NSTX-U

Supported by U.S. DEPARTMENT OF ENERGY Office of Science

NSTX-U Five Year Plan Contributions to ITER

S.M. Kaye

Deputy Program Director, NSTX-U

NSTX-U Five Year Plan Review
PPPL – B318
May 21-23, 2013

Coll of Wm & Mary
Columbia U
CompX
General Atomics
FIU
INL
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Old Dominion
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U Colorado
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U Tulsa
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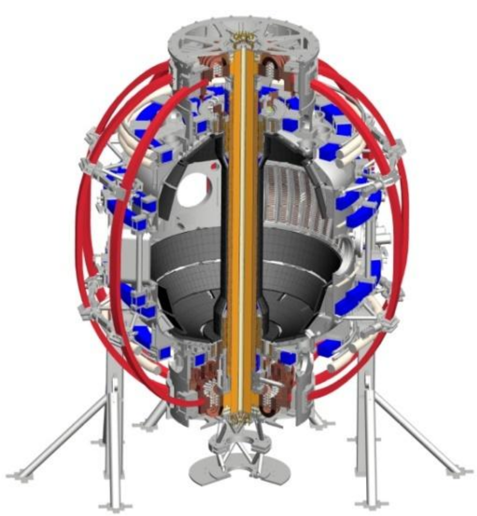
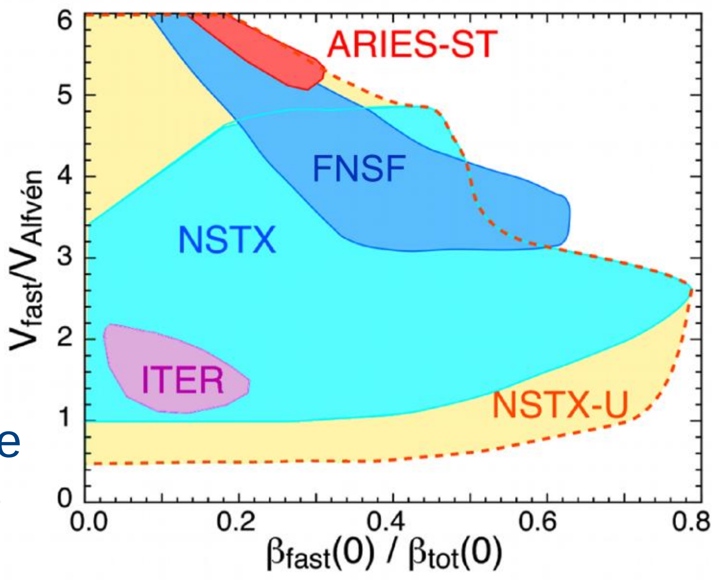
X Science LLC



Culham Sci Ctr
York U
Chubu U
Fukui U
Hiroshima U
Hyogo U
Kyoto U
Kyushu U
Kyushu Tokai U
NIFS
Niigata U
U Tokyo
JAEA
Inst for Nucl Res, Kiev
Ioffe Inst
TRINITI
Chonbuk Natl U
NFRI
KAIST
POSTECH
Seoul Natl U
ASIPP
CIEMAT
FOM Inst DIFFER
ENEA, Frascati
CEA, Cadarache
IPP, Jülich
IPP, Garching
ASCR, Czech Rep

NSTX-U Will Make Contributions to ITER in All Topical Science Areas

- Explore fundamental toroidal physics issues
- Use high toroidicity, shaping, expanded operating range as leverage for theory validation
- Develop operational/control/hardware approaches & capabilities
- In Energetic Particle area, direct overlap with some ITER parameters under normal, high-performance operating conditions



- Approach of this Overview is to summarize the 5 year physics research on NSTX-U that most strongly addresses the ITER R&D needs
  - Emphasis is on Urgent and High Priority needs for ITER
  - In most cases, NSTX-U will contribute to the longer term physics and operational scenario development, as opposed to near-term design issues

ITER High Priority R&D Items Outlined by D. Campbell in Dec. 2012 ITPA CC Meeting Presentation

- MHD
  - <u>Design of disruption mitigation system</u>
  - <u>High success detection to trigger rapid shutdown, MGI</u>
  - <u>Error fields, Locked mode, RWM control</u>
- Divertor and Plasma-Wall Interactions
  - <u>Heat fluxes to PFCs; SOL widths and dependences</u>
  - Tungsten: effect of transient and s-s heat loads, melting
  - <u>Migration</u>, fuel inventory, <u>dust</u>
- Pedestal and Edge Physics
  - <u>ELM control (3D fields and other)</u>
  - L-H threshold and ensuing pedestal evolution
- Transport and Confinement
  - H-mode ingress/egress, role of metallic PFCs
  - Particle transport and fueling: <u>impurity transport</u>
- Energetic Particles
  - <u>Predict AE stability, behavior, effect on fast ions: code V&V</u>
  - <u>Fast ion losses due to application of 3D fields</u>
- Integrated Operating Scenarios
  - <u>Develop integrated control scenarios</u>
  - <u>Investigate hybrid and steady-state scenarios</u>
  - <u>Validate heating and current drive scenarios</u>

Physics areas in which NSTX-U can contribute

In remainder of talk, will focus on areas where NSTX-U can make the greatest impact (<u>underlined</u>)

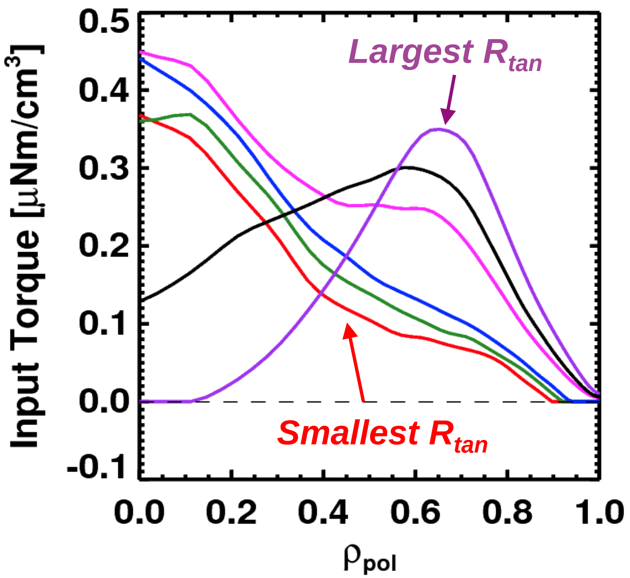
Through talk, will map NSTX-U research to specific TSG Research Thrusts (e.g., ASC-2)

NSTX-U Will Have Flexible Profile Control Capabilities That Will Benefit All Research Areas

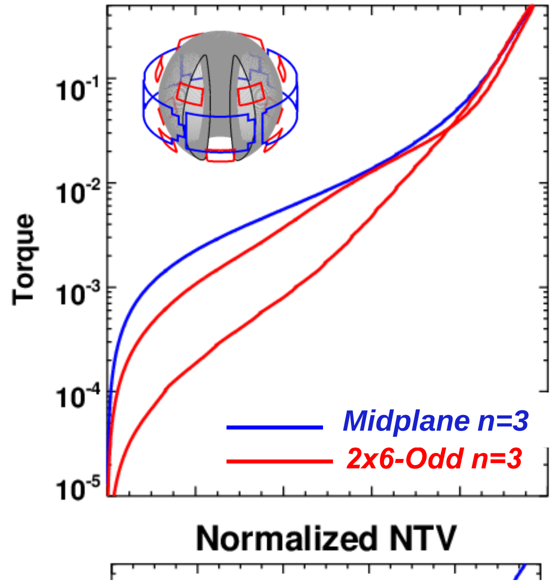
Rotation Profile Actuators

q-Profile Actuators

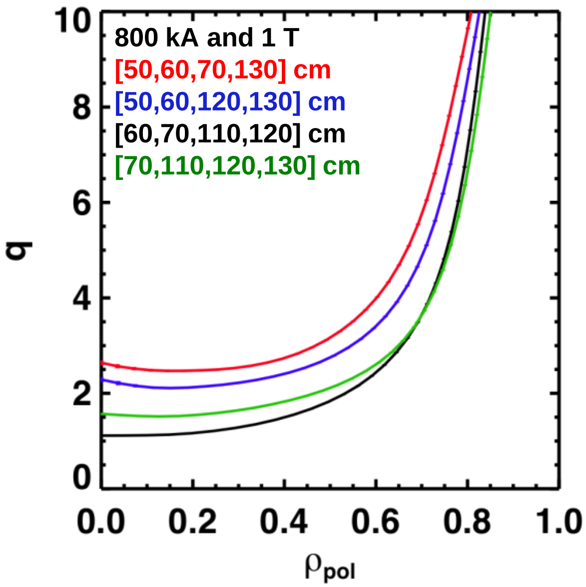
Torque Profiles From 6 Different NB Sources

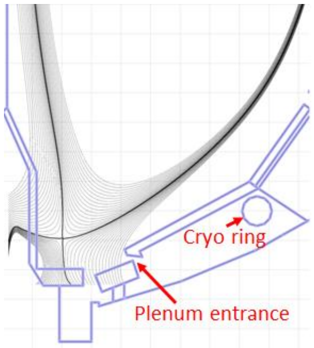


Normalized Integrated Torque From 3D Coils



Variations in Beam Sources

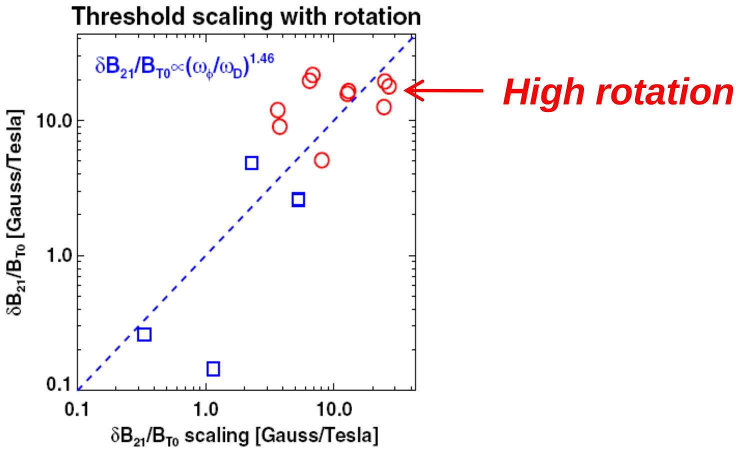




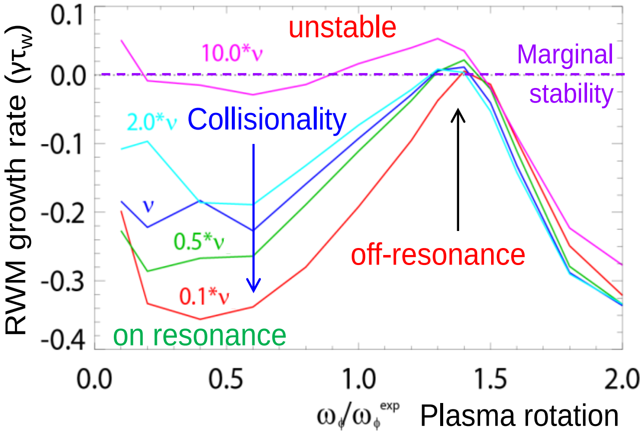
Cryopump, Li conditioning, higher I_p, B_T for lower ν^*

Multiple Physics Effects Govern Plasma Stability

Locked mode thresholds depend on EF and v_ϕ (MS-2, ASC-2)



RWM stability depends on ν^*, v_ϕ, kinetic effects (MS-1, ASC-2)



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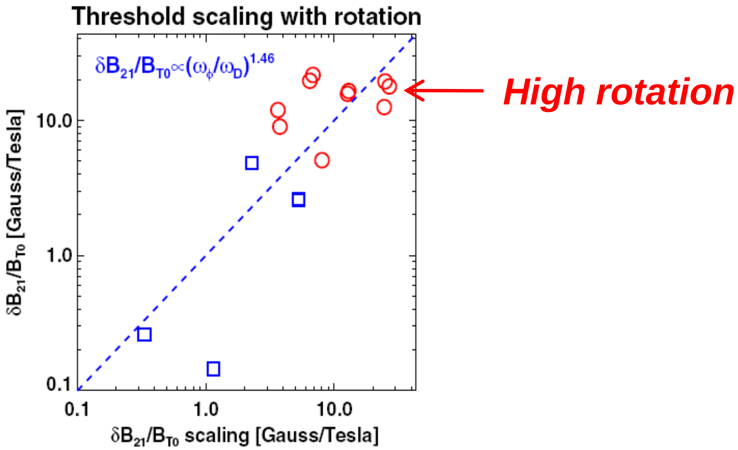

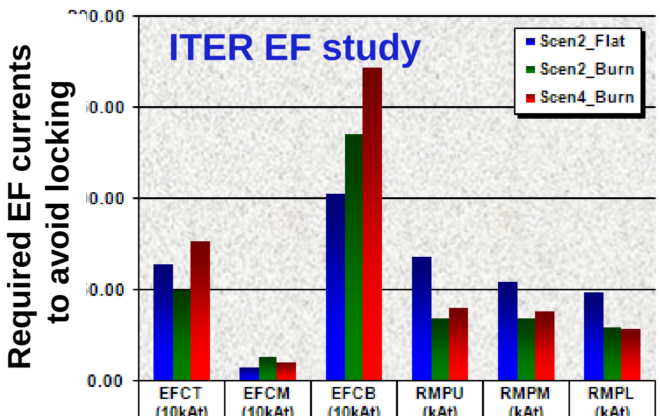

	EFCT (10kAt)	EFCM (10kAt)	EFCB (10kAt)	RMPU (kAt)	RMPM (kAt)	RMPL (kAt)
Scen2_Flat	64.13	7.71	102.60	68.40	54.00	48.86
Scen2_Burn	49.23	13.21	135.38	33.84	33.84	29.27
Scen4_Burn	76.44	10.12	172.00	40.47	38.22	28.67

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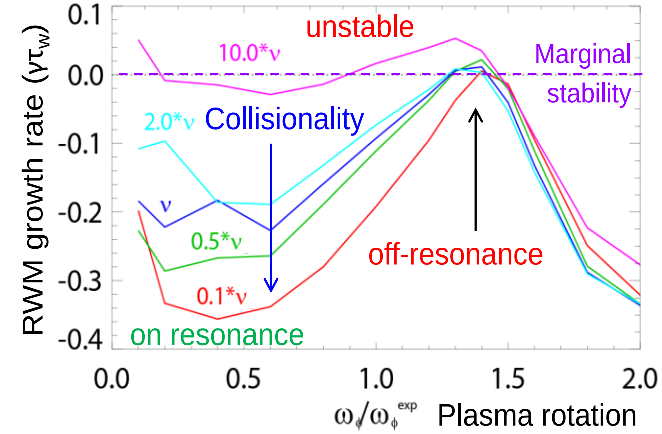
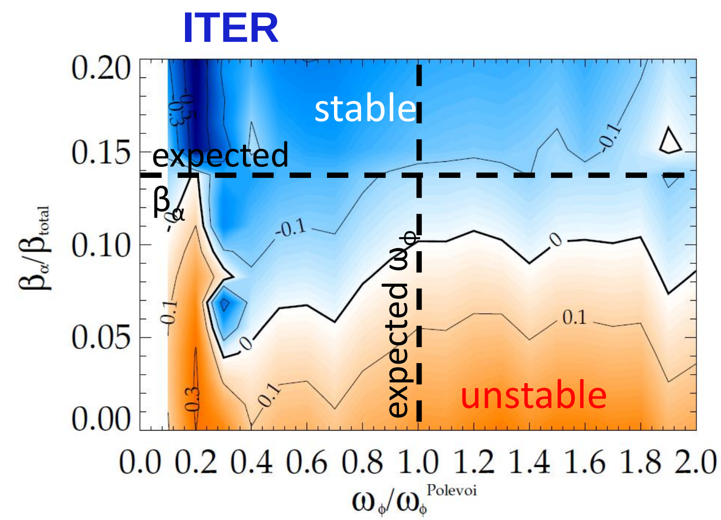
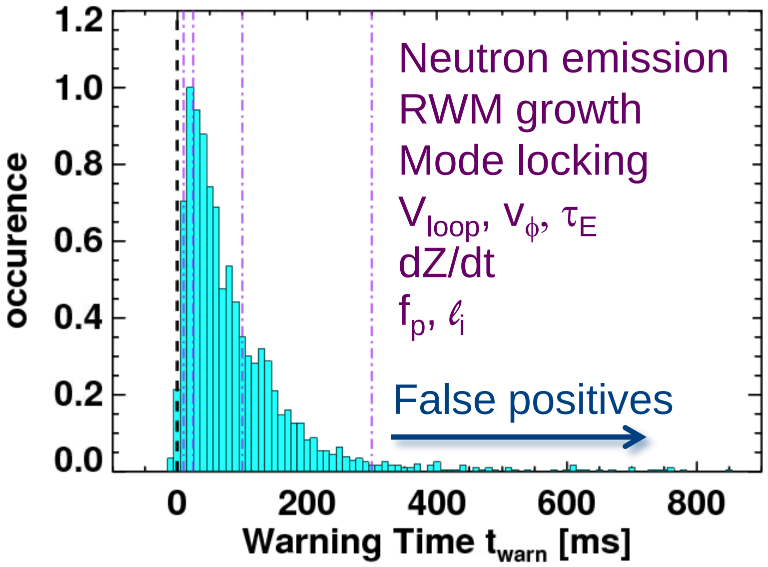


Contributions to ITER scenario stability have already been made by NSTX-U researchers



Successful Disruption Mitigation Requires Accurate Prediction and Ability to Limit TQ/CQ Effects

- Disruption Warning System (ASC-3)
  - Disruption warning algorithm based on combination of sensor- and physics-based variables
  - < 4% missed, 3% false positives (> 300 ms prior)
- Approach to be assessed on larger R/a devices through ITPA Joint Activity



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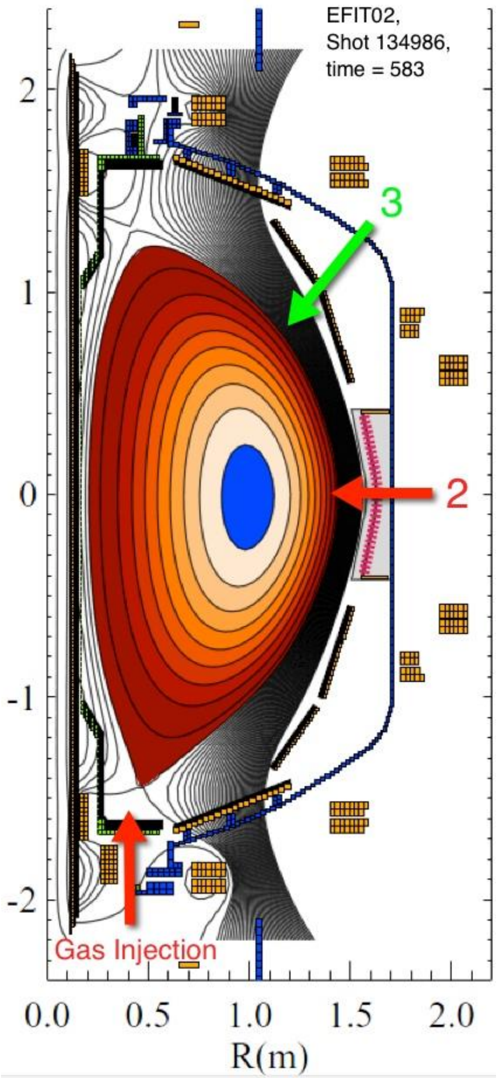
- MGI system will be implemented in YR1 of operation (MS-3)
  - Assess SOL gas penetration for different injection locations (esp. private flux region)
  - ***May be able to influence design for ITER***
- Electromagnetic Particle Injector (EPI)
  - Rail gun technique for rapid and large amount of particle injection
  - To be proposed by NSTX-U collaborator



Longer-term Objective is to Develop an Integrated, Physics-Based Disruption Prediction-Avoidance-Mitigation Framework

Plasma Operations

Predictors (Measurements)
- Shape/position
- Eq. properties (β, l_i, V_{loop},…)
- Profiles ($p(r)$, $j(r)$, $v_\phi(r)$,…..)
- Plasma response (n=0-3, RFA, …)
- Divertor heat flux

Control Algorithms: Steer Towards Stable Operation
- Isoflux and vertical position ctl
- LM, NTM avoidance
- RWM and dynamic EF control
- RWMSC (plasma response)
- Divertor radiation control

Avoidance Actuators
- PF coils
- 2nd NBI: q, v_ϕ, p control
- 3D fields (upgraded + NCC):
  - EF, v_ϕ control
- n=1-3 feedback
- Divertor gas injection

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Plasma response (n=0-3, RFA, …)
Divertor heat flux

General framework & algorithms applicable to ITER

Control Algorithms: Steer Towards Stable Operation
Isoflux and vertical position ctl
LM, NTM avoidance
RWM and dynamic EF control
RWMSC (plasma response)
Divertor radiation control

Avoidance Actuators
PF coils
2nd NBI: q, v_ϕ, p control
3D fields (upgraded + NCC):
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Divertor gas injection

Loss of Control

Disruption Warning System

Mitigation
Early shutdown
Massive Gas Injection
EPI (tbp)

Framework to be assessed in ITPA JEX/JAC

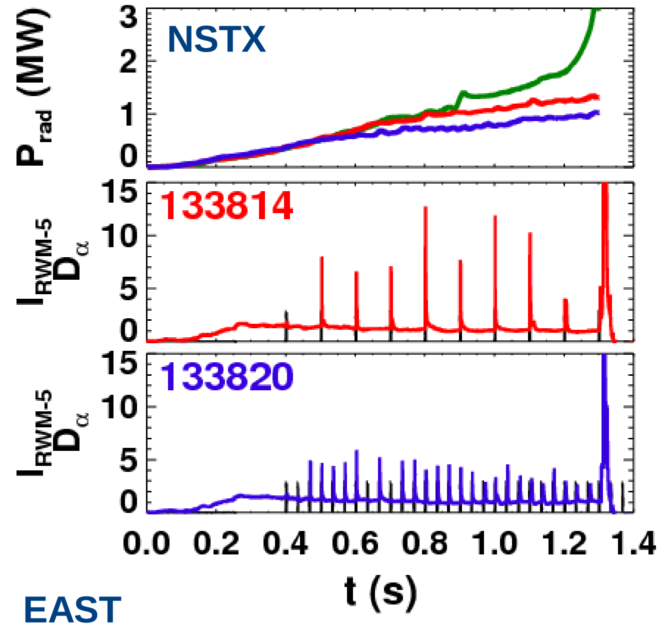
ELM Control is a High Priority R&D Issue for ITER, But Is Not Limited to ITER (BP-1)

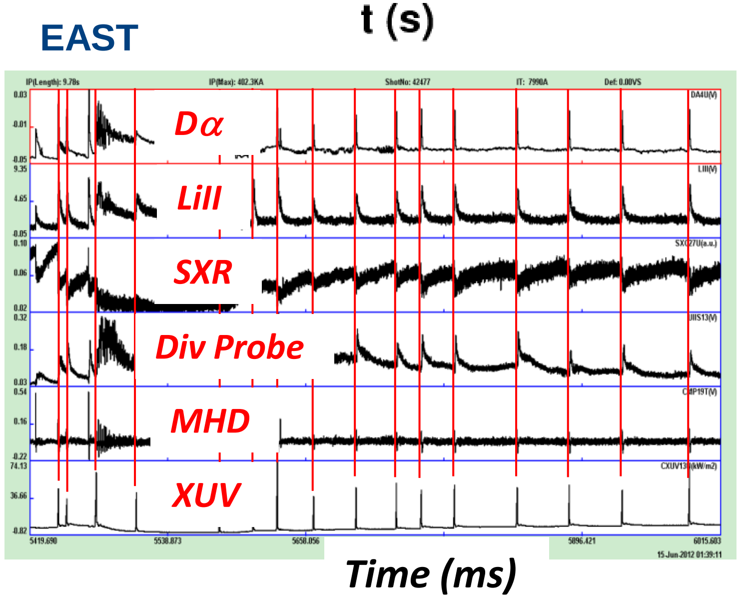
ELM control by applied 3D fields

- NSTX results show pacing, not suppression
- Expanded capability with upgraded 3D system + NCC
  - Greater range of poloidal mode spectra (suppression?)
  - Higher frequency ELM triggering
  - More edge-localized, less core rotation damping (NTV)
- Assess effect in lower ν^* pedestal

ELM control by other means

- Li granule injection: successful on EAST,
  - ***Be granule injection of possible interest for JET, ITER***
- Vertical kicks in expanded operating space
- Small-ELM & ELM-free regimes (EPH-mode?)

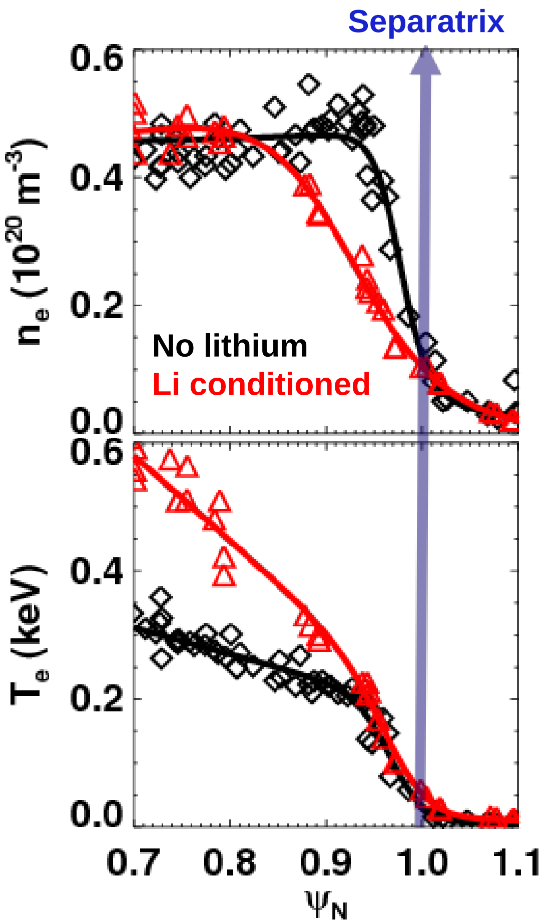




Understanding Pedestal Transport & Stability Will Provide Key to Optimizing ELM Control (BP-1)

- Use Li suppression of ELMs as a basis for studying the pedestal/ELM stability
- Identify dominant microinstabilities that govern pedestal structure

- Density profile change with Li conditioning changes μinstability properties, and determines stability to ELMs
- μtearing, hybrid TEM/KBM, ETG modes important in different regions of pedestal



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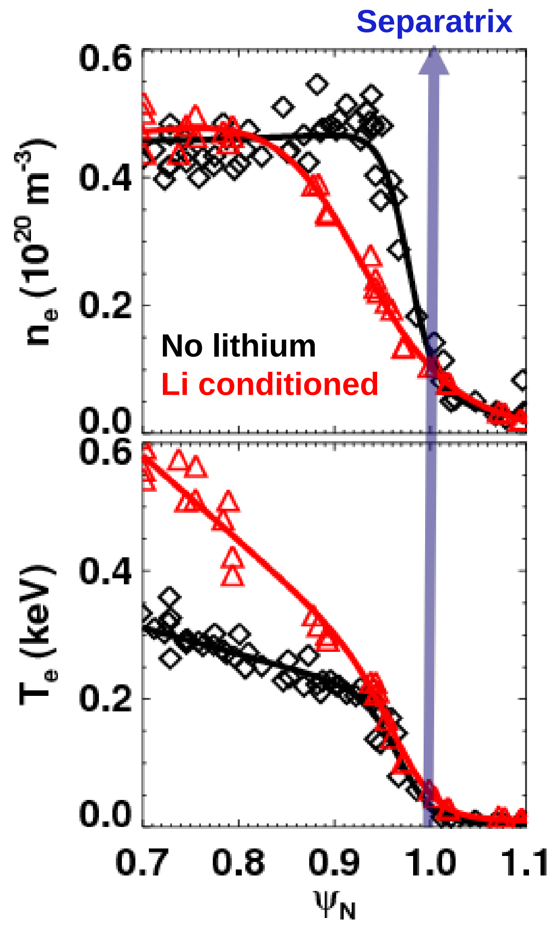
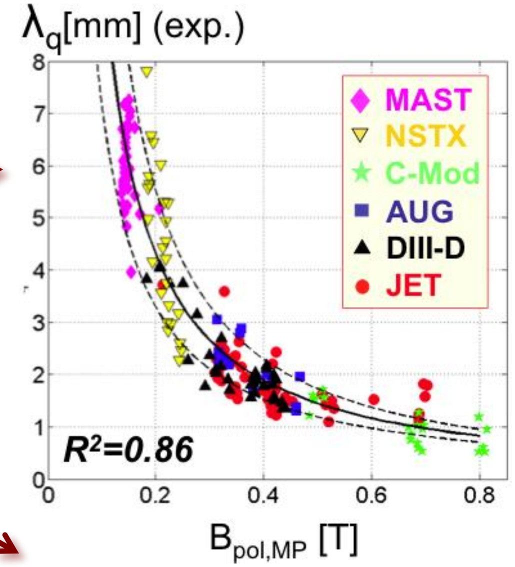
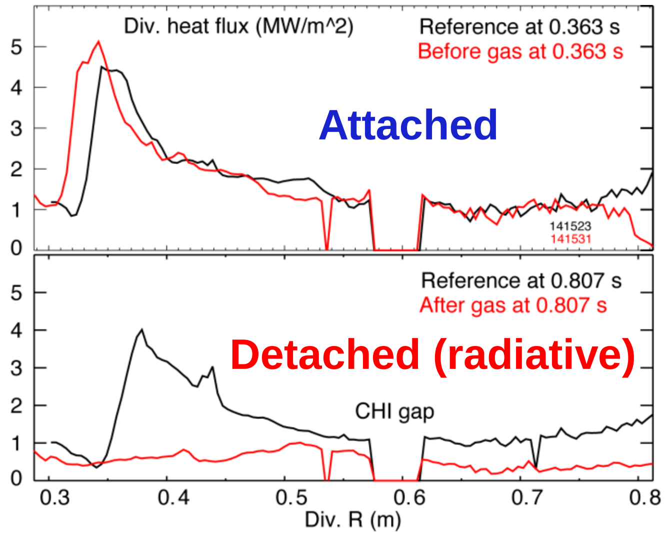
- Density profile change with Li conditioning changes μinstability properties, and determines stability to ELMs
- μtearing, hybrid TEM/KBM, ETG modes important in different regions of pedestal
- Use variety of tools on NSTX-U to study profile and μinstability changes
  - Conditioning, cryopump, expanded operating space for lower ν^*
- Polarimeter (δB) on NSTX-U to assess μtearing
  - Role of μtearing on ITER?
- Full k-range for δn (BES, μwave scattering)
- Knowing the n_e profile needed for optimized ELM control can guide the development of ITER fueling techniques



NSTX-U Will Study and Mitigate High Divertor Heat Fluxes in Long-Pulse Discharges

- P/R~20 MW/m, P/S~0.4 MW/m^2
  - ITER P/R~25 MW/m, P/S~0.2 MW/m^2
- Study SOL widths, dependences (BP-2)
  - Ability to double B_T, I_p, B_p and operate at lower ν^* to test SOL width scalings
- NSTX heat flux reduced by divertor gas puffing (BP-2, ASC-2)
  - Develop real-time divertor radiation control in NSTX-U
  - Extend SOL scalings to partially detached regime
  - Study effects of 3D on divertor heat flux
- High-Z PFCs can address ITER issues of metal PFC heat load handling, migration, dust (MP-2)
  - Row(s) of high-Z tiles can contribute to studying mixed material issues
  - Study effect of vapor shielding of PFCs for power reduction at divertor/first wall (MP-3)
    - High temperature Li surface, non-coronal Li radiation
    - Li/Mo or W in NSTX-U possible proxy for Be/W in ITER divertor/first wall





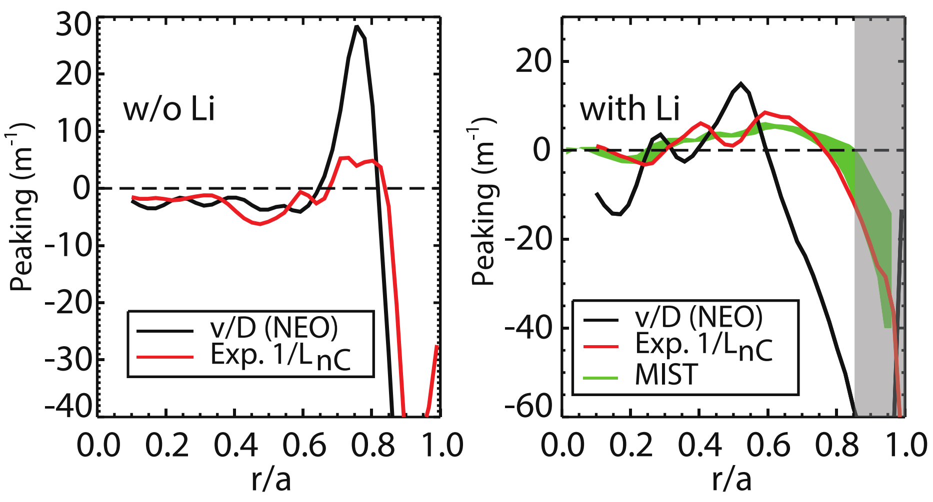
ITER Has Heightened Interest in Studying Impurity Transport in the Edge and Core Regions

- Impurity seeding with JET, AUG metal walls required for good confinement
  - Is impurity transport near edge neoclassical? Will impurities accumulate in core?
- Develop requirements for ELM-pacing to control impurity content

- C impurity studies using MIST, STRAHL indicate departures from neoclassical in the Li-conditioned plasma edge

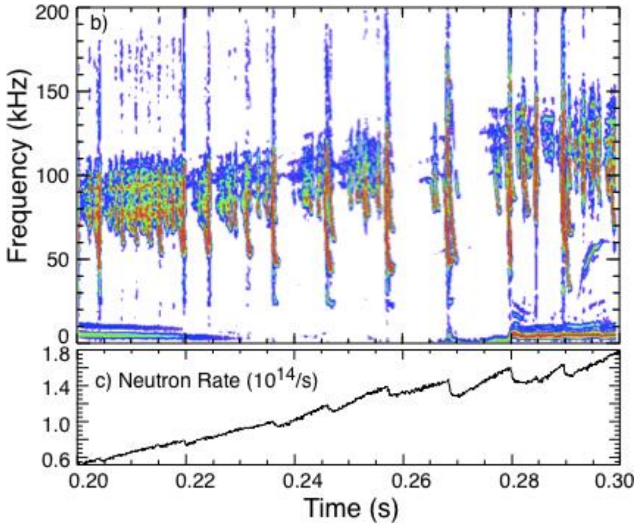
- NSTX-U will explore impurity transport at lower ν^* (TT-2)
  - Assess neo vs turbulent transport
    - BES ➔ High-k
    - Rotation shear control with 2nd NBI, 3D
  - Mixed impurity effects
  - High-Z transport: row(s) of high-Z PFC

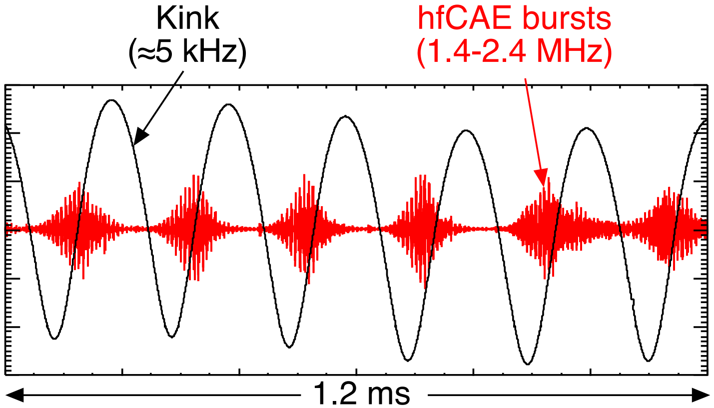
Carbon profile peaking



Energetic Particle Modes are Strongly Non-Linear in NSTX-U (& Possibly in ITER Hybrids and RS)

- Non-linear behavior of AE modes regularly seen in NSTX
  - Avalanches (mode overlap) & effect on fast ions; coupling to low-f MHD (kinks, RWM)
- NSTX-U research on avalanches and non-linear physics is essential for the code validation needed for projecting to ITER (EP-1)
  - **Ability to vary q, with 2nd NB – strong effect on non-linear behavior**
  - Higher TF, NB flexibility to vary v_{fast}, β_{fast}
  - AE antenna to study mode stability, excitation
  - Suite of fast ion diagnostics
  - Strong code development and validation effort (linear and non-linear)





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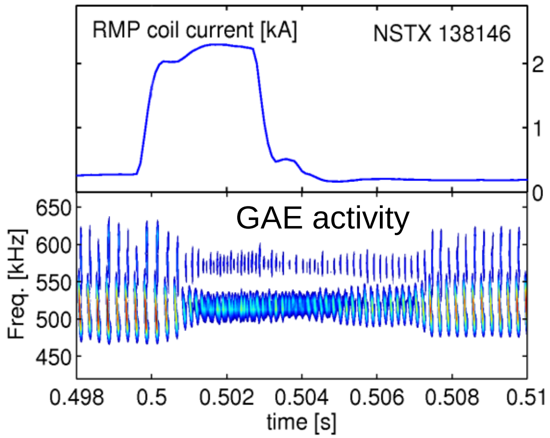
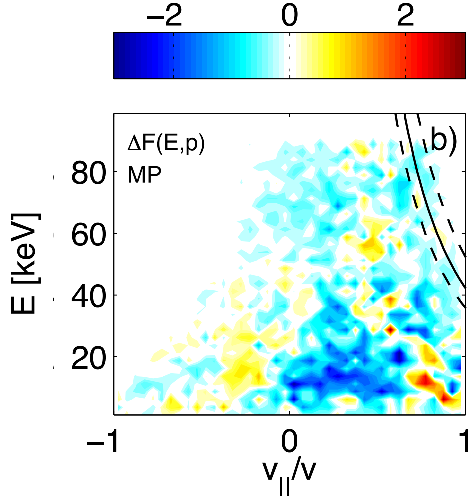
  - Suite of fast ion diagnostics
  - Strong code development and validation effort (linear and non-linear)
- Applied 3D fields affects AE stability and fast ion distribution, transport (EP-2)
  - Studies initiated on NSTX; high priority for ITER
  - Flexible NB, 3D (NCC) systems to be used

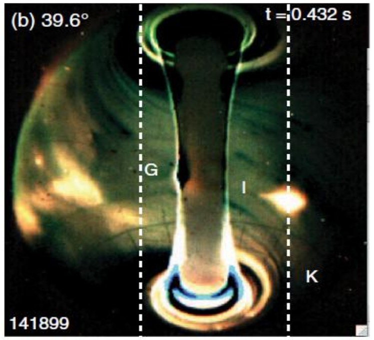




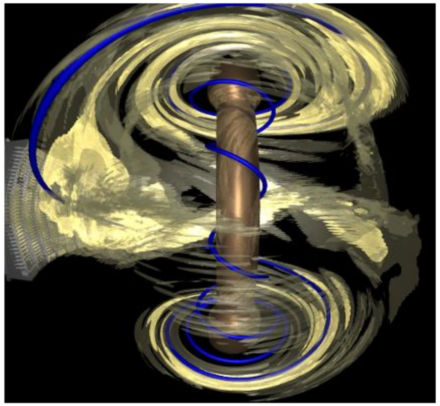
NSTX-U Will Develop and Validate Steady-State, Non-Inductive Operational Scenarios: Issues Relevant to ITER

- HHFW coupling studies (RF-1)
  - Dependence of coupling on geometry, edge profiles (conditioning, cryopump)
  - Interaction with fast ions (flexible NB)
  - HHFW power losses in SOL: validate RF codes (TORIC, AORSA-3D, CQL3D), probe arrays, IR cameras

Visible Light



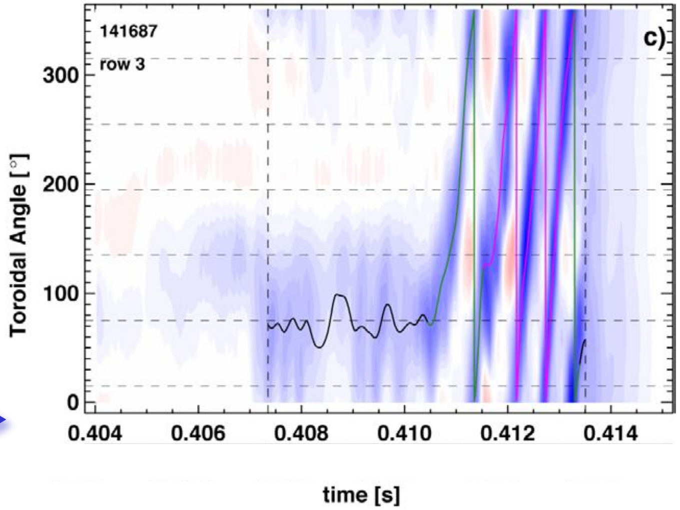
AORSA-3D



- NB/bootstrap current drive to produce fully/partially non-inductive plasmas (ASC-2)

- Control & disruption avoidance (integrated control algorithms+actuators)
  - Effect of rotating halo currents and resonant e-m loads on structure
    - How will this scale to ITER?

NSTX Halo Currents



Strong Participation in ITPA Joint Expts and Activities

- Representatives in every ITPA TG
- Leadership in many
  - S. Kaye: immediate past-Chair of Transport and Confinement
  - R. Maingi: Deputy Chair of Boundary Physics
  - S. Sabbagh: Leads WG on RWM Feedback control in MHD
  - C. Skinner: Leader of Special Working Group on First Wall Diagnostics
- NSTX-U physicists spokespersons for many JEX/JACs

ITPA JEX/JAC Involving NSTX-U Researchers as of Jan. 2013

	Pedestal/Edge Physics and DIVSOL		
DSOL-24	Disruption heat loads	PEP-27	Pedestal profile evolution following L-H/H-L transition
PEP-6	Pedestal structure and ELM stability in DN	PEP-29	Vertical jolts/kicks for ELM triggering and control
PEP-19	Basic mechanisms of edge transport with RMP	PEP-34	ELM energy losses and their dimensionless scaling
	Energetic Particles		
EP-2	Fast ion losses and redistribution from localized Aes	EP-6	Fast ion losses and associated heat loads from edge perturbations
	Integrated Operating Scenarios		
IOS-3.2	Define access conditions to get to SS sceanrio	IOS-4.3	Collisionality scaling of confinement in advanced inductive regime
IOS-4.1	Access conditions for advanced inductive scenario	IOS-5.2	Maintaining ICRH coupling in expected ITER regime
	MHD		
MDC-2	Joint experiments on resistive wall mode physics	MDC-17	Active disruption avoidance
MDC-8	Current drive prevention/stabilization of NTMs	MDC-18	Evaluation of axisymmetric control aspects
MDC-15	Disruption database development		
	Transport and Confinement		
TC-9	Scaling of intrinsic rotation with no external momentum input	TC-15	Dependence of momentum and particle pinch on collisionality
TC-10	Exptl id of ITG, TEM and ETG turbulence and comparison with codes	TC-17	ρ^* scaling of the edge intrinsic torque
TC-11	He and impurity profiles and transport coefficients	TC-24	Impact of RMP on transport and confinement
TC-12	H-mode transport and confinement at low aspect ratio		

NSTX-U Research Contributes to ITER High-Priority ITER R&D Needs

- Strong contributions will be made in a large number of areas
- Contributions to ITER R&D facilitated by device upgrades
  - Higher B_T: lower ν^*, RF coupling, *AE stability
  - Higher I_p: lower ν^*, higher B_{pol} (SOL scalings)
  - Cryopump: lower ν^* (core and ped), steady-state ops
  - 2^{nd} NB (off-axis); rotation control, q control
  - Enhanced 3D coils/NCC: rotation and ELM control, stability, steady-state
  - Li granule injector ELM control
  - Integrated control algorithms, MGI, EPI: steady-state, disruption mitigation
- Will mostly contribute to longer-term physics basis and operational scenario development
  - NSTX-U MGI research may impact near-term design for ITER
- Use unique NSTX-U configuration and capabilities as leverage for validating physics models that are used for predictions at higher R/a (including for ITER)
- Strong participation in ITPA, leadership in a number of areas