NSTX

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The relationships between ELM suppression, pedestal profiles, and lithium wall coatings in NSTX

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GENERAL ATOMICS

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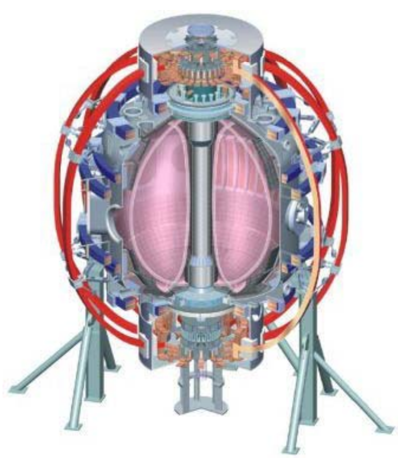

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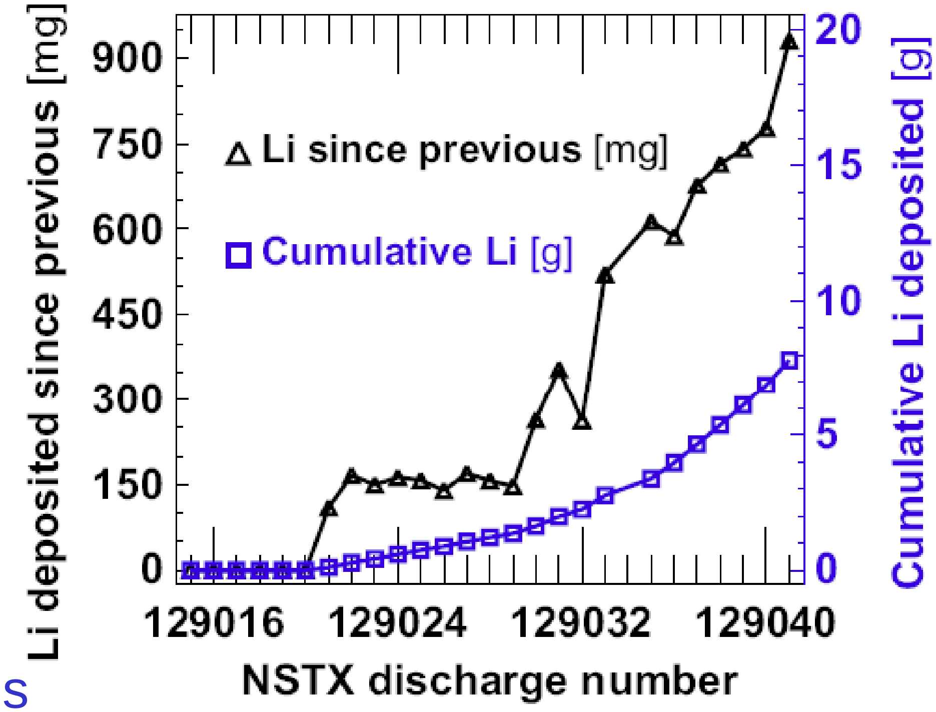
The relationships between ELM suppression, pedestal profiles, and lithium wall coatings in NSTX

- Same experiment as previous talk
- Examine how the edge profiles changed as increasing Li suppressed Edge Localized Modes (ELMs)
  - Compare representative profiles
  - Compare fitting parameters from all profiles throughout Li scan
- Compare observed changes in ELM stability to predictions from peeling ballooning theory



Experiment: **Kugel et al 2009 JNM**
ELM observations: **Mansfield et al 2009 JNM**
Profile/stability: **Maingi et al 2009 PRL**
Analysis of full scan: **Boyle et al 2011 PPCF**

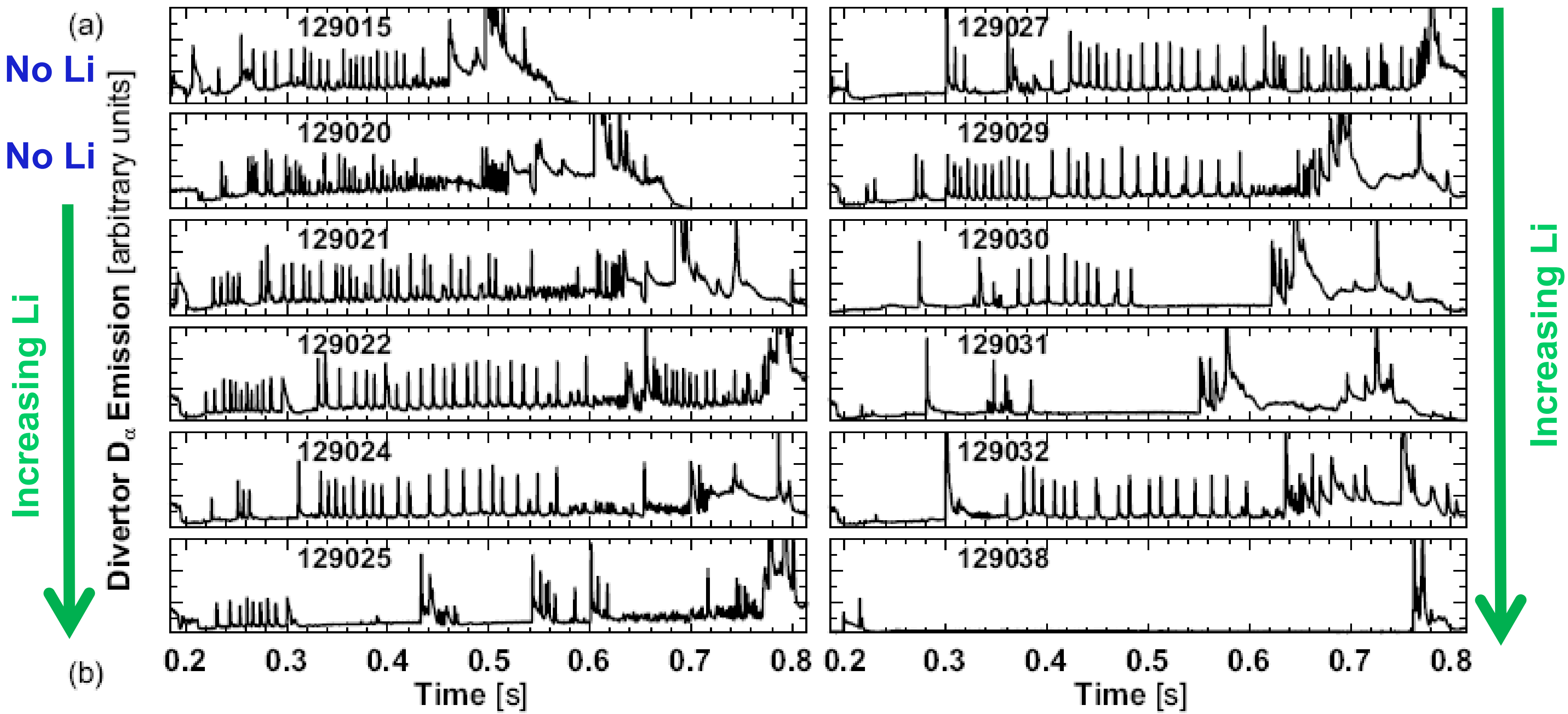
Density profile modification due to lithium pumping is the key in changing edge stability

Lithium reduces recycling → Fueling from recycling reduced → Density profile relaxes

↓

Kink/peeling stability improved -> ELMs suppressed ← Edge bootstrap current modified ← Edge pressure gradient peak moves away from separatrix

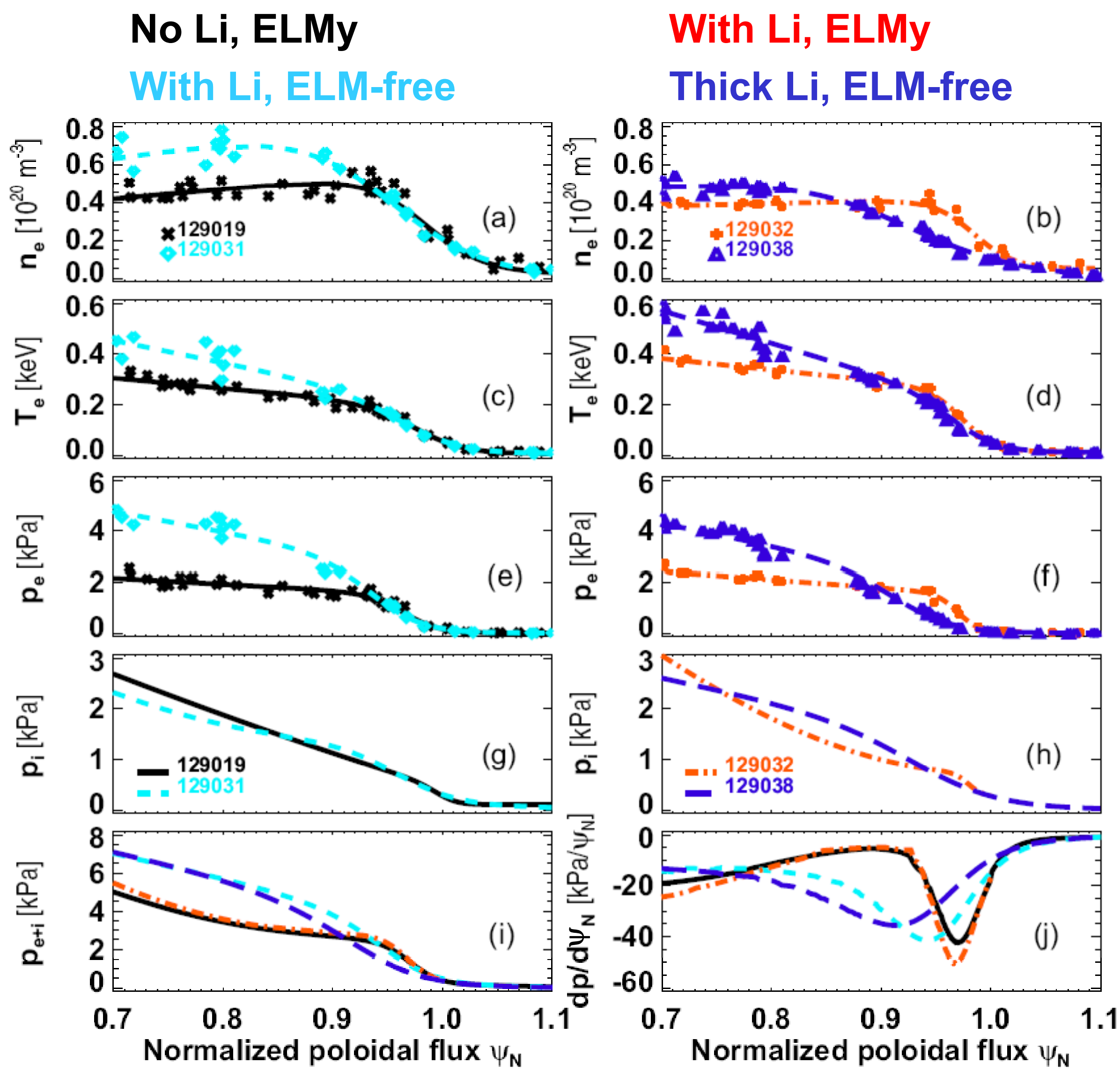
Increasing lithium gradually suppresses ELMs



- Suppression of ELMs not quite monotonic
  - Enlightening to compare no-Li ELMy to with-Li ELMy

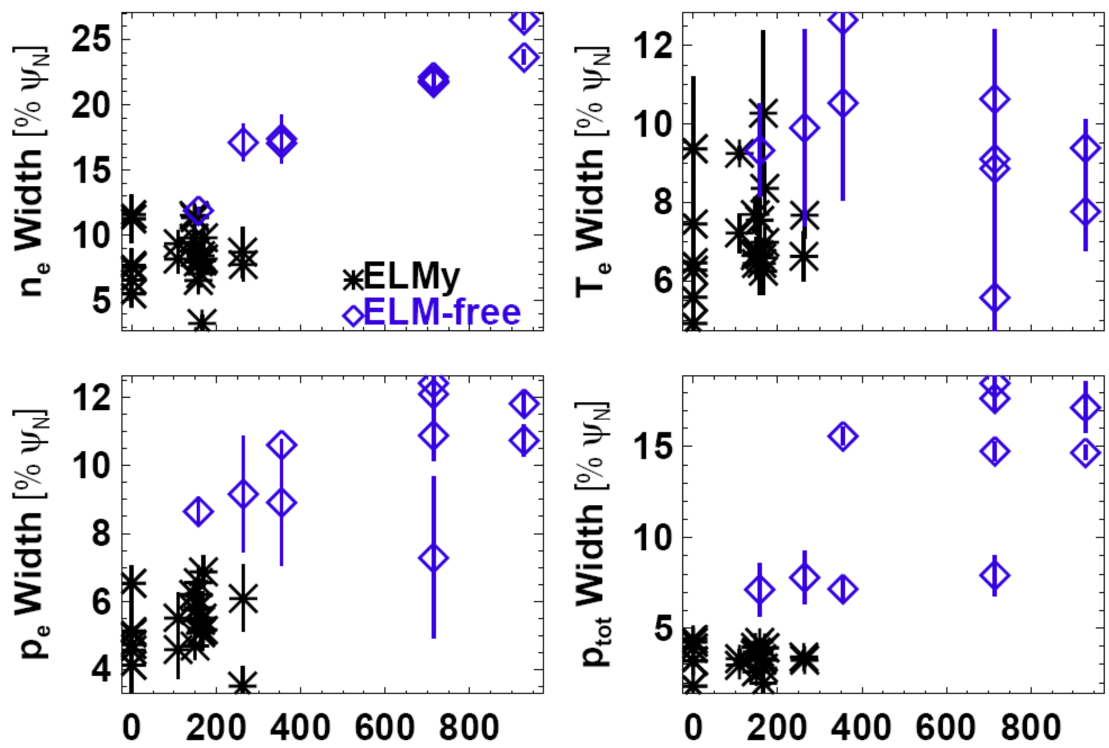
In ELM-free discharges, Li has modified edge density profile

- ELM-free n_e and p_e pedestals are wider, p_e pedestals higher
- ELMy profiles same with or without Li
- T_e clamped for $\psi_N > 0.95$
- P_i shows less change
- ELMy and ELM-free pressure gradient peaks same size, but ELM-free wider and shifted inward



Density and pressure pedestals wider in ELM-free plasmas

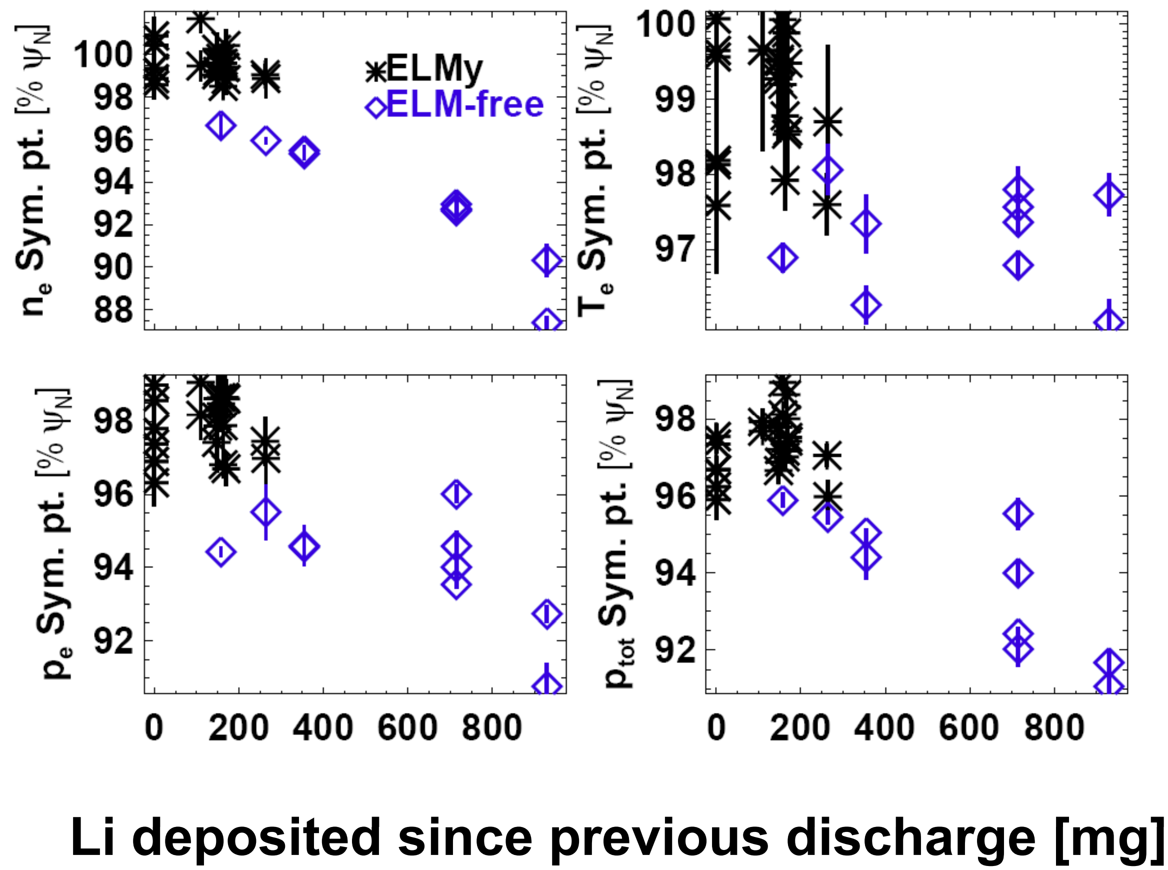
- n_e, p_e, p_{tot} pedestal widths correlated with Li
- T_e pedestal width does not separate ELMy from ELM-free and is not correlated with Li



Li deposited since previous discharge [mg]

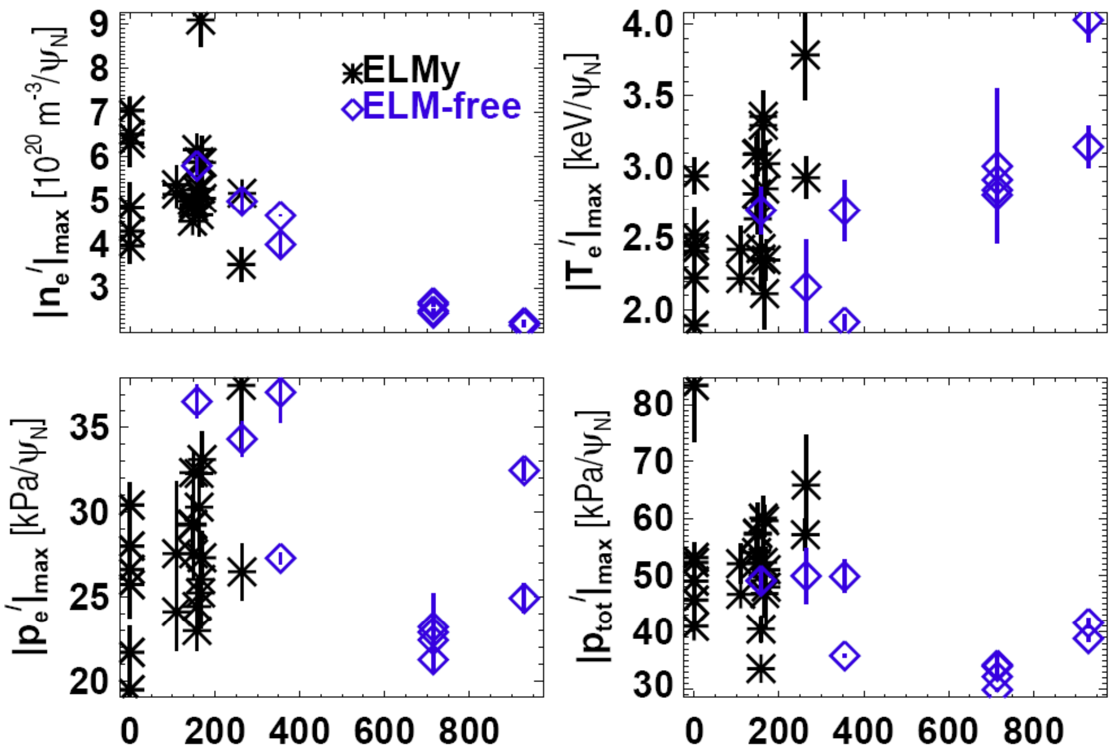
Peak density and pressure gradients farther from separatrix in ELM-free plasmas

- n_e, p_e, p_{tot} symmetry points correlated with Li
- T_e symmetry point does not separate ELMy from ELM-free and is not correlated with Li



Peak gradients magnitudes do not separate ELMy from ELM-free

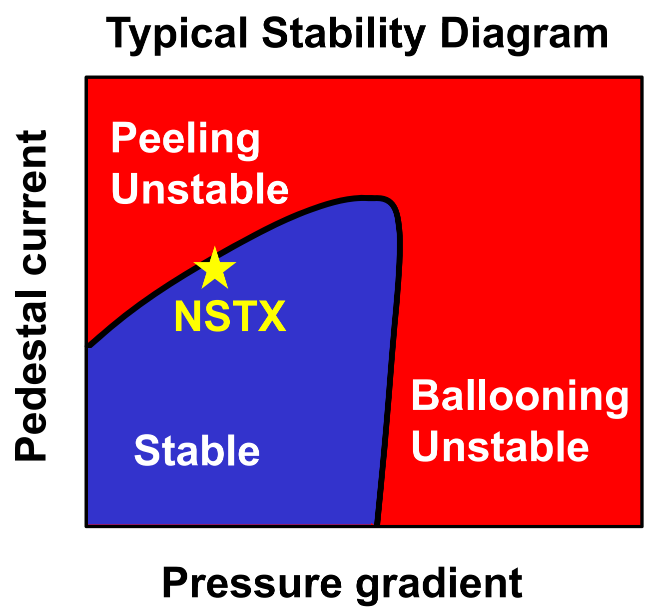
- Peak gradient magnitudes may be correlated with Li



Li deposited since previous discharge [mg]

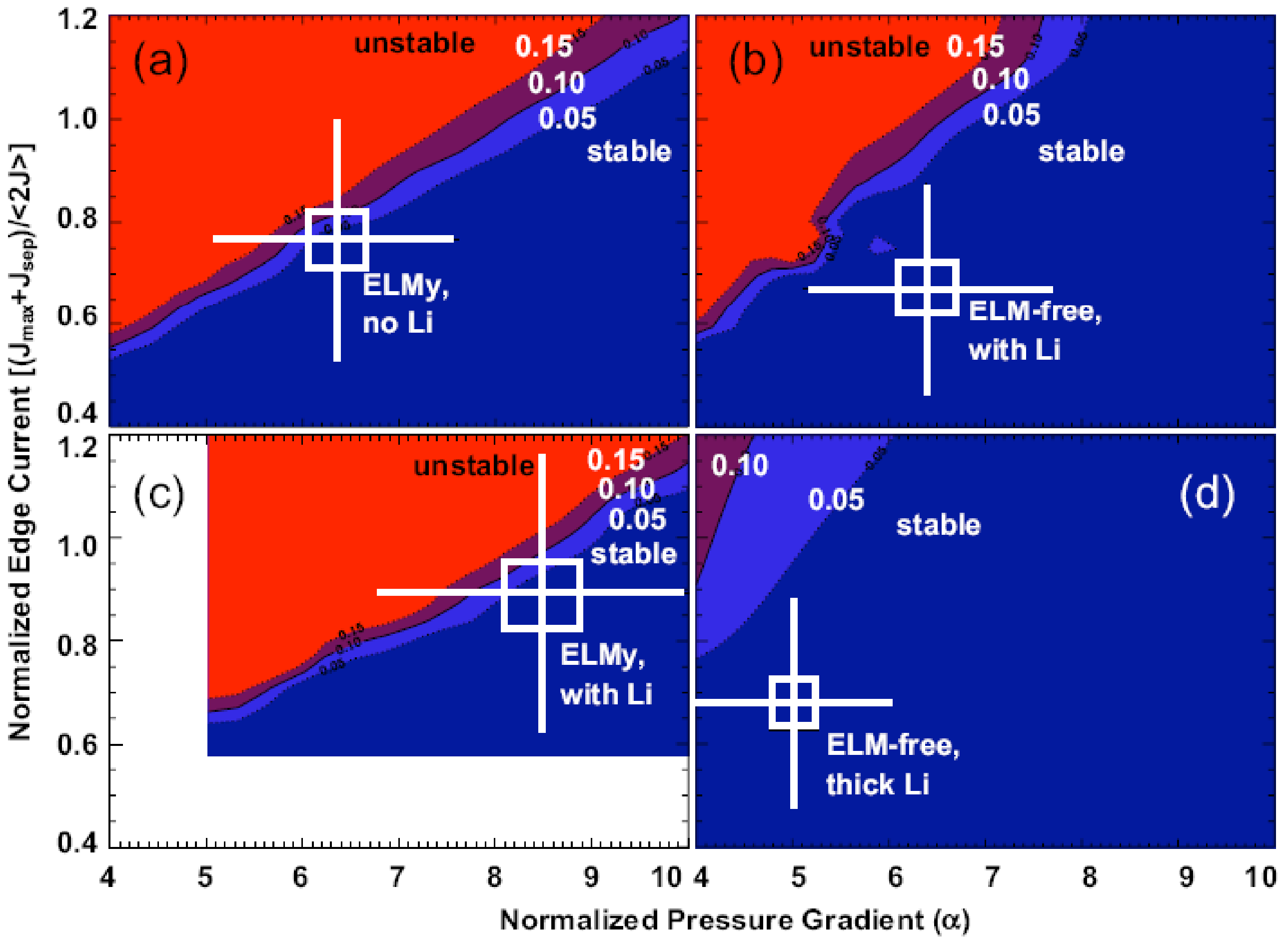
Peeling-ballooning modes believed to cause ELMs

- Stability determined by edge current and pressure gradient
- Crossing stability boundary causes current driven peeling modes or pressure driven ballooning modes.
- In this experiment, peak gradient magnitudes are **not** key parameter for ELM stability
- Location of the stability boundary depends on location of peak gradients
  - Farther from separatrix is stabilizing



ELM-free discharges farther from peeling stability boundary

- ELITE calculations show NSTX discharges are close to peeling stability
- Stabilization occurs when boundary moves up and left
- ELMy with-Li similar to no-Li



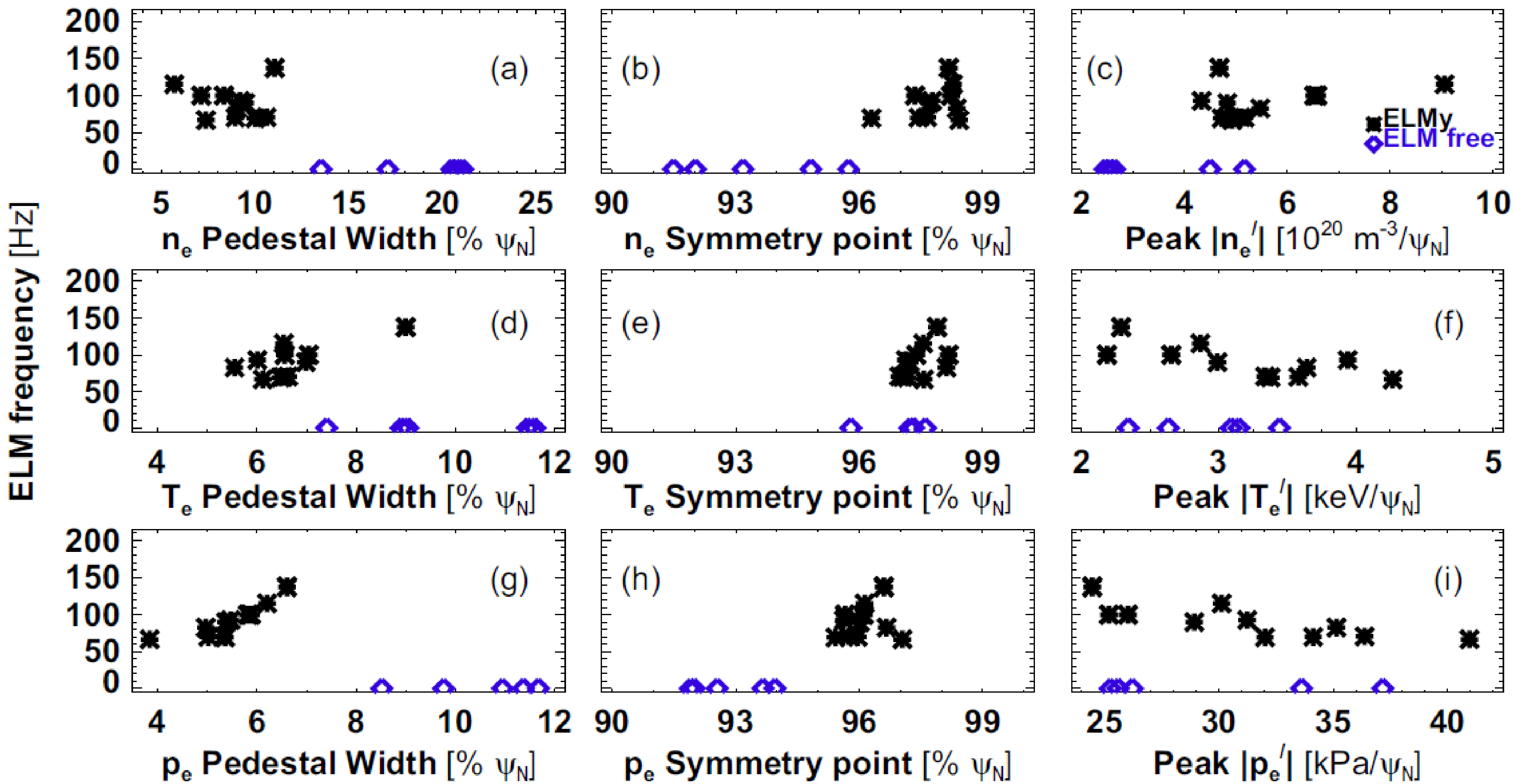
Density profile modification due to lithium pumping is the key in changing edge stability

Lithium reduces recycling → Fueling from recycling reduced → Density profile relaxes → Edge pressure gradient peak moves away from separatrix → Edge bootstrap current modified → Kink/peeling stability improved -> ELMs suppressed

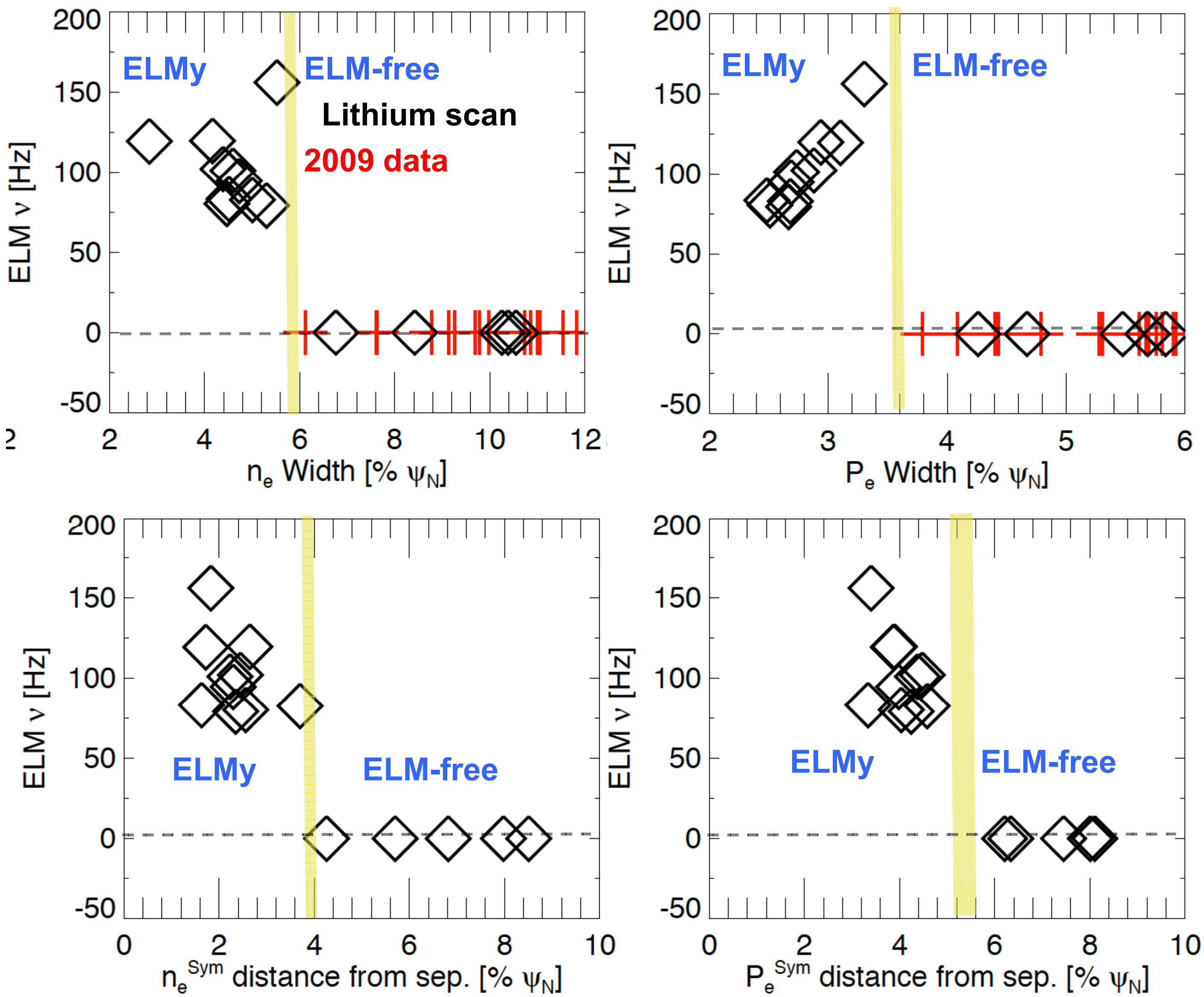
Edge transport reduced, Confinement improved

Thank you

ELM Frequency plots



Widening of pedestal widths also correlates with movement of the peak gradient locations farther from separatrix

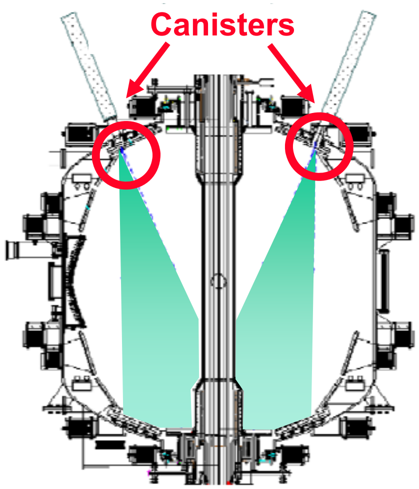


NSTX lithium wall coatings induce ELM-free H-mode

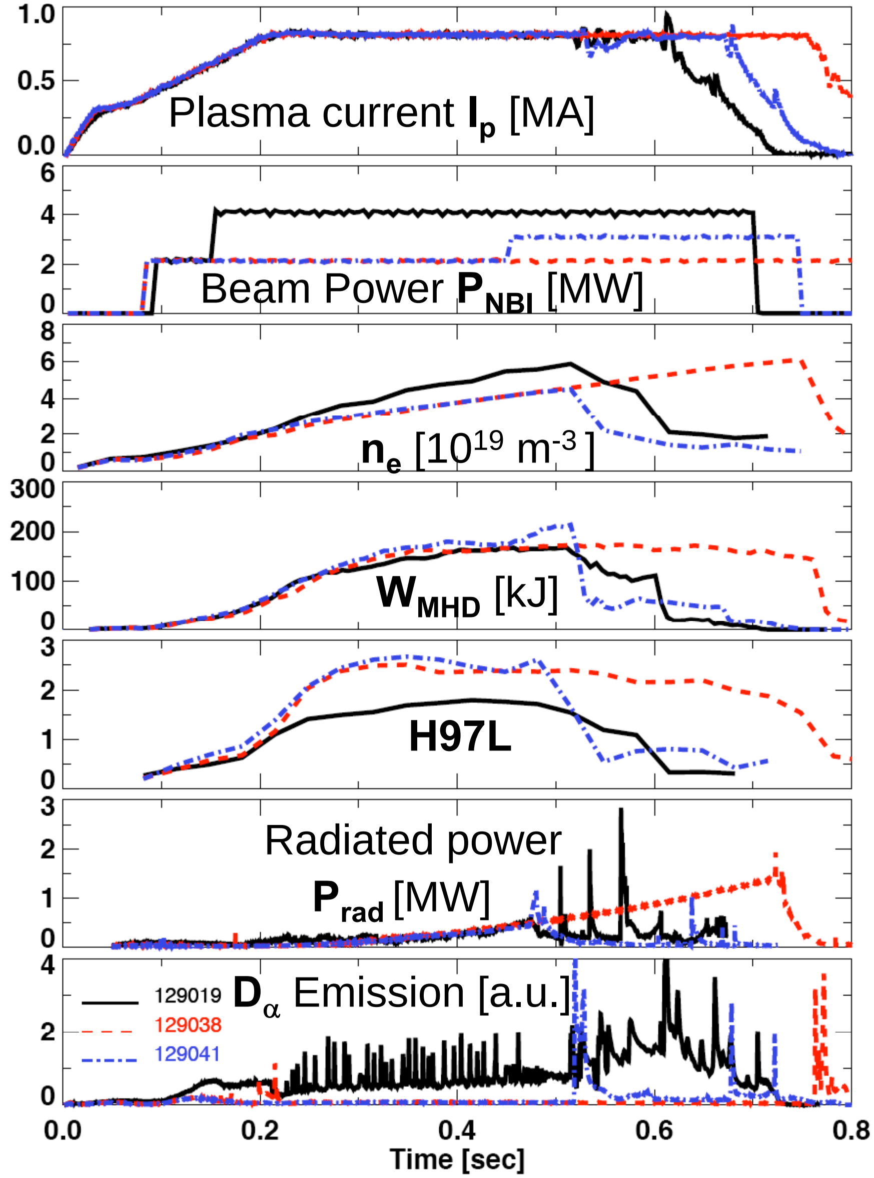
Pre-Li

Post-Li

Post-Li @ β limit



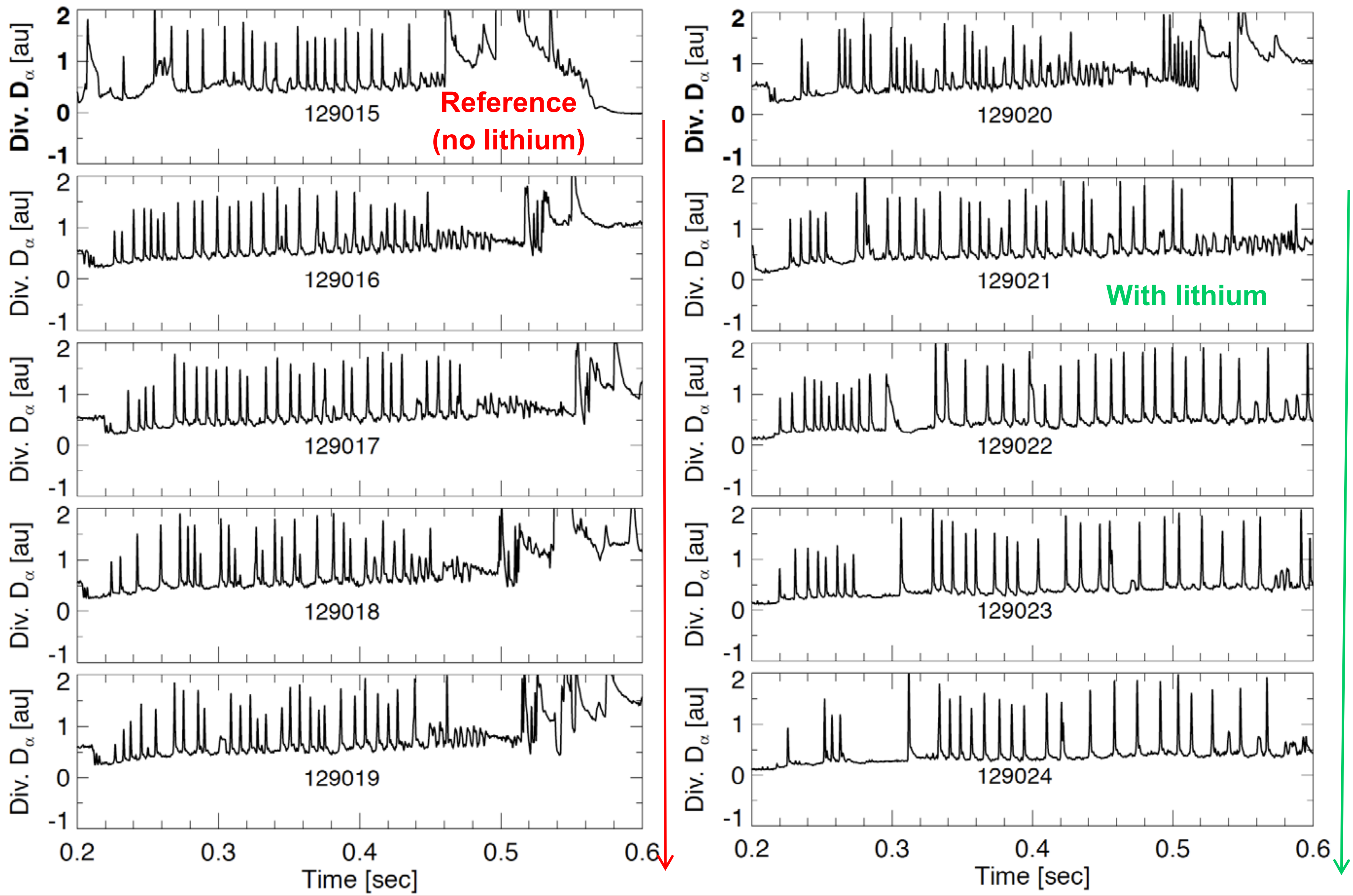
~ 700mg Li before 129038



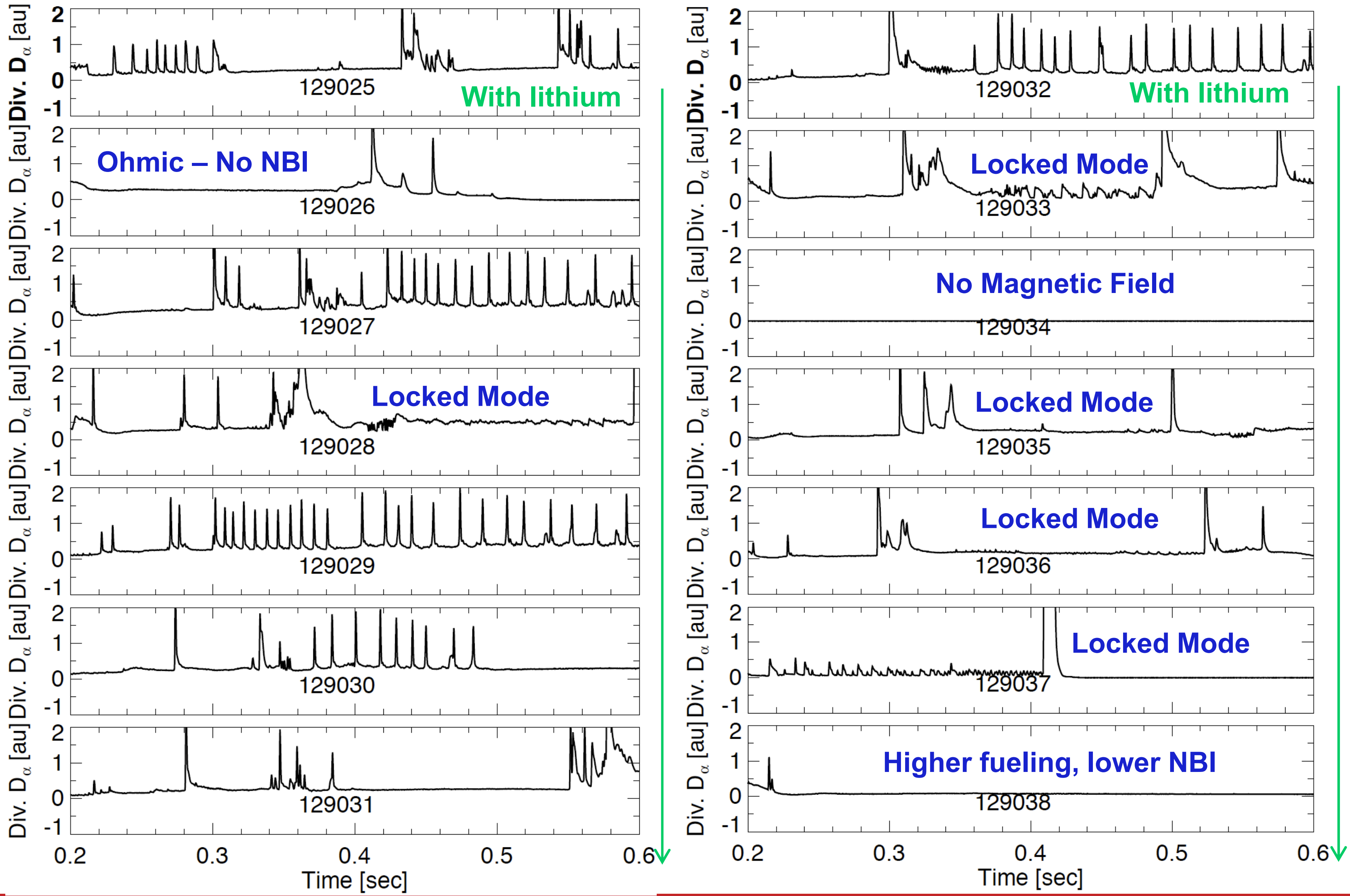
- Longer discharges
- Lower NBI to avoid β stability limit
- Slower growth of electron density
- Same stored energy w/ less heating
  - Improved confinement
- H-factor 40% higher
- Same P_{rad} but keeps growing after 0.5 s
  - Higher P_{rad} /P_{heat}
  - Impurity buildup w/o ELMs
- ELM-free, reduced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

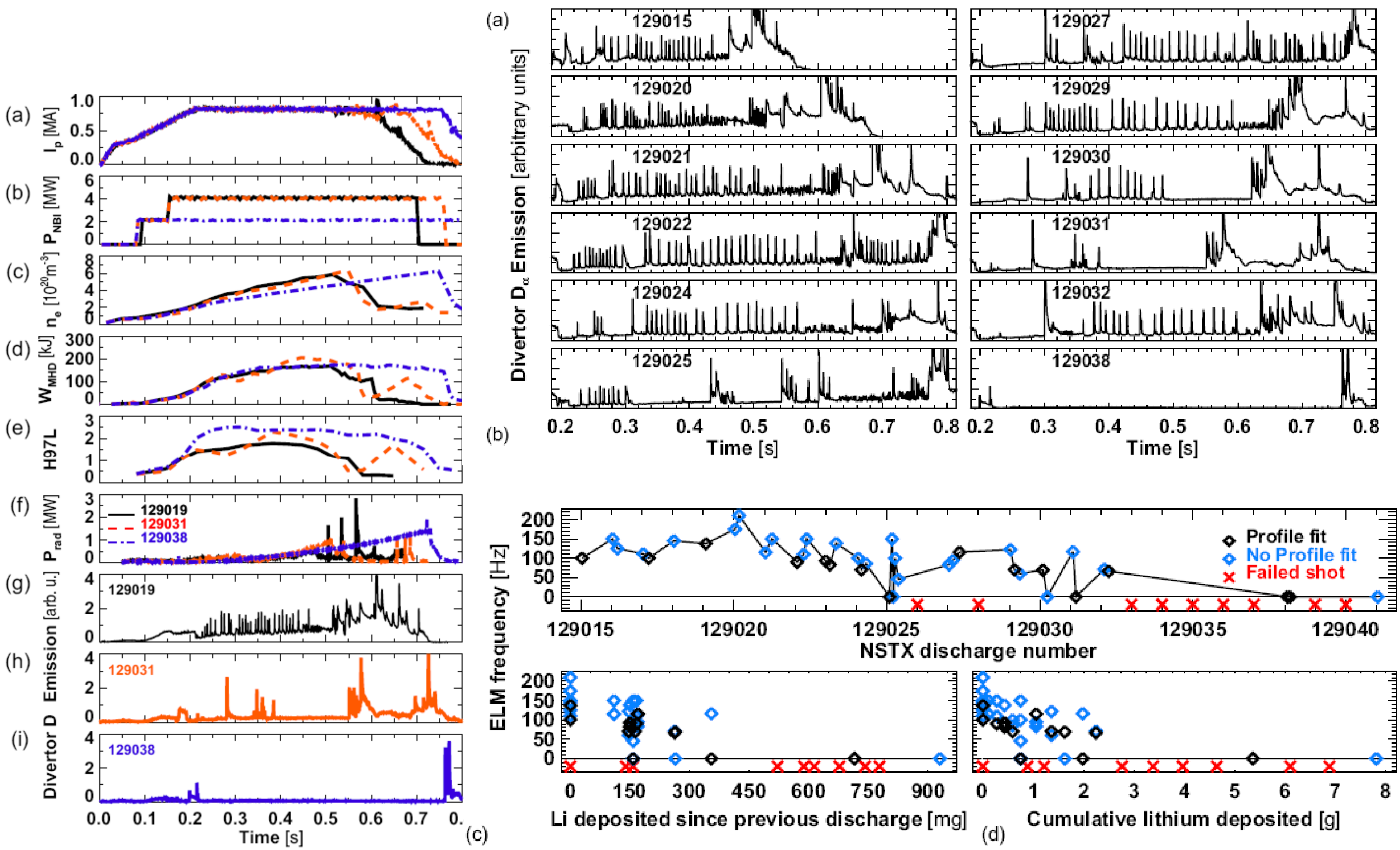
Maingi PRL 2009

ELM evolution with shot number



Quiescent phases increase with increasing lithium coating



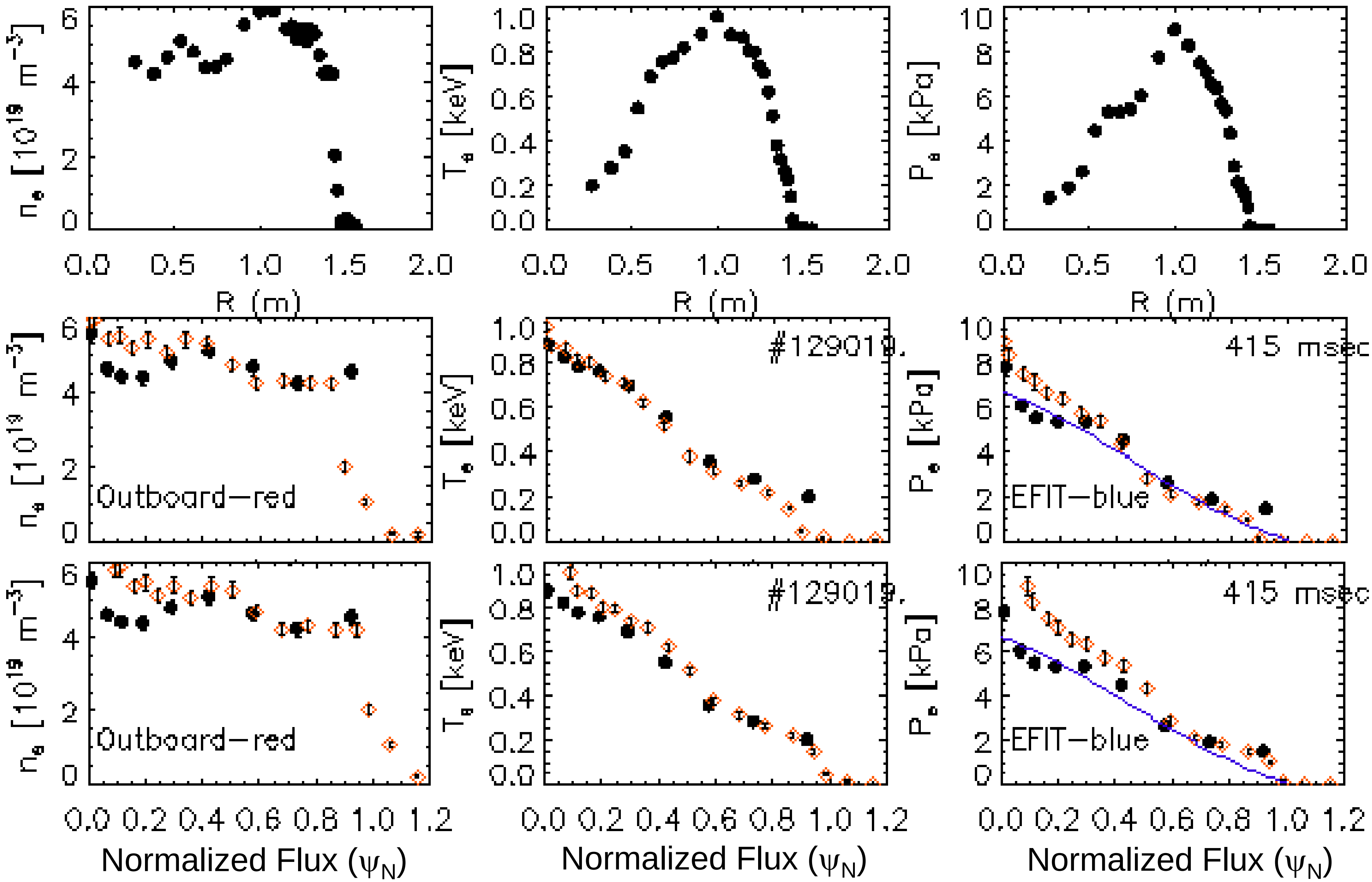


(a)
(b)
(c)
(d)
(e)
(f)
(g)
(h)
(i)
I_p [MA]
P_NBI [MW]
n_e [10^20 m^-3]
W_MHD [kJ]
H97L
P_rad [MW]
Divertor D Emission [arb. u.]
129019
129031
129038
Time [s]
Divertor D_α Emission [arbitrary units]
129015
129020
129021
129022
129024
129025
129027
129029
129030
129031
129032
129038
Time [s]
ELM frequency [Hz]
Profile fit
No Profile fit
Failed shot
NSTX discharge number
Li deposited since previous discharge [mg]
Cumulative lithium deposited [g]

Edge profile & stability analysis procedure

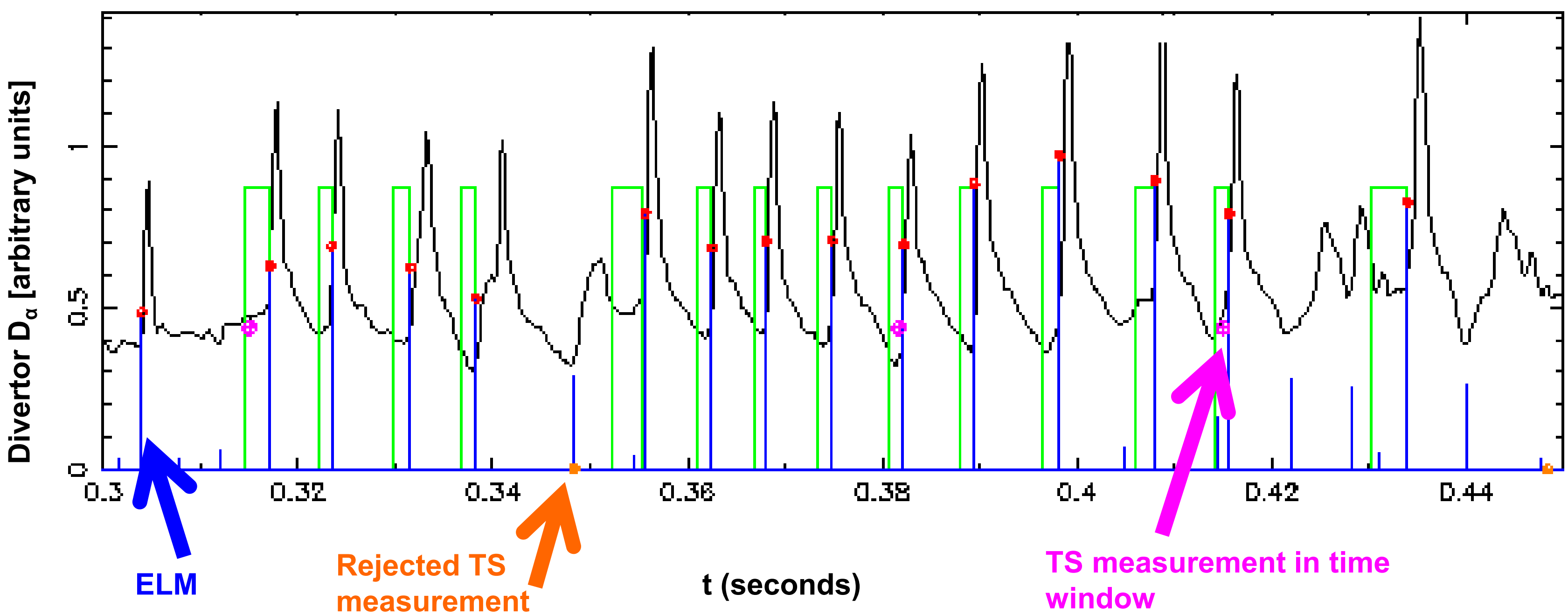
- EFIT equilibrium reconstruction code run at Thomson scattering (TS) profile times for flux (ψ_N) mapping
- Profile fitting with multiple time slices
  - Pre-lithium discharge profiles from last 20-70% of ELM cycle selected
  - Post-lithium discharge profiles used in 100-200 msec windows
- Free boundary 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

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



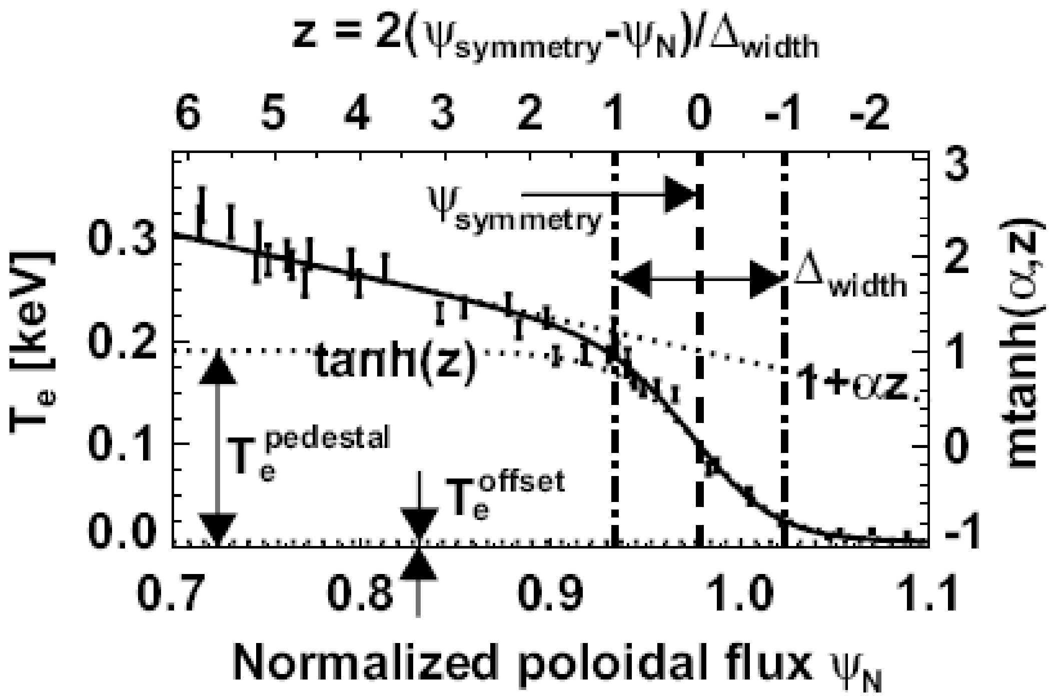
Multiple TS profiles combined for better edge resolution

- 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



Modified Tanh fits

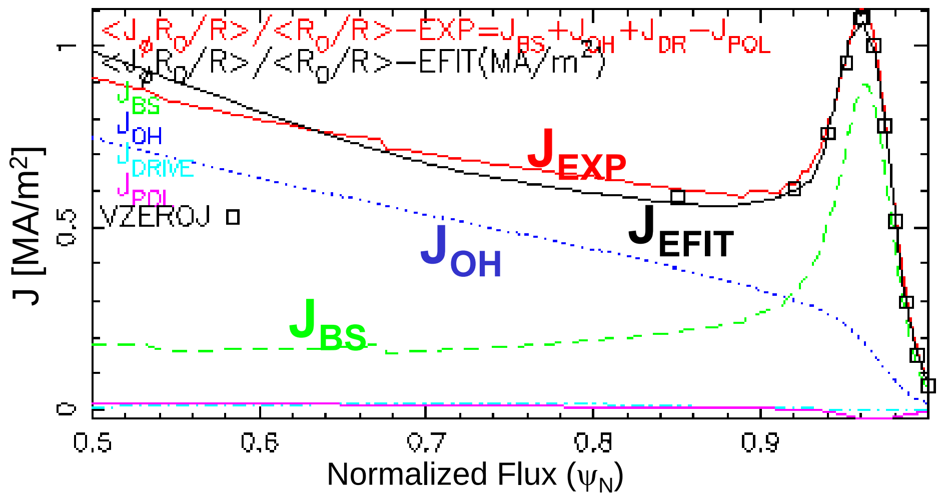
- Compare pedestal parameters from all of the discharges in the scan
- From various different times, throughout shots, though all after 300ms.
- Larger dataset than in PPCF paper, using upgraded pyTools, now with error bars!



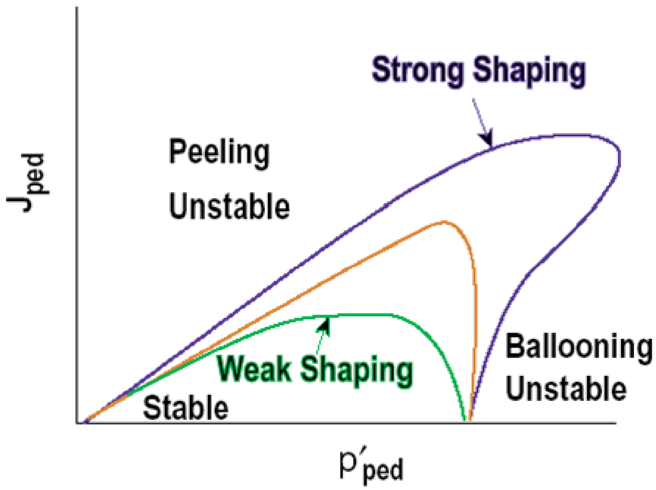
Kinetic EFITs reconstruct equilibria using additional constraints

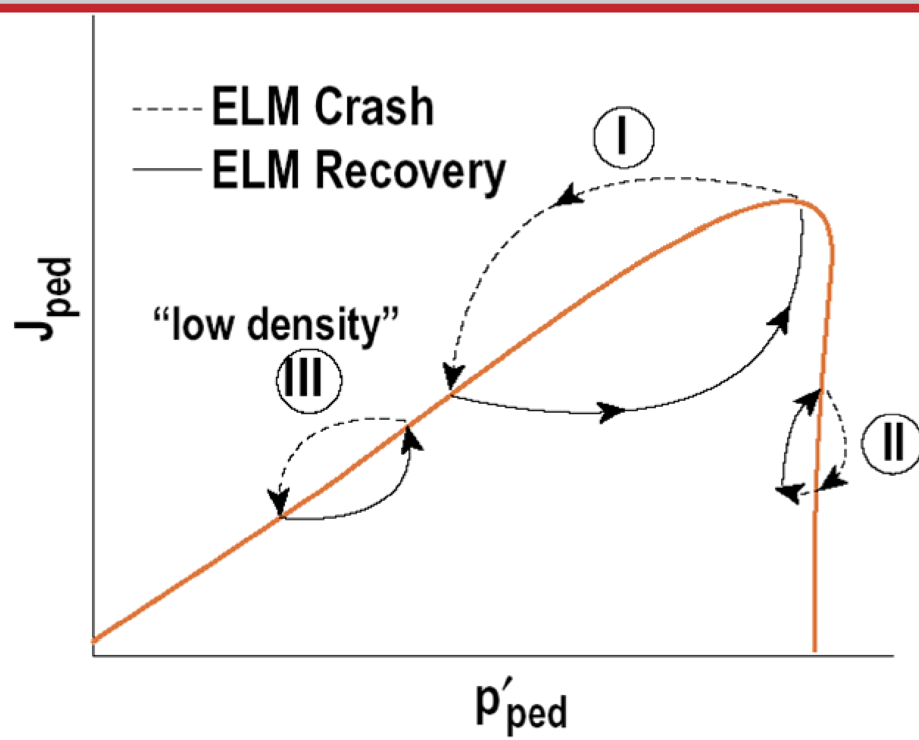
- Constrained by measured P, J profiles
  - Bootstrap current calculated from neo-classical model

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



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

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 similar change in calculated bootstrap current
  – Edge stability improved

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?