSTX Presentations at the 54th APS DPP Meeting

Invited / Tutorial Talks

Tuesday

- Modifications of impurity transport and divertor sources with lithium wall conditioning in NSTX — **Scotti** — **GI2.005** (11:30 AM – 12:00 PM)
- Interplay between coexisting MHD instabilities mediated by energetic ions in NSTX H-mode plasmas — **Bortolon** — **JI2.002** (2:30 PM – 3:00 PM)

Thursday

- Physics of tokamak plasma start-up — **Mueller** — **UT3.001** (2:00 PM – 3:00 PM)

Friday

- Assessing low wavenumber pedestal turbulence in NSTX with measurements and simulations — **Smith** — **YI3.004** (11:00 AM – 11:30 AM)

Contributed Talks

Tuesday

NSTX Overview	**Sabbagh**	**GO6.001**
Ohmic H-mode intrinsic rotation	**J-K. Park**	**GO6.002**
CAE/GAE structure and ID	**Crocker**	**GO6.003**
CAE/GAE-induced transport	**Tritz**	**GO6.004**
Divertor heat asymmetry	**Ahn**	**GO6.006**
Impurity effects on lithium wall	**Capece**	**GO6.008**
RWM control / physics	**Berkery**	**GO6.009**
Co-axial helicity injection	**Raman**	**GO6.011**
RF power flow in SOL	**Perkins**	**GO6.012**
2D ELM precursor studies	**Sechrest**	**GO6.013**

Wednesday

Bootstrap current model	**Chang**	**PO7.007**

Poster Session

Session PP8: Wednesday Afternoon
(Room: Hall BC)