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NSTX Plasma Response to Lithium Coated Divertor

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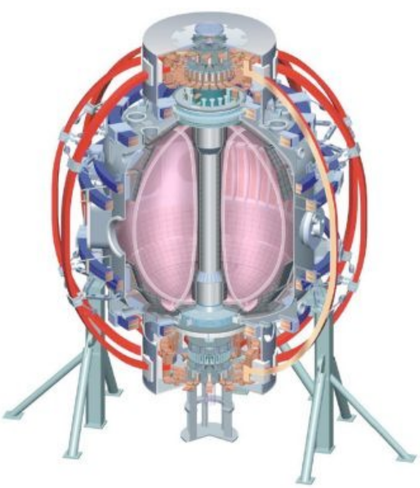
H.W. Kugel

and the NSTX Research Team

19 Int. Conf. on Plasma Surface Interactions
San Diego, CA, May 24-28, 2010



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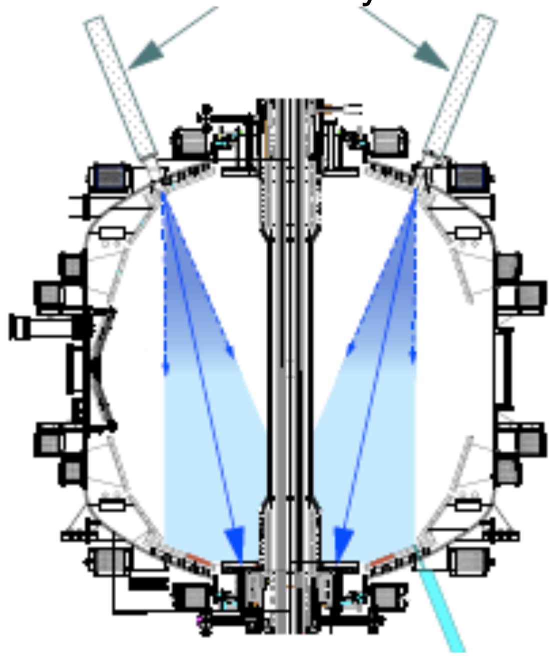
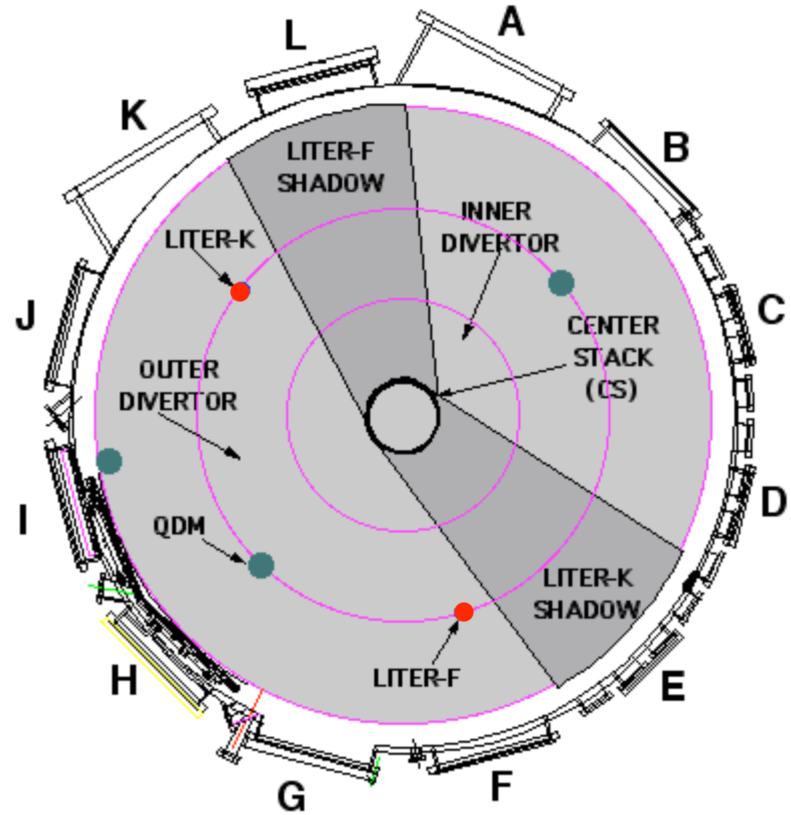
NSTX Experiments are Exploring Lithium-edge Conditions Using Solid Coatings on the Lower Divertor and Recently a Liquid Lithium Divertor

- NSTX solid lithium and liquid lithium coatings:
  - pump D^+ and D^0 through the formation of lithium deuteride (LiD)
  - pump incident 500-2000 eV D to an estimated pumping depth of 100-250 nm
  - average Li deposition exceeds the pumping depth over ~50% of lower divertor strike point area
- Pumping capacity of lithium can be reduced by:
  - Coverage of some areas by less than full active depth
  - Localization of interaction to region around divertor strike point
  - Passivation of lithium by formation of compounds with the residual gasses of the vacuum (*e.g.,* LiOH, Li_2O_2, Li_2O, Li_2C_2, Li_2CO_3)
  - Diffusion into the graphite substrate
- Improvements in NSTX plasma performance following solid lithium coatings include:
  - elimination of the formerly required HeGDC time between discharges
  - decreased core, edge, SOL plasma density and neutral edge density
  - improved energy confinement and stored energy
  - suppression of ELMs
- Improved confinement and suppression of Elms results in an increase in:
  - effective ion charge Z_{eff} and core radiation

Dual LIThium EvaporatoRs (LITERs) Are Used to Deposit Lithium Coatings on Lower Divertor Between Discharges



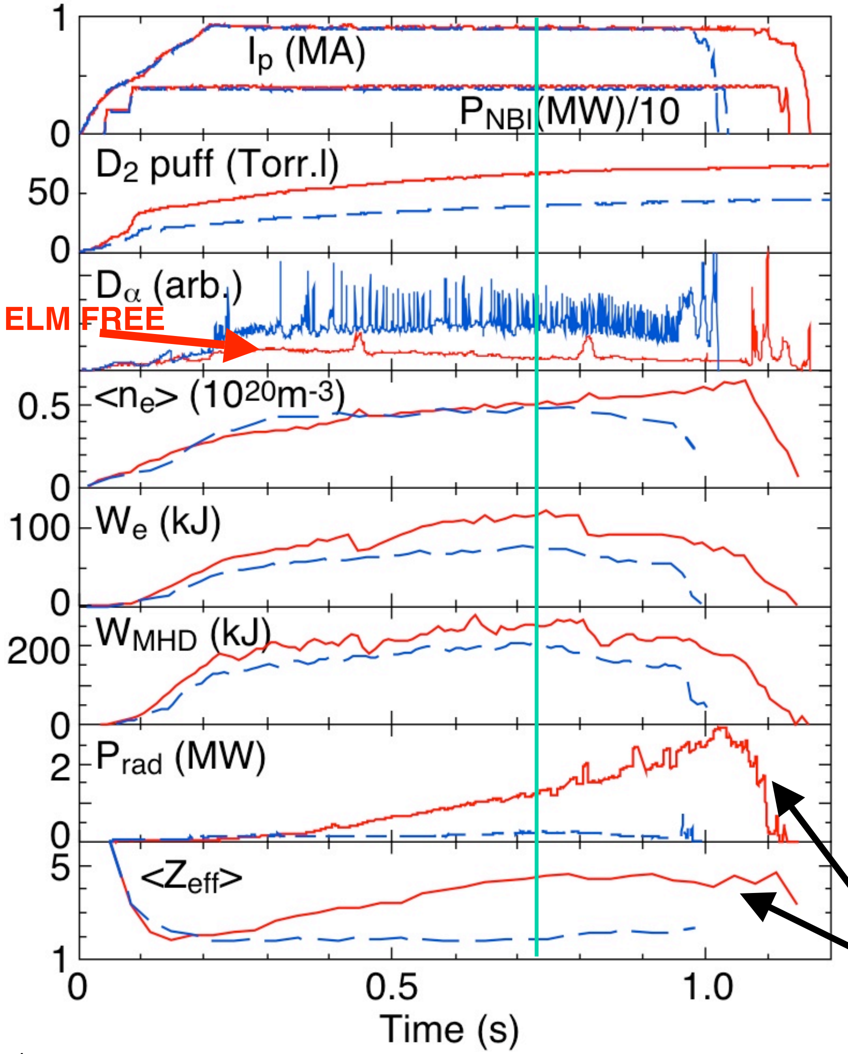


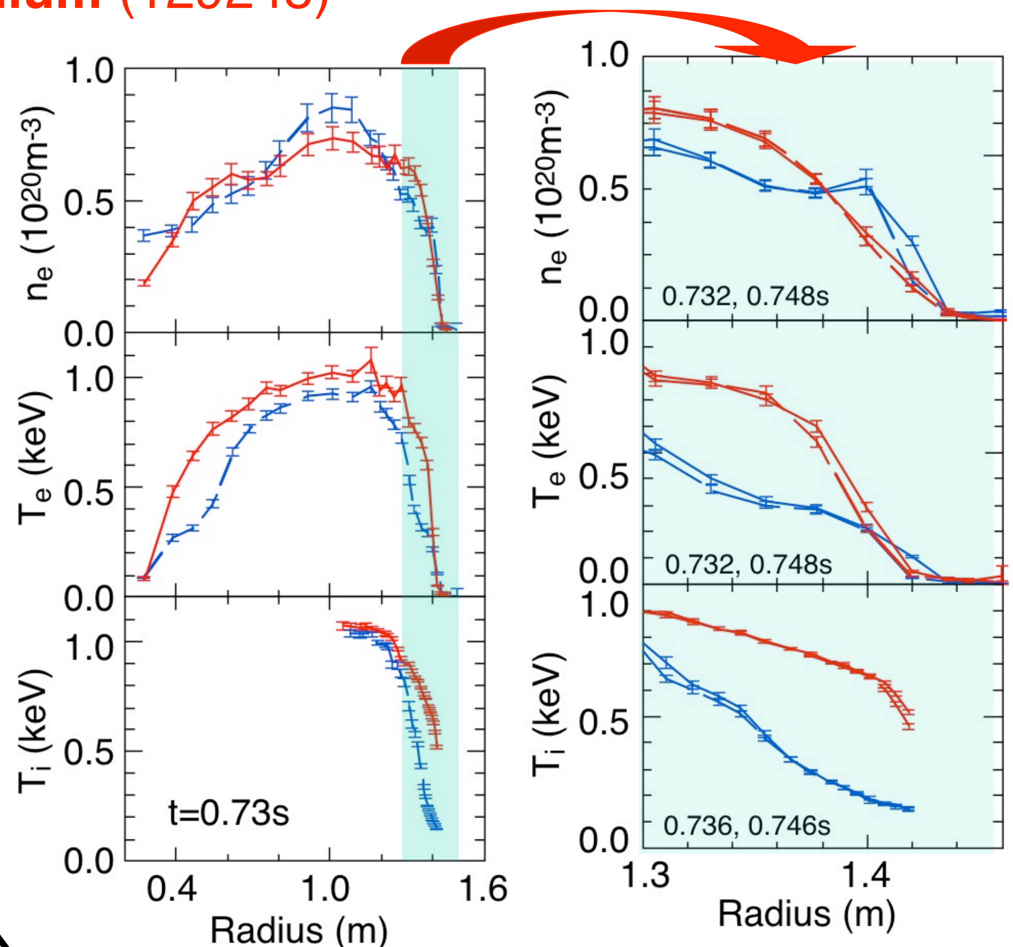
- LITER central aiming axis to graphite divertor and 1/e widths of gaussian distribution with angle

- Toroidal locations of LITER and Quartz Deposition Monitors (QDM)

Solid Lithium Coating Reduces D Recycling, Suppresses ELMs, Increases Stored Energy, Improves Confinement

No lithium (129239); **260mg lithium** (129245)



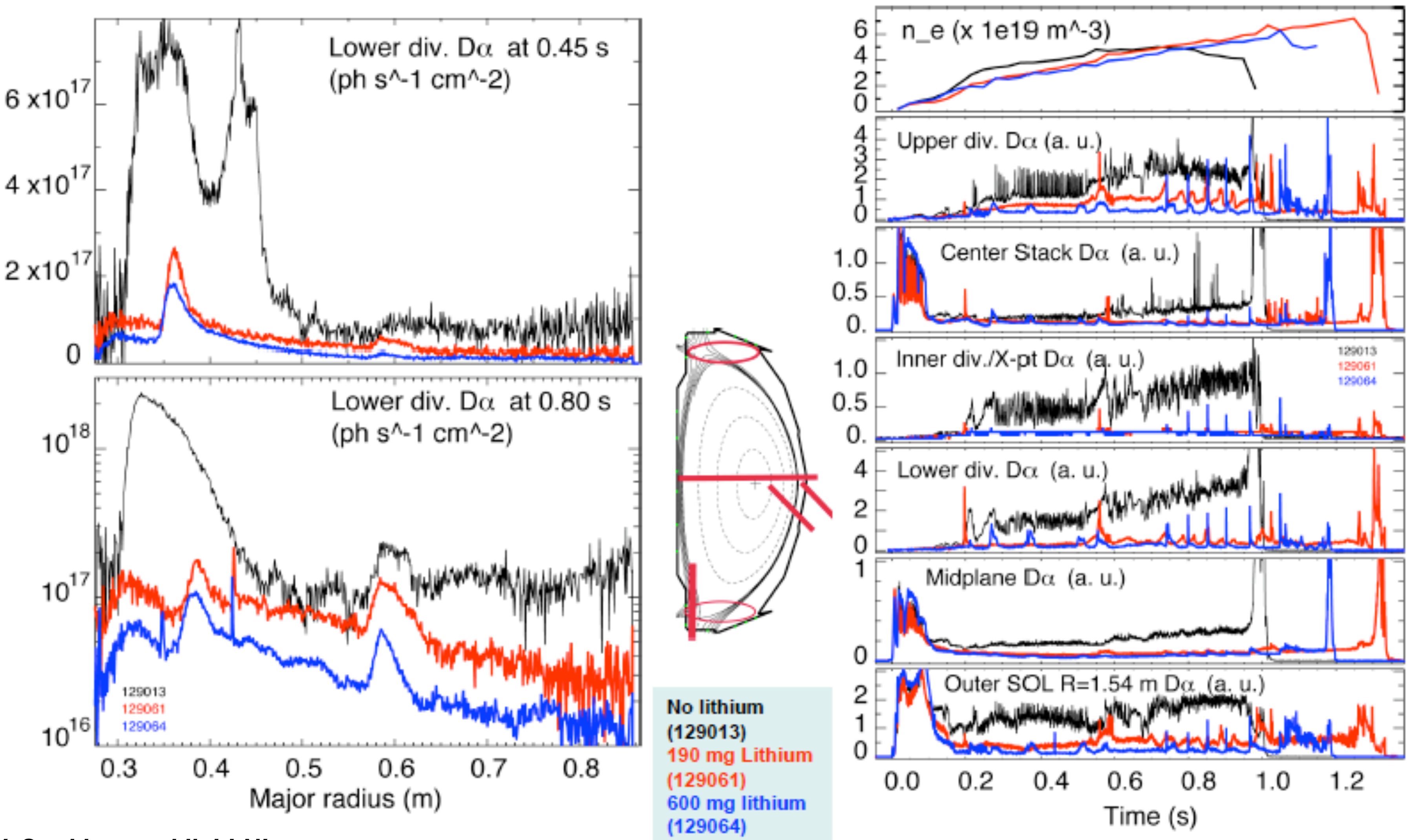


Without ELMs[1], impurity accumulation increases radiated power and Z_{eff}[2]

[1] ELM suppression predicted by L. Zakharov, 2000

[2] refer to ELM Pacing Experiments, J. Canik, et al. PRL

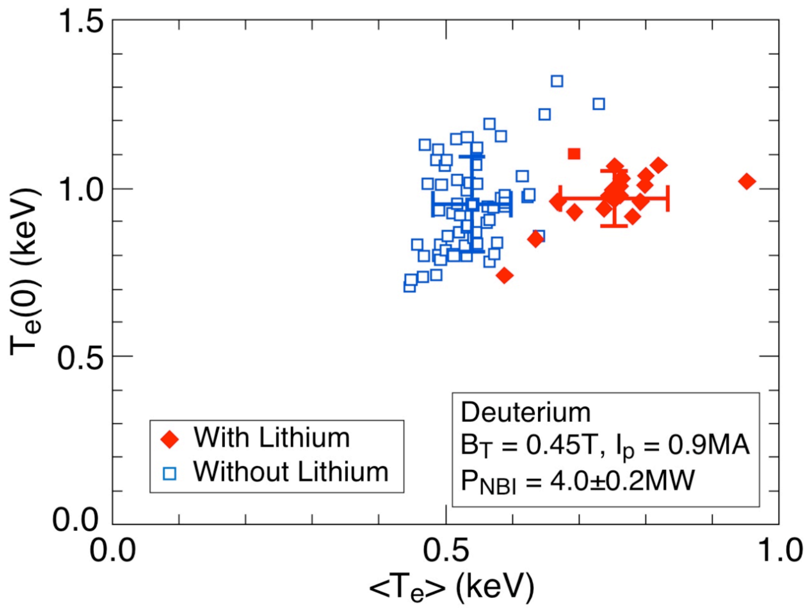
Li-edge Pumping Reduces Polodial Flux Recycling

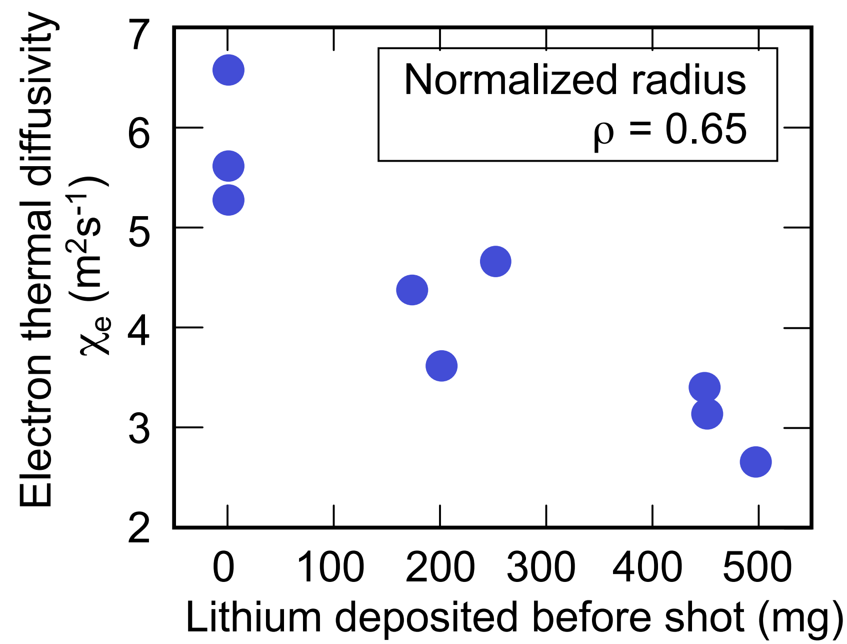


No lithium (129013)
190 mg Lithium (129061)
600 mg lithium (129064)

V. Soukhanovskii, LLNL

Improvement in Electron Confinement With Lithium Edge Conditions Arises from Broadening of Temperature Profile





- TRANSP analysis confirms electron thermal transport in outer region progressively reduced by lithium.
- Fast-ion contribution to total energy increased.
- Thermal ion confinement remains close to neoclassical level both with and without lithium.

M. Bell, B. LeBlanc, S. Kaye, S. Ding

In NSTX, Plasma Density Profile Modification from Lithium Edge Pumping Changes ELM Stability

- Observations

Lithium reduces recycling → Edge fueling reduced → Edge density profile relaxes → Peak edge pressure gradient moves inward to reduced magnetic shear

- Analysis

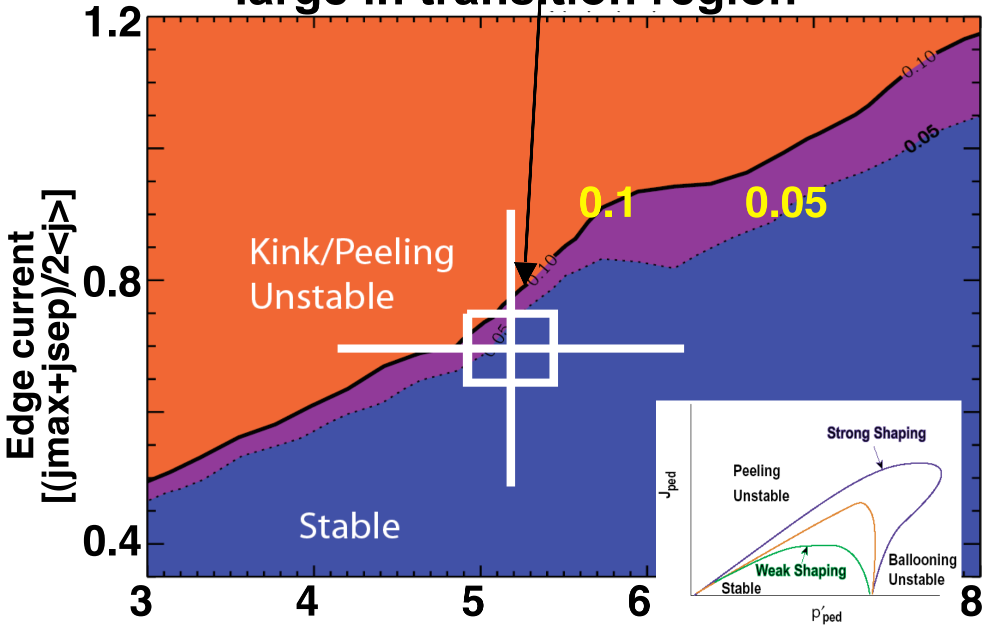
Peak edge pressure gradient moves inward to reduced magnetic shear → Edge bootstrap and parallel currents modified → Kink/peeling stability improved -> ELMs suppressed

R.Maingi, ORNL

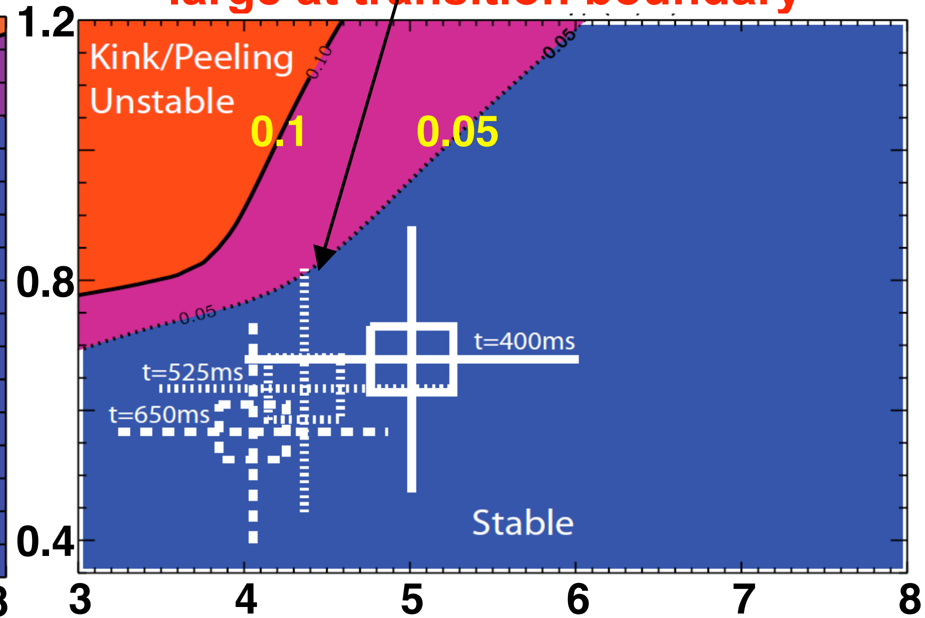
NSTX Pre-lithium Edge Profiles Close to kink/peeling Instability Threshold (ELITE)

Edge Stability Space Diagram of Normalized Edge Current as a Function of the Normalized Pressure Gradient

No lithium.: $\gamma_{lin}/(\omega^*/2)$ becomes large in transition region



With lithium: $\gamma_{lin}/(\omega^*/2)$ becomes large at transition boundary

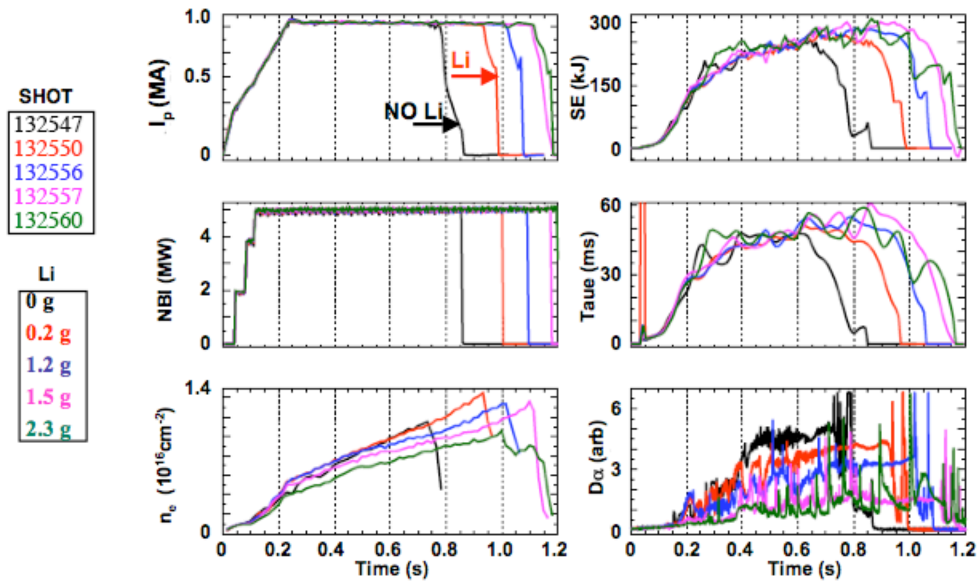


- The colors represent contours of ratio of mode linear growth rate γ to diamagnetic drift freq. ω^*
- No-lithium cases close to unstable limit; post-lithium cases are stable to these modes
- Low n=1-5 pre-cursor oscillations observed before ELM crash

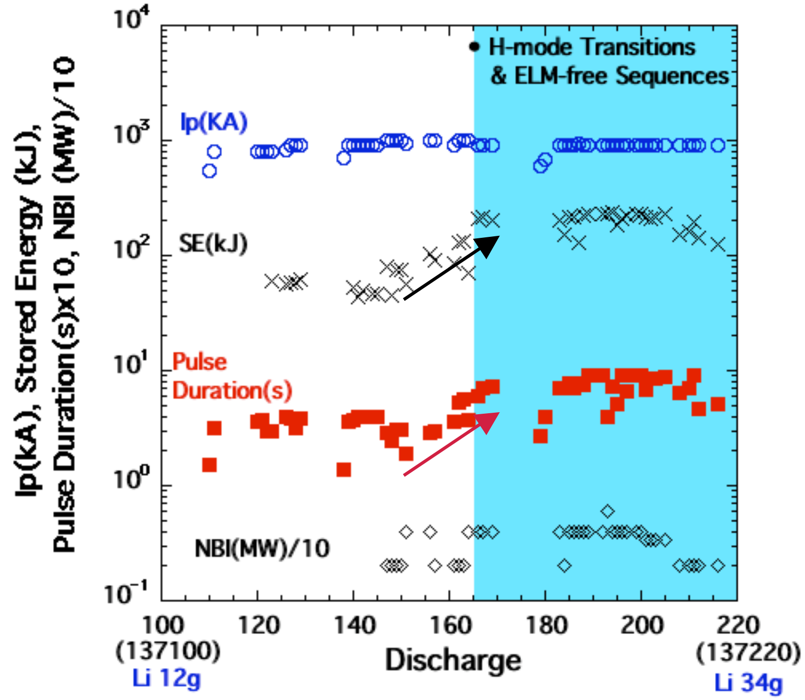
R. Maingi, ORNL

NSTX Lithiumization Promptly Restores Edge Stability Conditions Without Boronization

- In 2009, with walls heavily coated with Li_2CO_3 from 2008 operation and vent, following bakeout and TMB boronization, plasmas still exhibited high oxygen content. After 6 wks of discharge conditioning, and ArGDC, NeGDC, and HeGDC, plasmas still high oxygen content.



- After 2.3g of Li deposition, Li-edge conditions restored in less than 10 discharges



- In 2010, with lithiumization-only (no boronization), startup reduced from several weeks to 2.5 days (included discharges spent on new plasma control development)

NSTX Has Started to Test the Potential Benefits of Liquid Lithium Divertor for Integrating High Plasma and PSI Performance

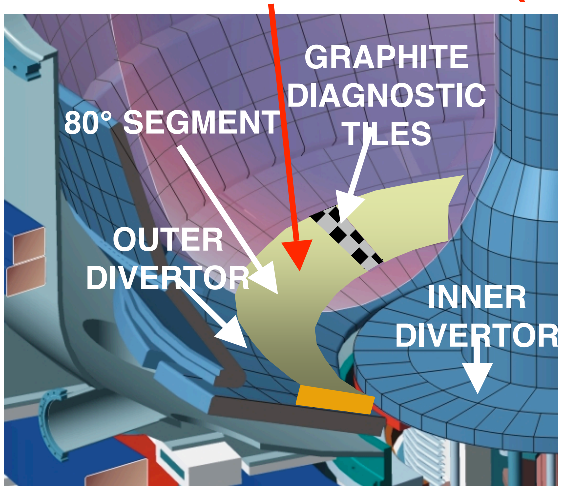
- *Solid Li provides short pulse capability but has limited LiD D pumping capacity as demonstrated by the need to evaporate fresh coatings between discharges.*

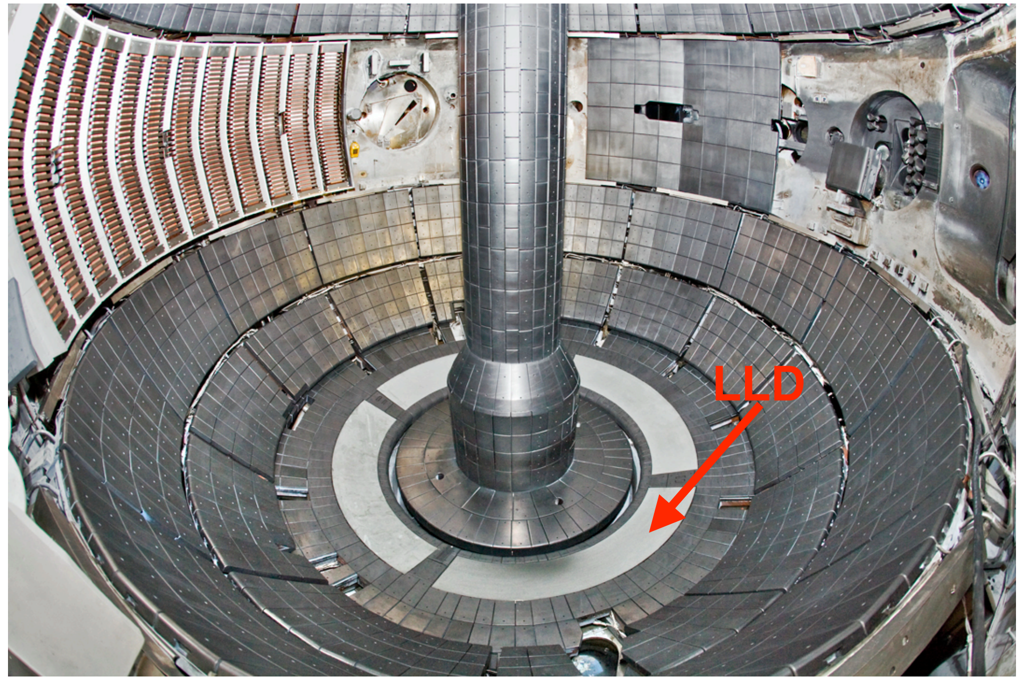
- *The liquid Li may have much higher LiD D pumping capacity, and has potential for power handling and self healing.*

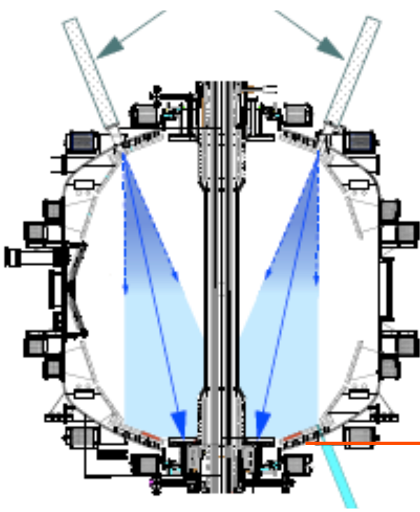
- Over the longer term, NSTX will investigate if liquid lithium can help integrate 4 important potential benefits for fusion
  a. Divertor pumping over large surface area compatible with high flux expansion solutions for power exhaust and low collisionality
  b. Improved confinement (reported in FY08)
  c. ELM reduction and elimination (reported in FY08)
  d. High-heat flux handling (capillary flow, swirl tubes, helium gas, hypervaportrons, /evaporative cooling)

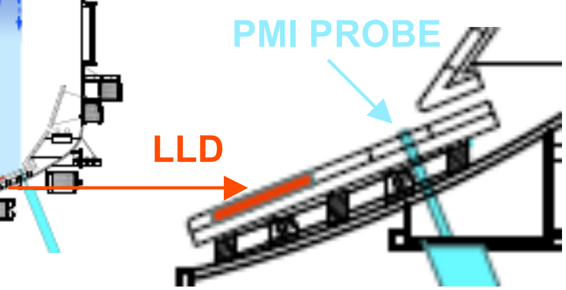
Liquid Lithium Divertor (LLD) Installed 2010 with a 0.165mm, 45% Porus Molybdenum Face to Hold Lithium

Liquid Lithium Divertor (LLD)



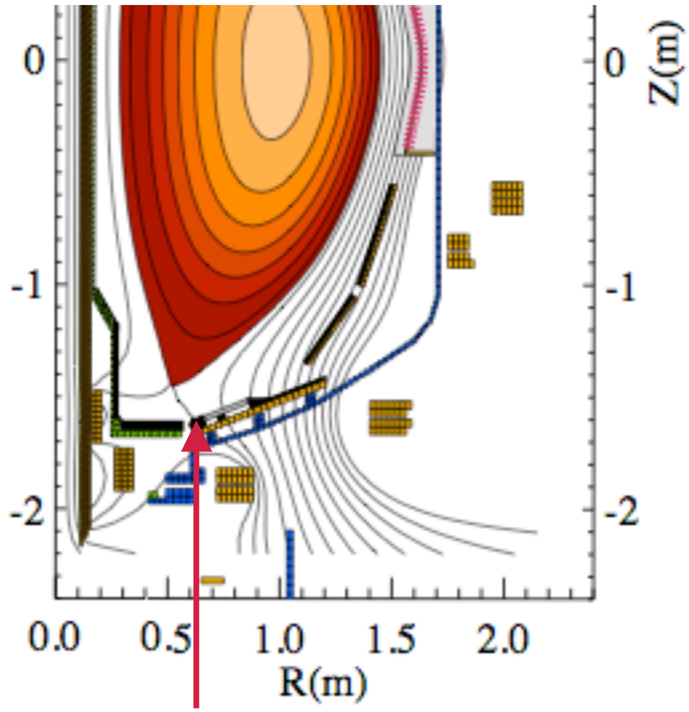




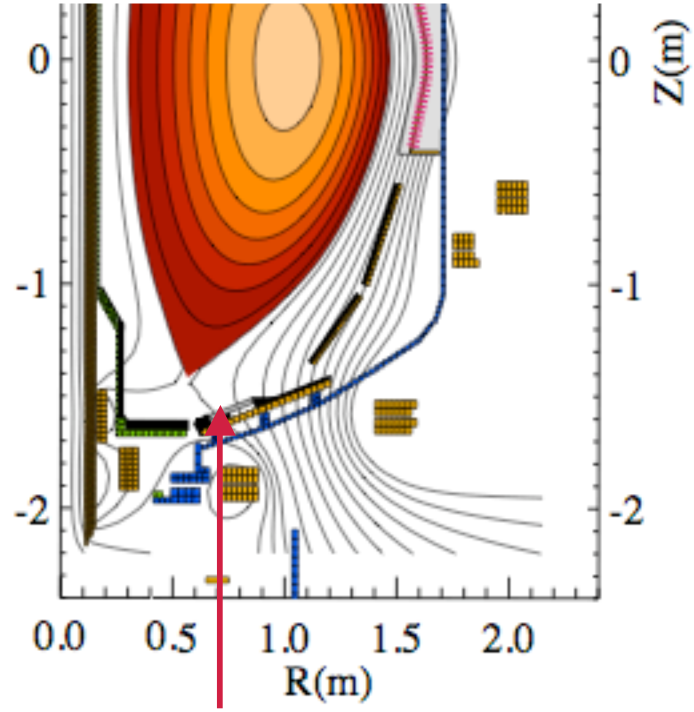


- 0.165 mm Mo plasma sprayed with 45% porosity, on a Li barrier of 0.25 mm 316-SS, brazed to 2.22 cm Cu
- Initial LLD filling method is using LITER evaporators
- LITER deposition efficiency on LLD ~5%

Two Plasma Positions Were Measured with Pumping from Both Active Liquid Lithium on LLD and Solid Lithium on Surrounding Graphite Tiles



OSP R=63cm on graphite tile next to LLD (5%filled)



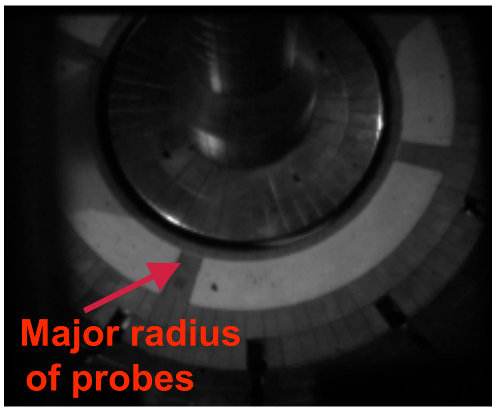
OSP R=70cm on LLD (5% filled)

- Measurements performed with OSP at R=63cm near LLD and at R=70cm on LLD
- Using the LITER system at a rate of 20-40mg/min, depositions were performed with the LLD at 30°C, then at 220°C (m.p. 180°C), and then up to 320°C.
- Little pumping difference compared to previous solid lithium coatings over the same region prior to installation of LLD (similar area ratios, short pulse duration).

Fast Camera Images Show Effect of Liquid Lithium Absorption Into the Porous Mo LLD; Probe Array Track OSP

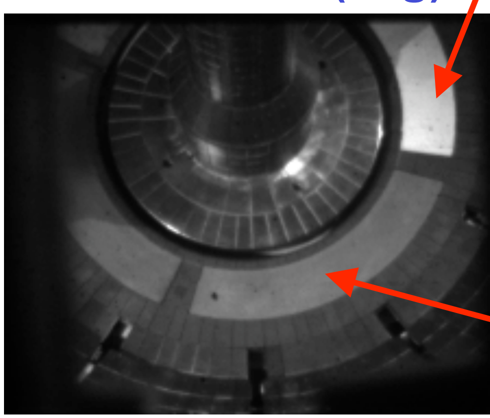
- Unheated plate exhibited higher reflectivity than heated plates as Li soaked into the porosity of the heated plates

Pre Lithium (unheated)



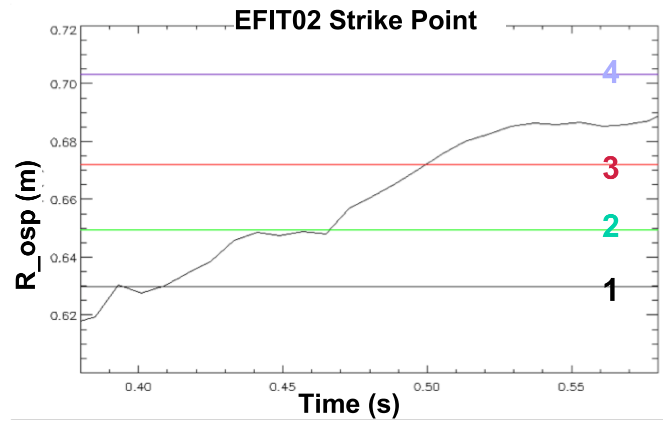
Post Lithium (12g)

Unheated during Li deposition



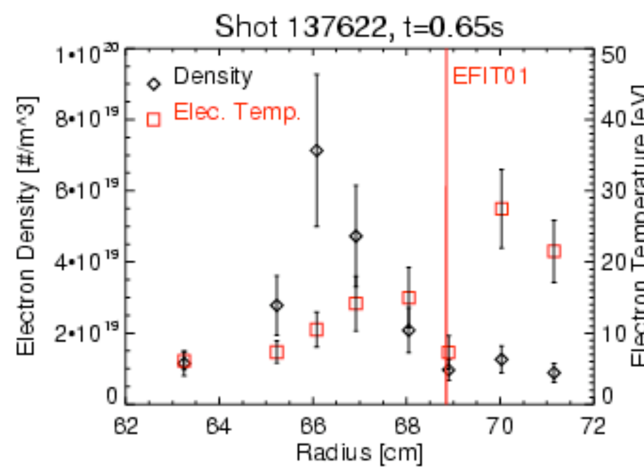
220°C during Li deposition

F. Scotti



J.Kallman

- **4 Sweep probes tracked OSP motion**



M. Jaworski

- **Triple Langmuir (UIUC)probe profile. Line labeled 'EFIT01' indicates magnetic reconstruction strike point location.**

Summary of Recent Results With LLD Filled 5% with Liquid Li and Divertor Graphite Tiles Coated With Solid Active Li

- The LLD was installed. The LLD was operated sucessfully with no Mo or halo current effects observed. The LLD diagnostics systems were operationed.
- As lithium deposition increased, reproducible, ELM-free, H-mode, flattops were obtained with selected outer strike points at major radii ranging from inner divertor out to on the LLD.
- ELM-free, H-mode, flattop discharges were obtained and exhibited noteworthy reproducible higher energy confinement times and reduced flux consumption early in these discharges relative to non-lithium-edge conditions.
- Edge pumping by the combination of the LLD in 5% filled liquid state and the solid lithium coating on the graphite tiles exhibited little difference compared to previous solid lithium coatings over the same region prior to installation of LLD.
- In NSTX, solid Li coatings saturate in about 1-2 dischartges. The next step is to fill the LLD to 50% and with LITER still depositing on the lower divertor region, take reference discharges. Then turn-off LITER, and let the solid coatings saturate. The resulting Li-edge effects may be due predominantly to the liquid LLD.