NSTX

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

Edge profile and stability analysis as Edge-Localized Modes (ELMs) disappear with increasing lithium wall coatings in NSTX

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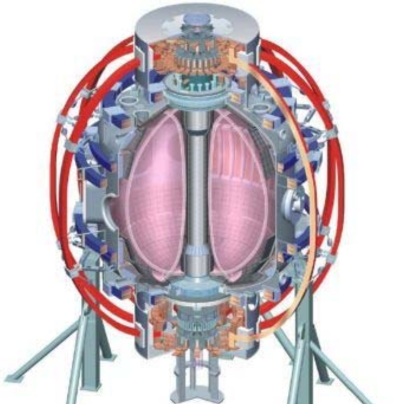
and the NSTX Research Team

PPPL Princeton Plasma Physics Laboratory — Oak Ridge National Laboratory — General Atomics

52nd APS DPP meeting
Chicago, IL USA
8-12 Nov 2010



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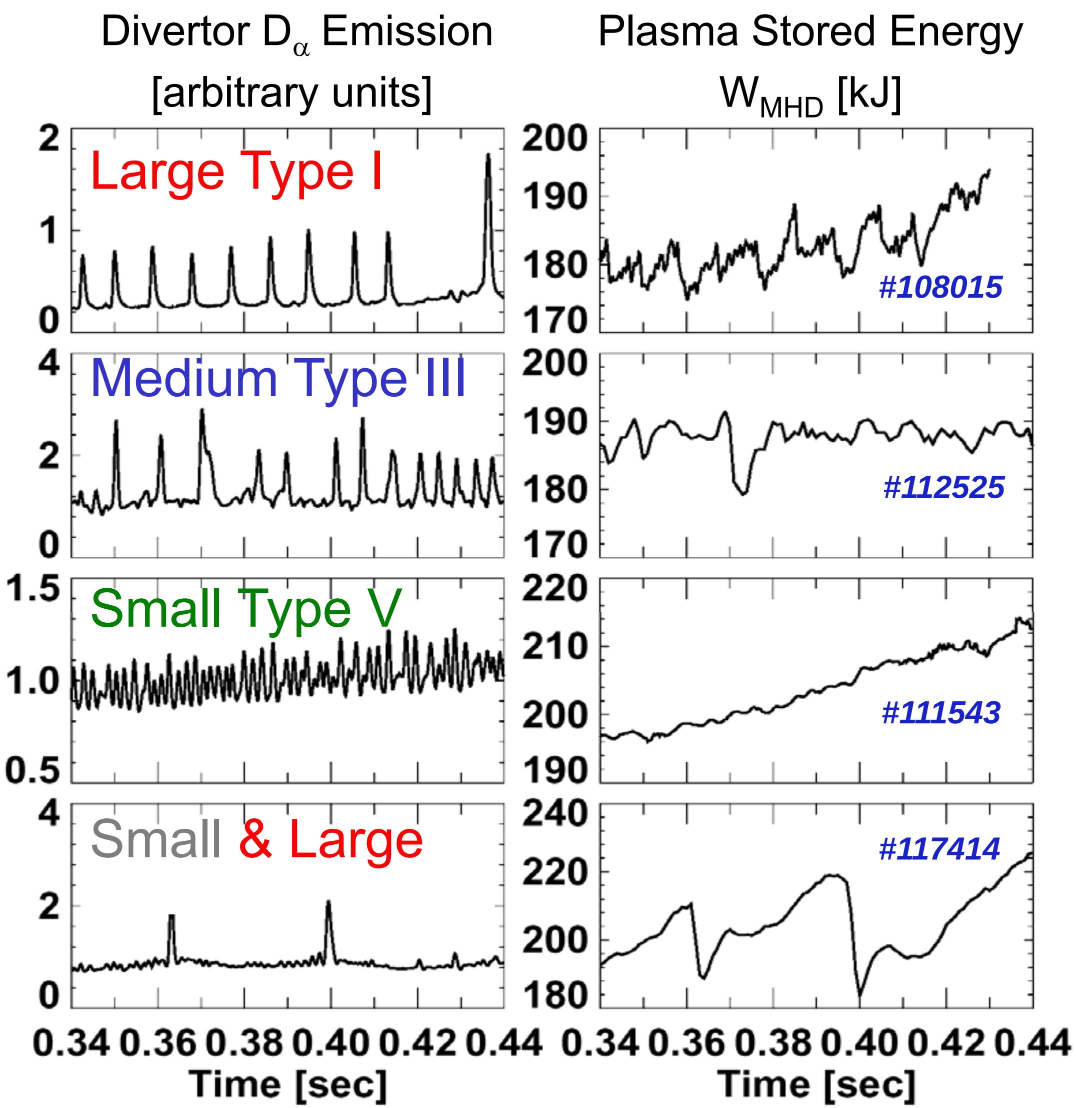
Lithium wall coatings control recycling and edge density, and lead to ELM-free H-mode

- Analysis of a well-controlled lithium coating sequence in which ELMs gradually disappear
  - Edge density, temperature, and pressure profiles are modified with lithium
- Edge peak pressure gradient moves farther from separatrix, and pedestal gets wider
  - Causes change in calculated bootstrap current
  - Edge stability improved

H-mode leads to instabilities called

Edge-Localized Modes (ELMs)



$\Delta W_{ELM}/W_{MHD} \sim$ 3-20%

$\Delta W_{ELM}/W_{MHD} \sim$ 1-5%

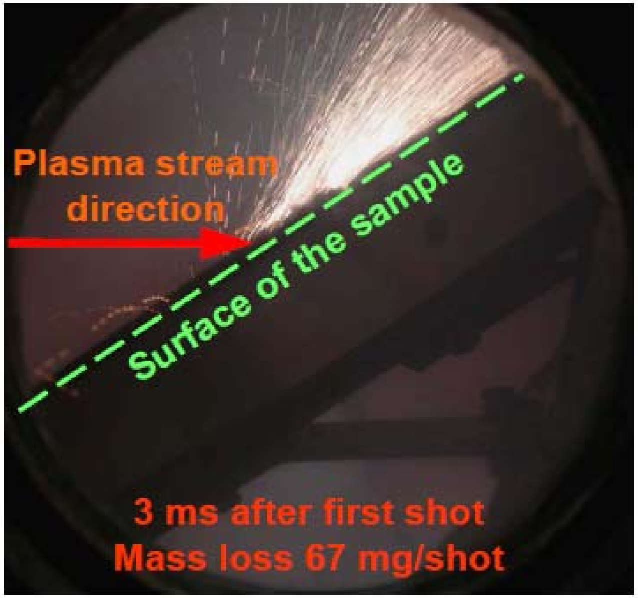
$\Delta W_{ELM}/W_{MHD} \leq$ 1%

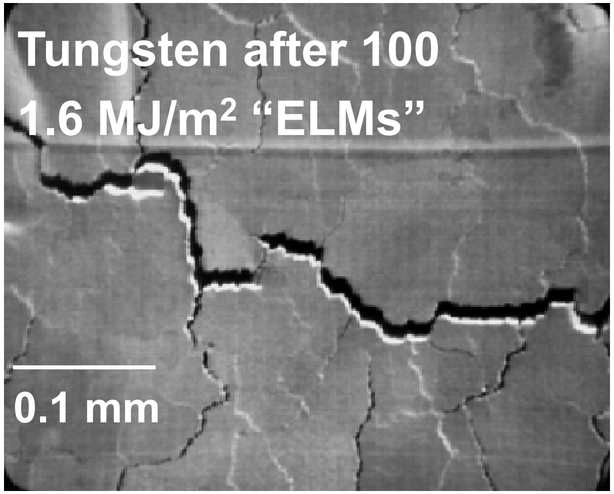
$\Delta W_{ELM}/W_{MHD} \leq$ 30%

R. Maingi, JNM 2005

ELMs: The good, the bad, and the ugly

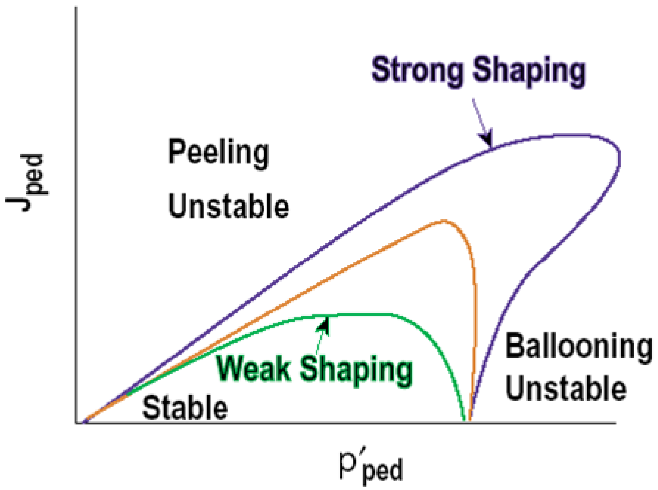
- The good: Eject impurities
- The bad: Erosion, melting, and cracking of plasma facing components (PFCs), reduced confinement
- The ugly: Large ELMs very destructive
  - ITER needs a small or no ELM regime to ensure PFC integrity
  - Requires $\Delta W_{ELM}/W_{TOTAL} \leq 0.3\%$ for steady ELMs
  - No Large ELMs allowed!

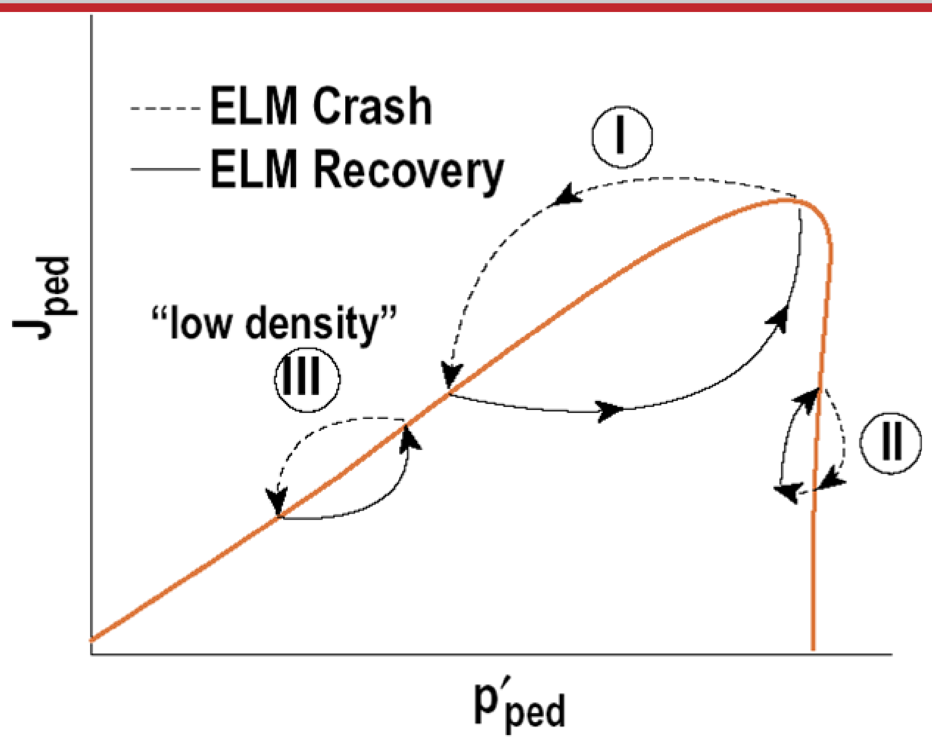




Zhitlukin, Linke
PSI 2006

Different types of ELM cycles can be envisioned

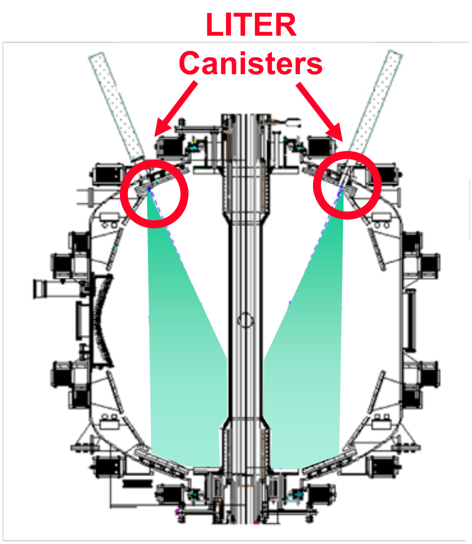




- ELMs triggered by peeling-ballooning modes, ELM size correlates to depth of most unstable mode and to location in parameter space
- Pressure rises up on transport time scale between ELMs, current rises to steady state value more slowly
- Predict changeover in ELM behavior when $J_{ped}<J_{peel} \Rightarrow$ strong density and shape dependence

UKAEA Fusion *Snyder, Wilson* GENERAL ATOMICS

NSTX lithium wall coatings induce ELM-free H-mode



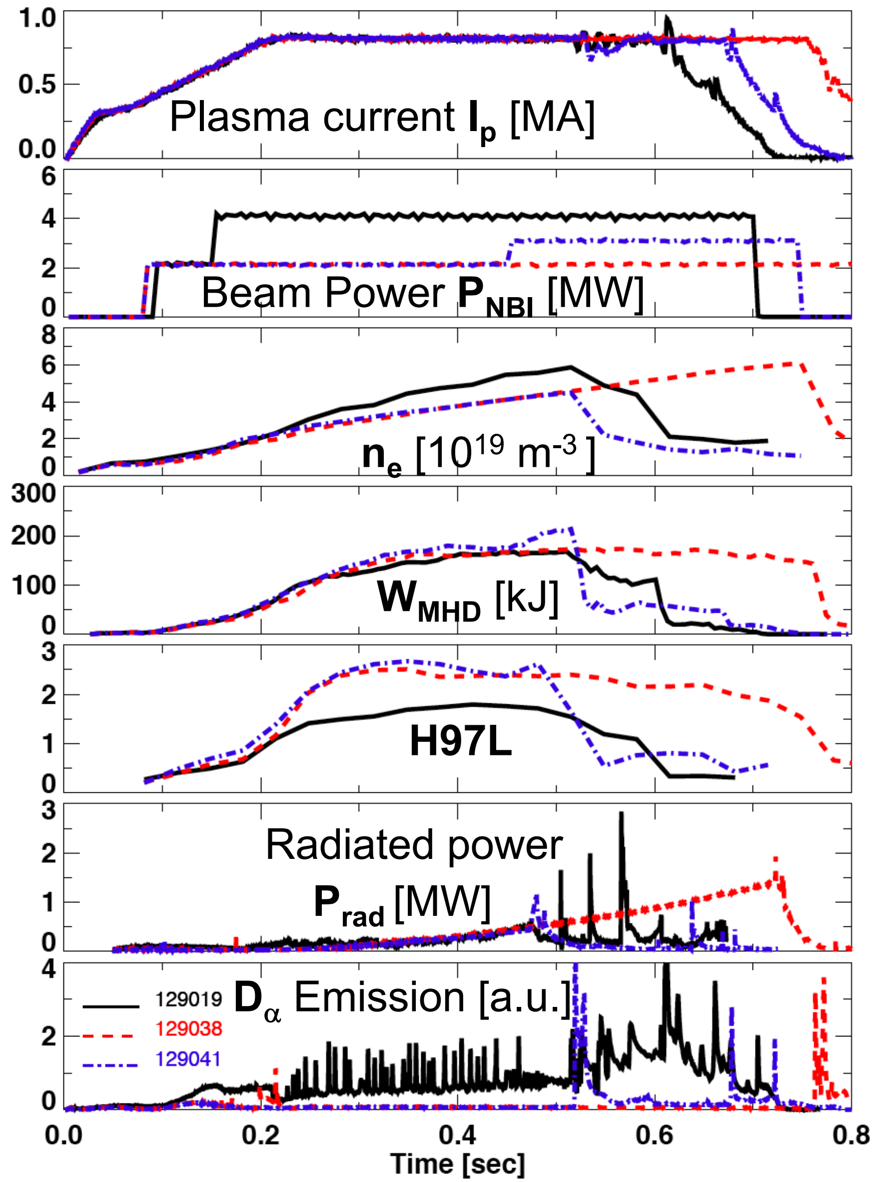
Pre-Li

Post-Li

Post-Li

@ β limit

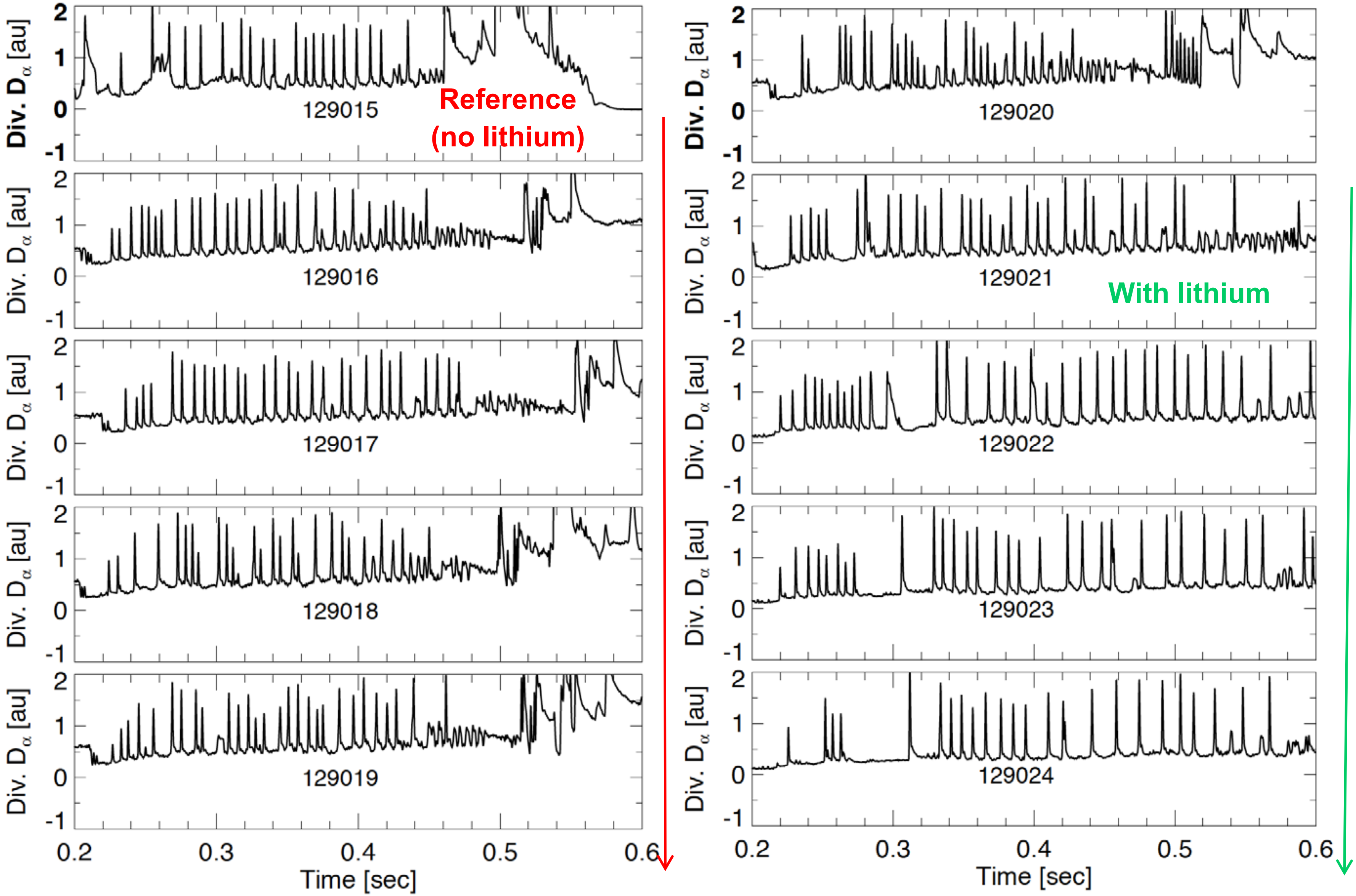
~ 700mg Li before 129038



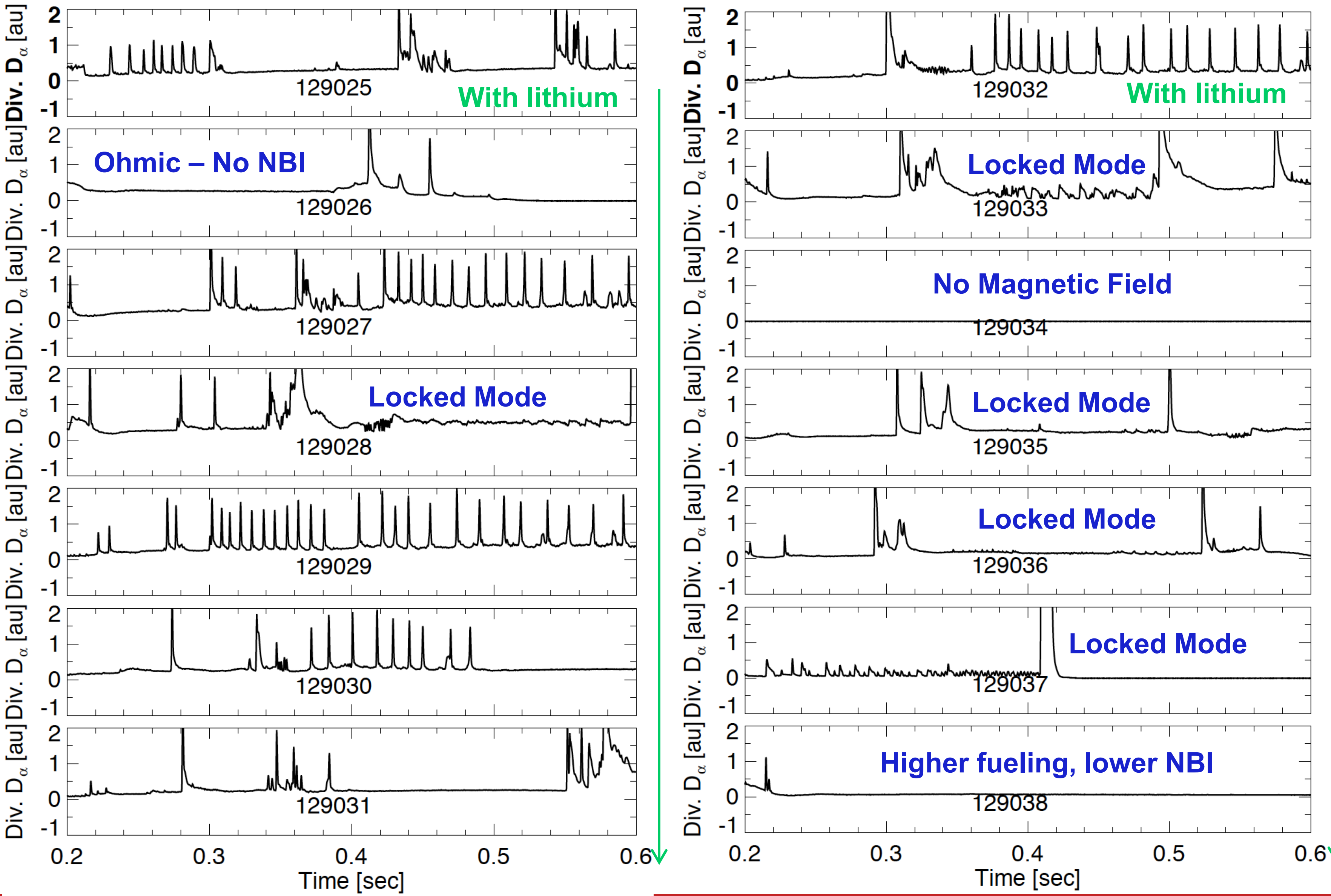
- Longer discharges
- Lower NBI to avoid β stability limit
- Slower growth of electron density
- Same stored energy w/ less heating
  - Improved confinement
- H-factor 40% higher
- Same P_{rad} but keeps growing after 0.5 s
  - Higher P_{rad} /P_{heat}
  - Impurity buildup w/o ELMs
- ELM-free, reduced divertor recycling

Maingi PRL 2009

ELM evolution with shot number



Quiescent phases increase with increasing lithium coating



How does lithium make ELMs go away?

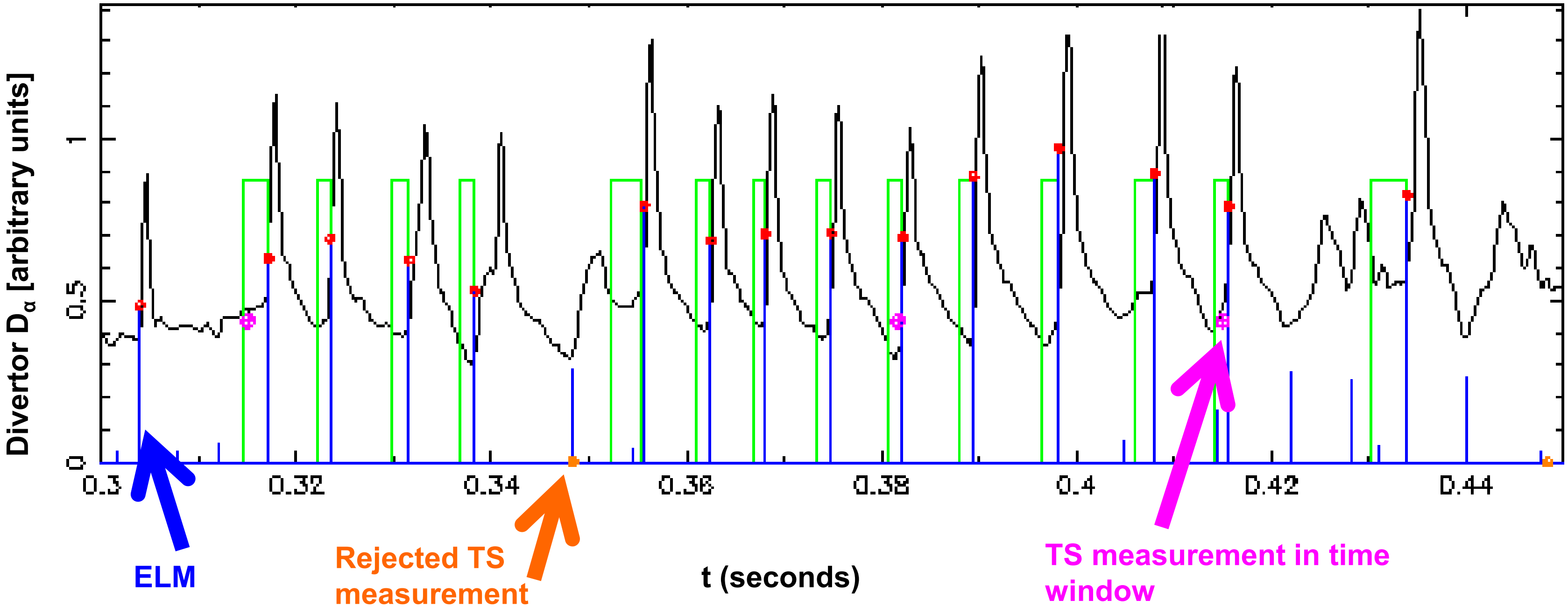
- How are n, T, P, J profiles different?
- How is the edge stability different?
- How do stability calculations reflect changes in ELM behavior?

Edge profile & stability analysis procedure

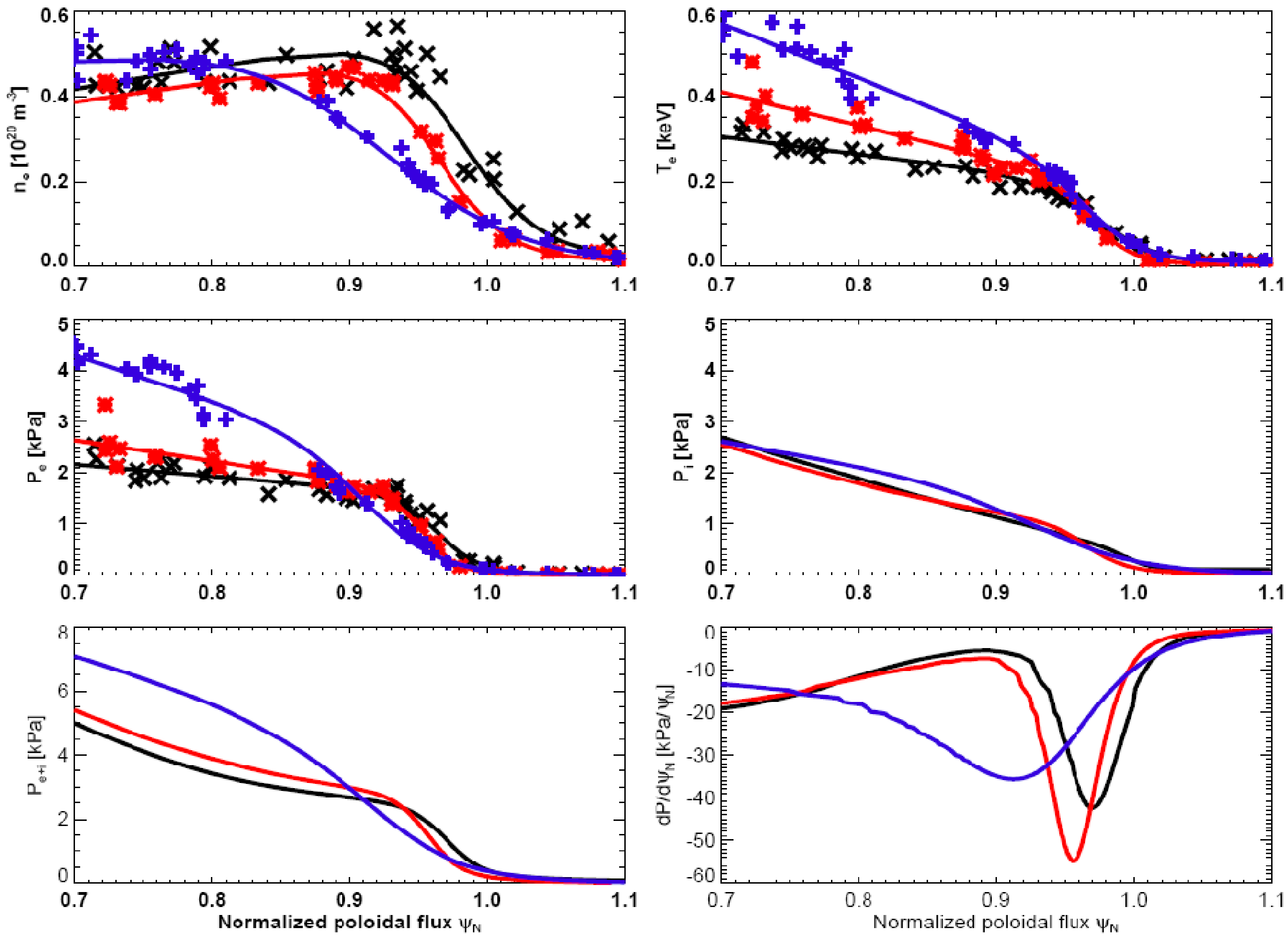
- EFIT equilibrium reconstruction code run at Thomson scattering (TS) profile times for flux (ψ_N) mapping
- Profile fitting with multiple time slices
  - Pre-lithium discharge profiles from last 20-70% of ELM cycle selected
  - Post-lithium discharge profiles used in 100-200 msec windows
- Free boundary kinetic EFITs run to match pressure & current profiles
  - Edge bootstrap current computed from Sauter neoclassical model
    - No direct measurement ➡ biggest uncertainty
  - Stability evaluated with PEST code
- Fixed boundary kinetic EFITs run with variations of edge pressure gradient and edge current
  - Stability boundary evaluated with ELITE code

Multiple TS profiles combined for better edge resolution

- ELM free shots combined over ~100 ms window
- ELMy shots combined using ELM syncing
  - only use data from end of ELM cycle
- CHERS, magnetics data also combined

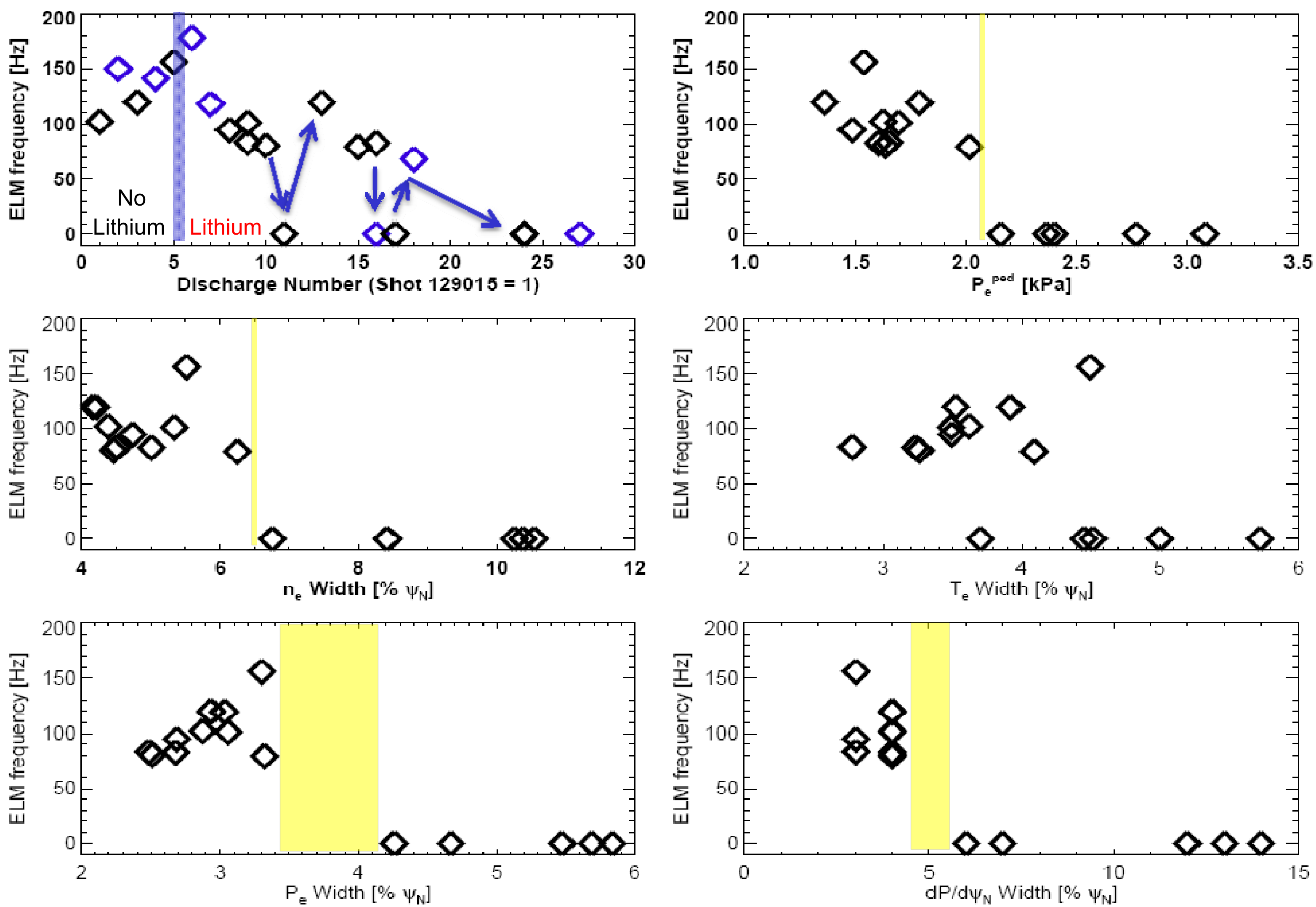


ELM-free pedestals wider, higher



Shot 129015 (ELMy) **Shot 129030 (Less ELMy)** **Shot 129038 (ELM-free)**

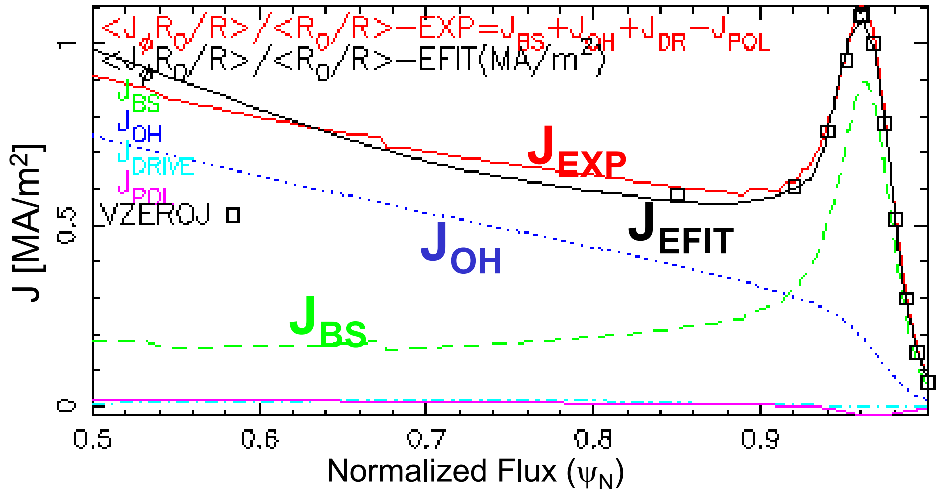
ELMy to ELM-free transition ordered by n_e and P pedestal width



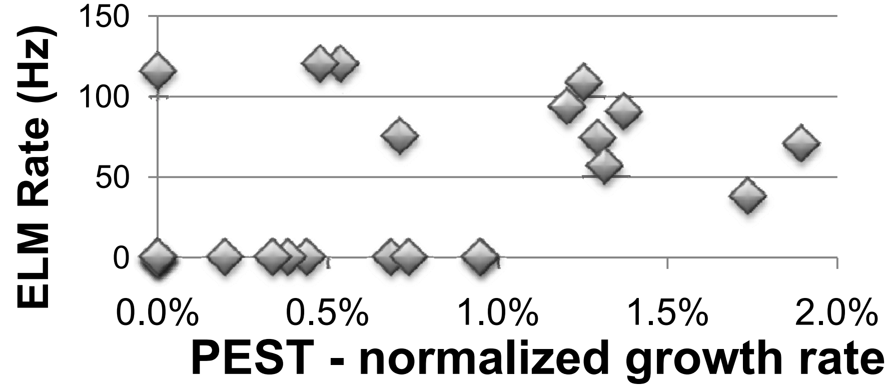
Kinetic EFITs reconstruct equilibria using additional constraints

- Constrained by measured P, J profiles
  - Bootstrap current calculated from neo-classical model

$$\mathbf{J}_{BS} \propto \nabla n, \nabla T$$



- PEST code uses EFITs to calculate growth rates
  - Uses Ideal MHD
  - Not limited to edge instabilities so caution necessary

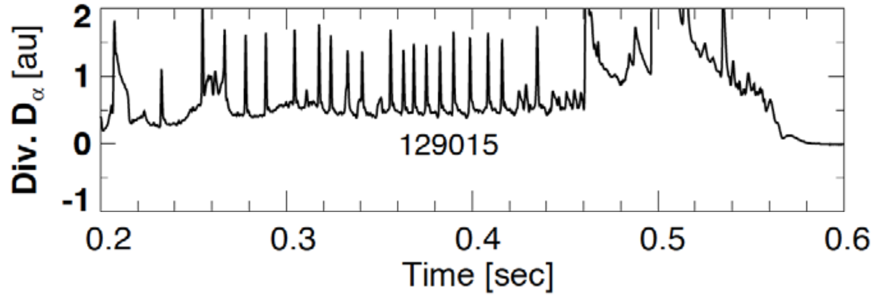


Fixed boundary-kinetic EFITs + ELITE give stability diagram

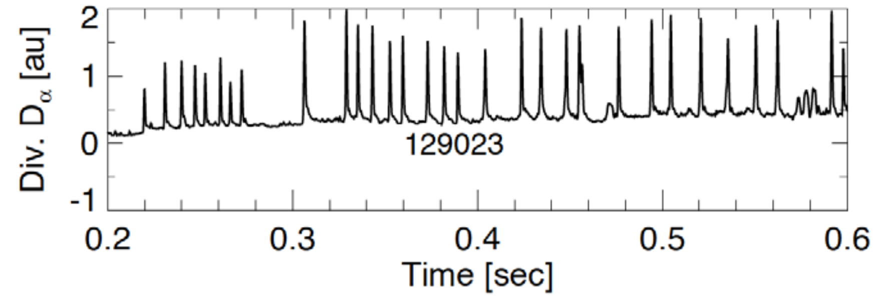
- Edge pressure gradient, currents scaled for new kinetic EFITs
  - Uses fixed-boundary from original kinetic EFIT
  - Can also scale *n*, *T*, W, ν* or shift n_e, T_e, P_e pedestal
- ELITE code calculates stability for each combination of P'_{ped} and J_{ped}
  - Only sensitive to edge instabilities
  - Gives stability diagram

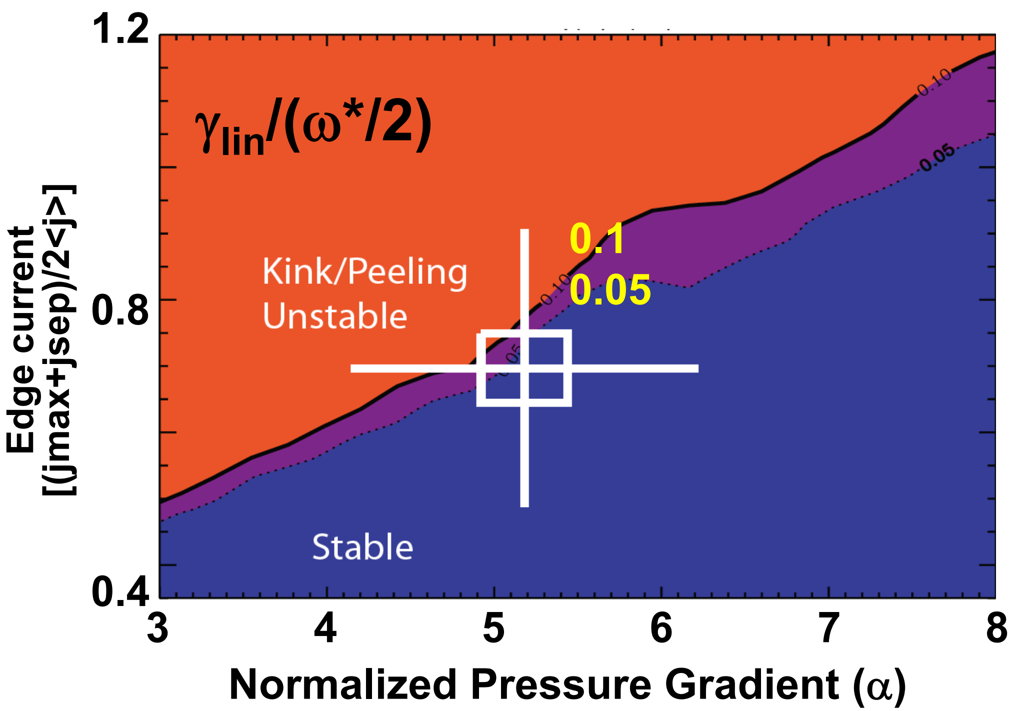
Close to instability threshold when plasma is ELMy

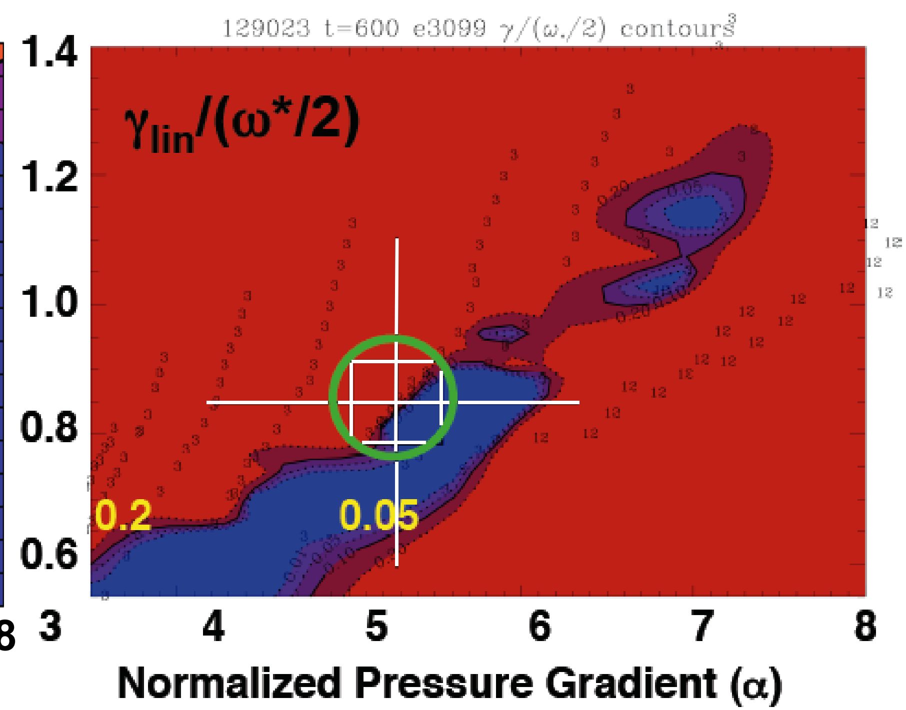
No lithium - ELMy



With lithium - ELMy

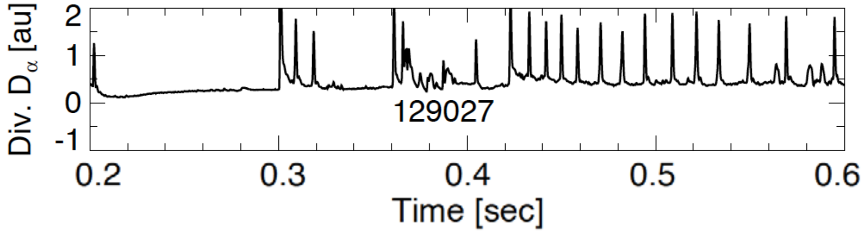




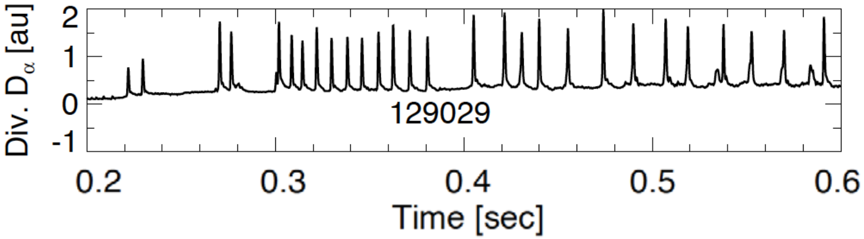


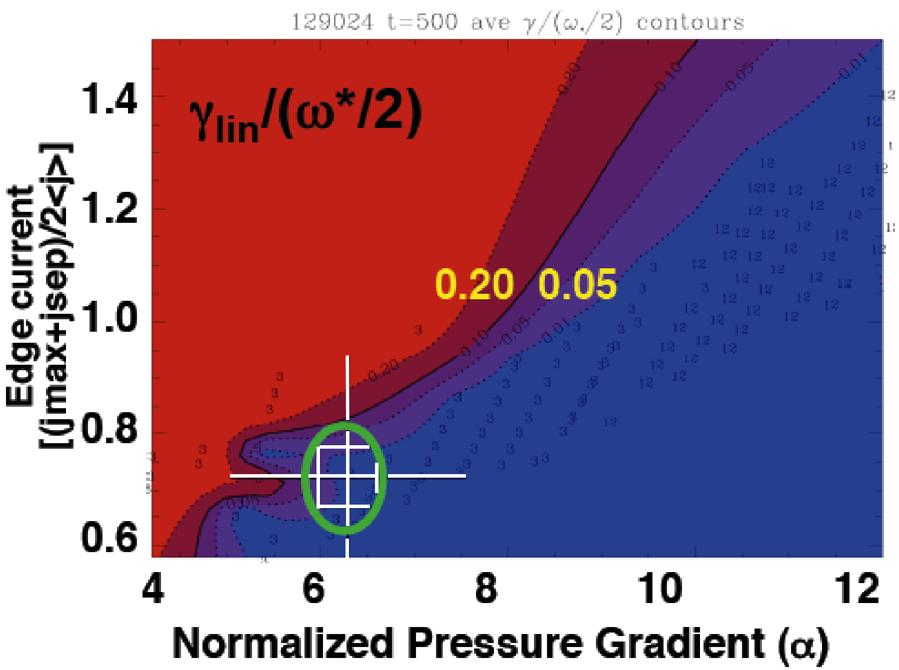
Stability boundary shifts after some lithium but ELMs continue

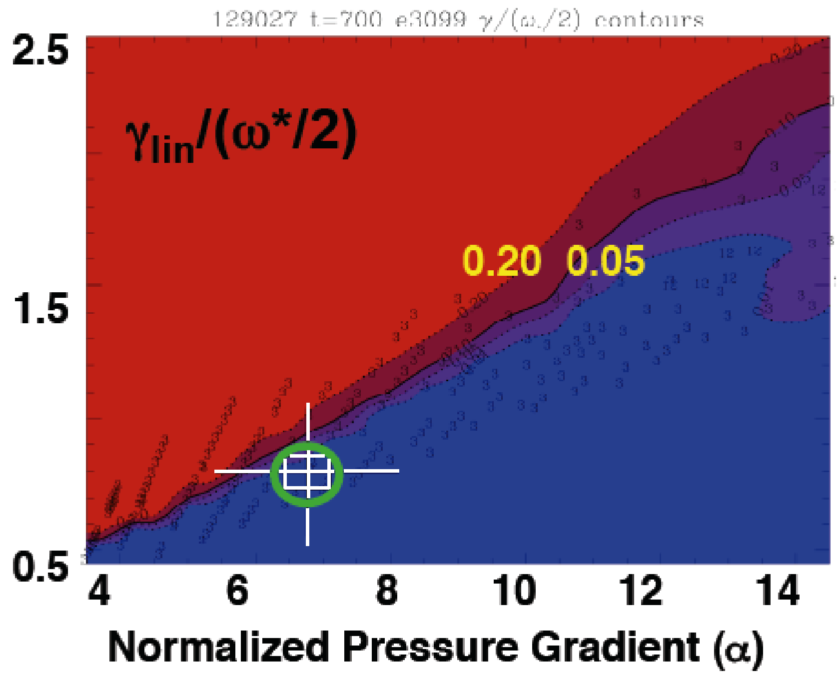
With lithium- ELMy



With lithium - ELMy

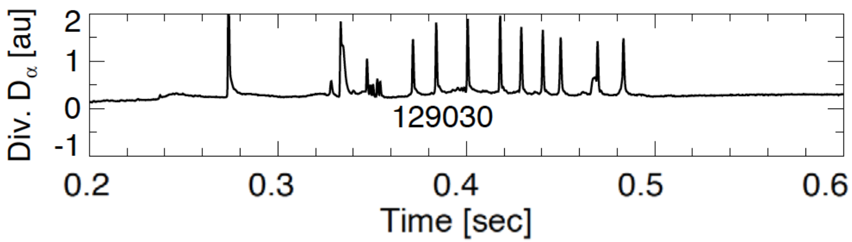


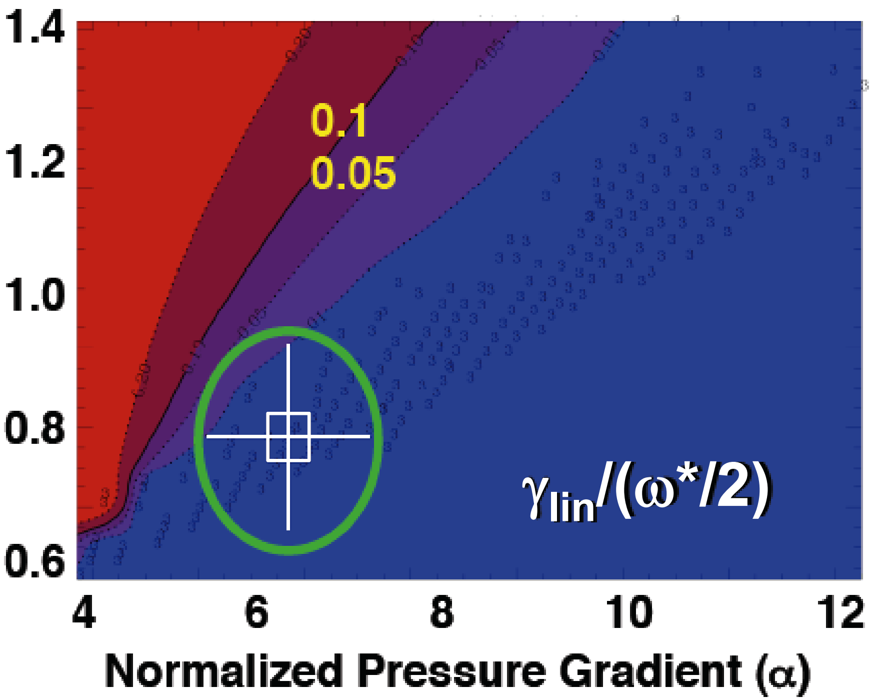




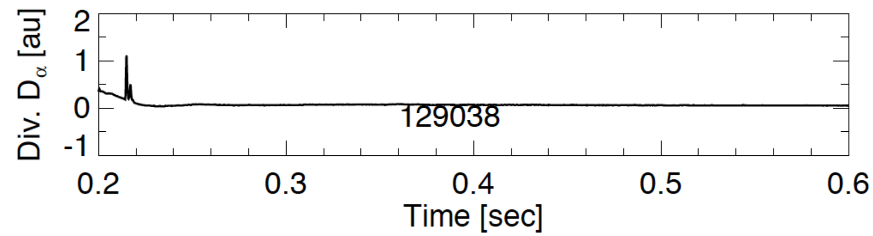
Farther from instability threshold when ELM-free

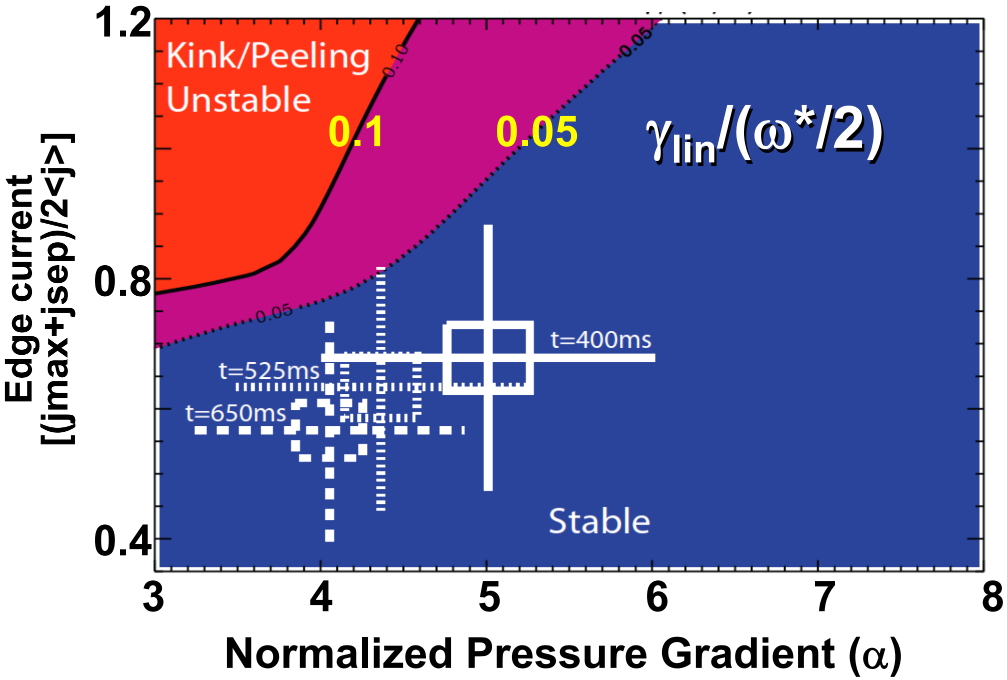
With lithium (Reduced ELMs)





With lithium (ELM-free)





Conclusions

- Lithium wall coatings in NSTX gradually reduced, then completely eliminated ELMs
  - ELM-free plasmas have wider n_e pedestals
  - Also have wider & higher P_e & P pedestals
  - Peak pressure gradient shifted inward
  - n_e pedestal gradient reduced with increasing lithium
  - Edge T_e, T_i increase and profiles change substantially
- ELM-free plasmas are farther from the edge stability boundary
  - Both boundaries and profiles move as lithium added

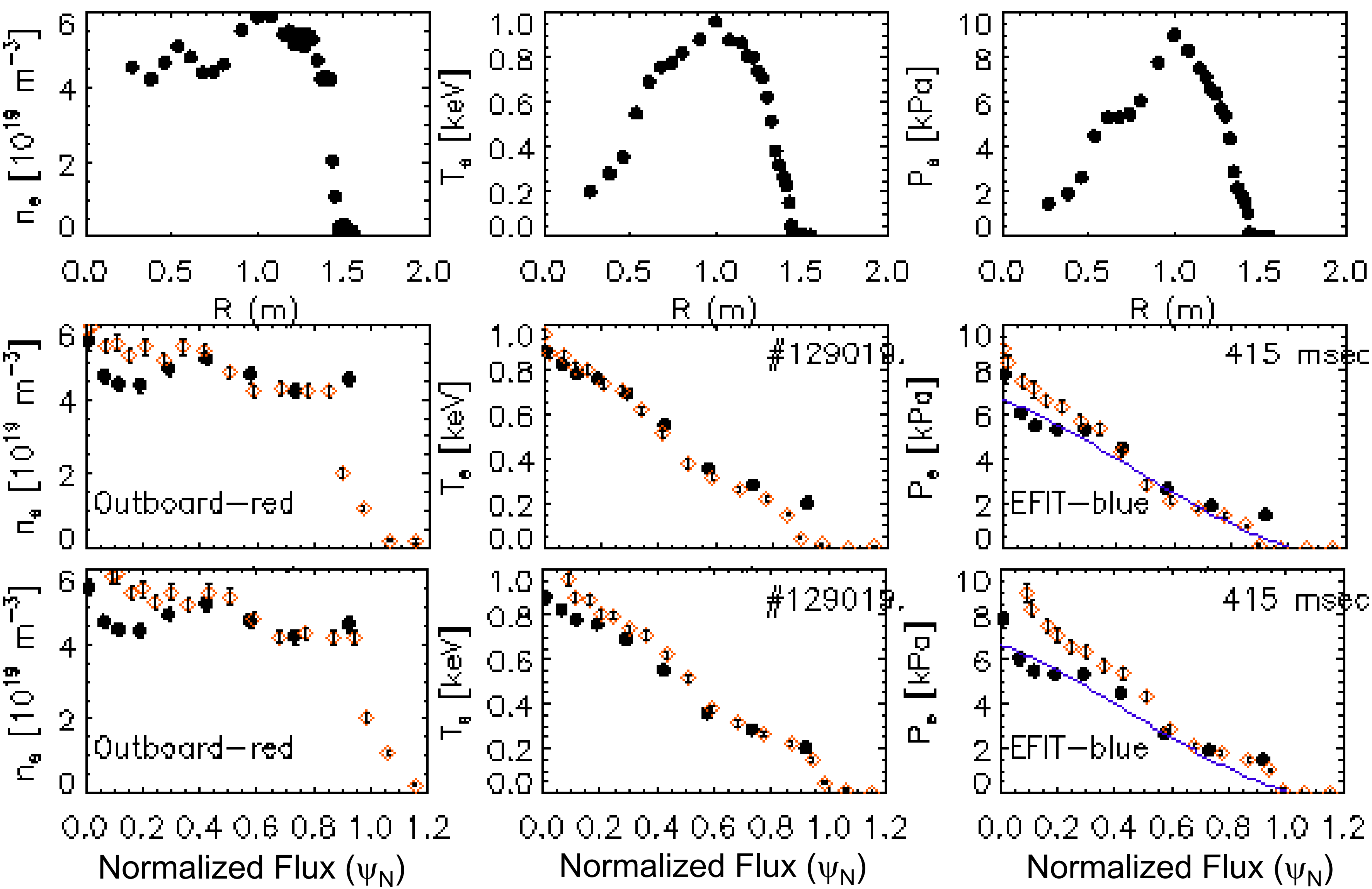
Density profile modification due to lithium pumping is the key in changing edge stability

Lithium reduces recycling → Core fueling reduced → Density profile relaxes → Peak edge pressure gradient moves to reduced magnetic shear → Edge bootstrap and parallel current modified → Kink/peeling stability improved -> ELMs suppressed

Future Work

- Calculate stability while varying model profiles
- Why are the ELMs not stabilized by diamagnetic drift, as in higher aspect ratio tokamaks?
  - Low growth rates: $\gamma_{lin}/\omega_A \geq 1\%$ unstable experimentally
  - Should be stabilized by diamagnetic drift: $\gamma_{lin}/(\omega^*/2) \leq 5\text{-}10\%$
- Why do ELMs go away the way they do i.e. with increasing periods of quiescence?
  - Details of density/pressure profile modification may be beyond present ability to measure experimentally
    - Additional Thomson channels being installed for 2011
    - Better edge resolution could make multiple TS times unnecessary
  - How do profiles and stability evolve through ELM cycle?

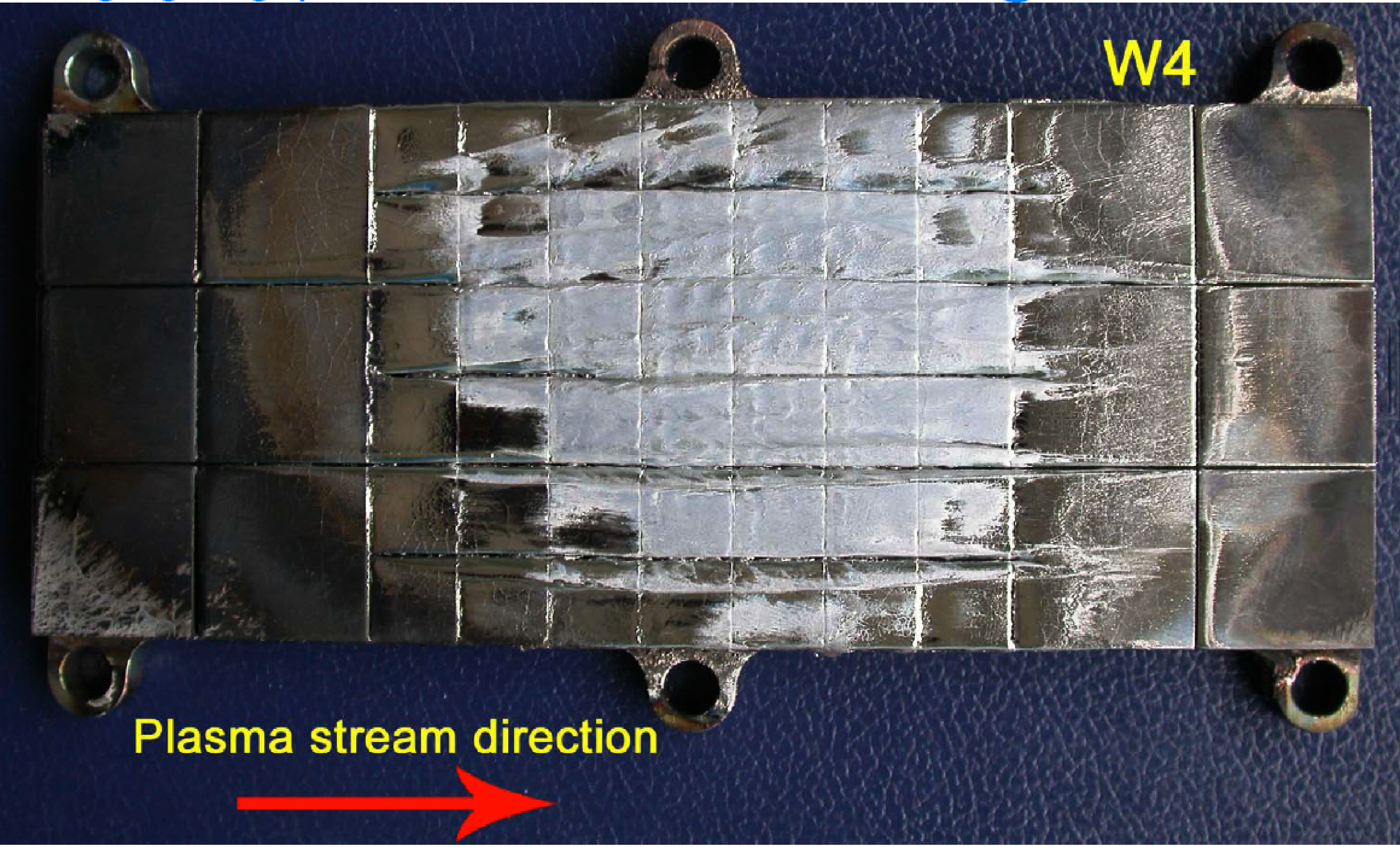
EFITs require setting outboard T_e at separatrix for flux mapping of Thomson scattering profiles

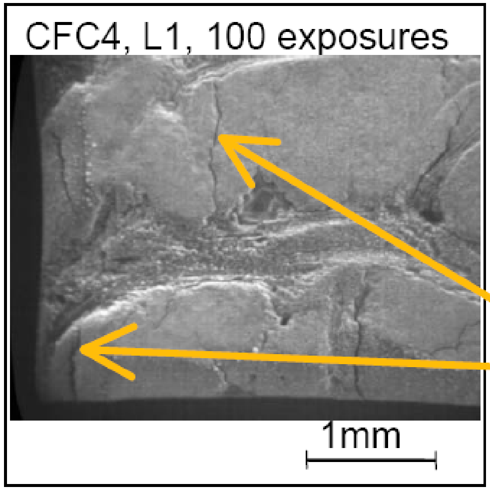


Experimental results (7)

Troitsk Institute for Innovation and Fusion Research

Bridging of gaps due to melt motion, 100 shots @ w = 1.6 MJ/m^2





w = 1.0 MJ/m^2

Plasma stream direction

crack formation

•Carbon: erosion of fibers, cracking of fibers, dust

•Tungsten: melting -> bridge tile gaps, crack formation