NSTX

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ELM suppression through density/pressure profile modification in NSTX

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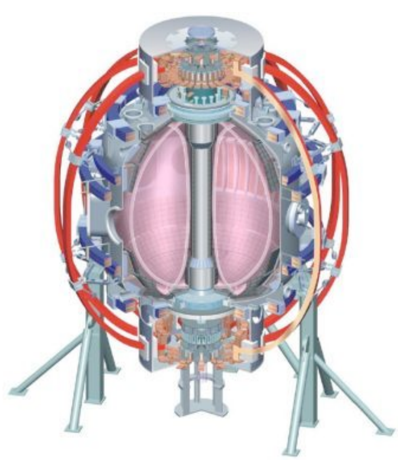

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Summary

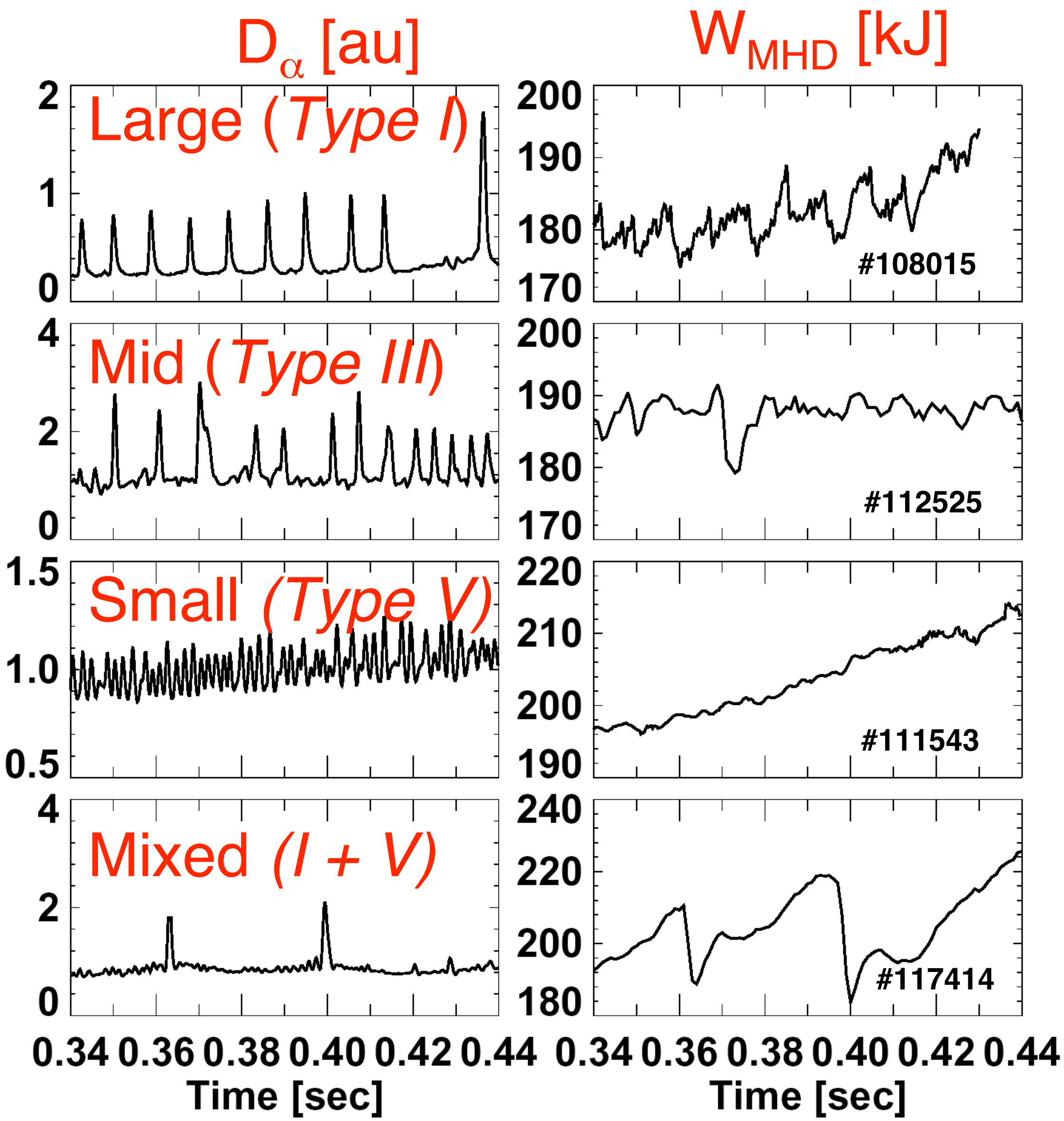
We think we understand

- Lithium wall coatings improve confinement and induce ELM-free H-mode
- Reduction of peak P_e (n_e) gradient and shift toward region of reduced magnetic shear responsible for stabilization of ELMs

We need more analysis to understand:

- Complete evolution: why do ELMs go away the way they do i.e. with increasing periods of quiescence?
- Do the profiles change, leading to ELM suppression, or do the ELMs get suppressed, leading to profile changes?
- What is the role of failed discharges/L-mode in observing ELMs on following discharges?

ELMs routinely observed in nearly all NSTX discharges



$\Delta W_{MHD}/W_{MHD} \sim$ 3-15%
$P_{heat} >> P_{L\text{-}H}$

$\Delta W_{MHD}/W_{MHD} \sim$ 1-5%
$P_{heat} \geq P_{L\text{-}H}$

$\Delta W_{MHD}/W_{MHD} \leq$ 1%
Wide P_{heat} range

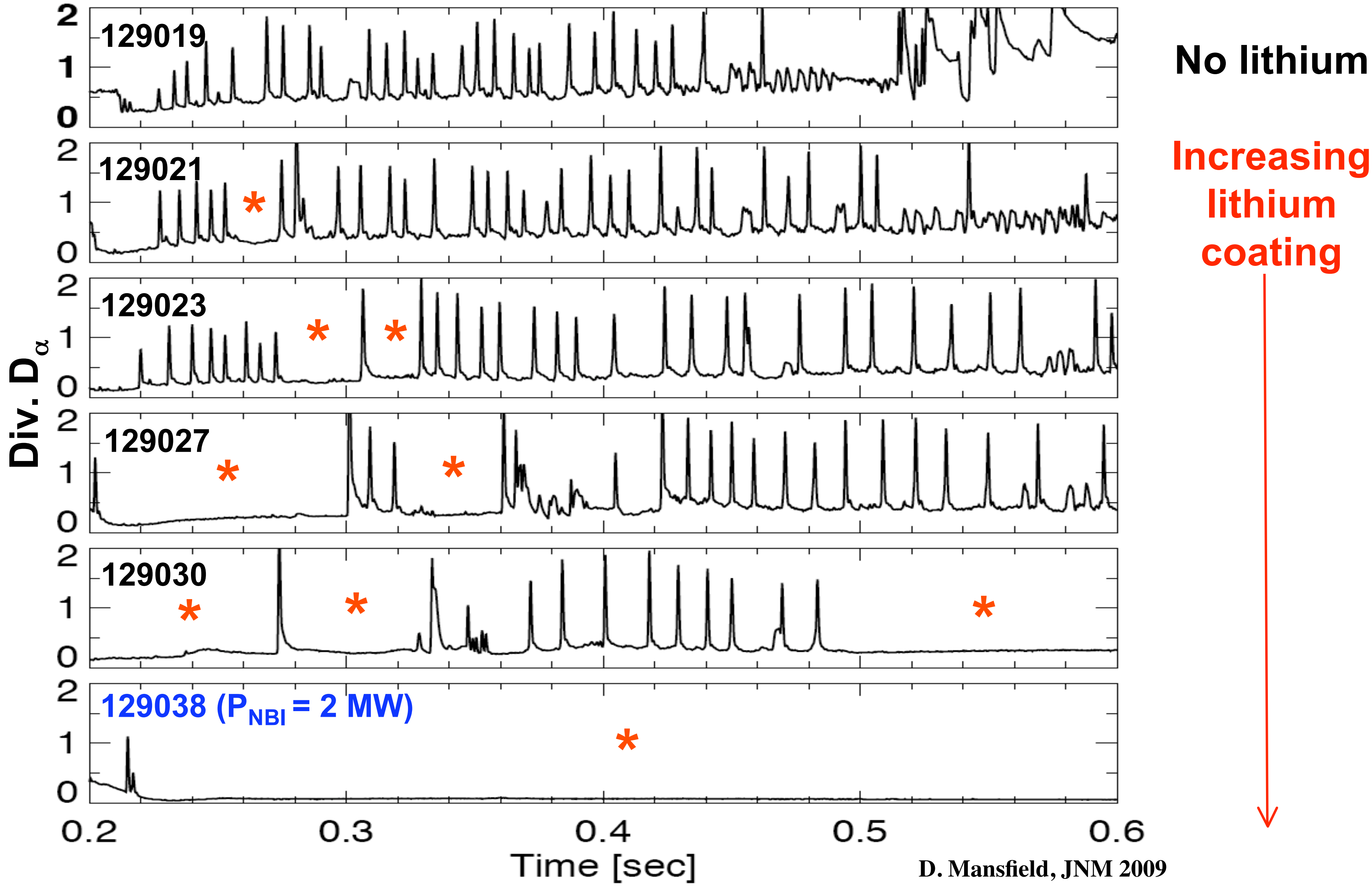
$\Delta W_{MHD}/W_{MHD} \leq$ 30%
High P_{heat}, β_N

R. Maingi, JNM 2005

Suppression of all ELMs with lithium wall coatings

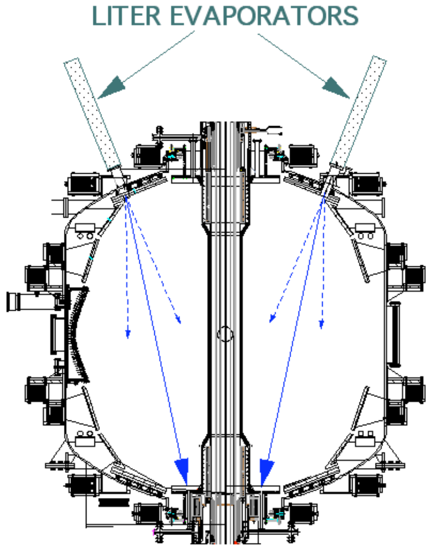
- Lithium wall coatings improve confinement and induce ELM-free H-mode
  - Core stability limits (β_N ~ 5.5-6) encountered before edge (ELM) stability limits
  - Impurities accumulate and radiated power increases with time
- Reduction of peak P_e (n_e) gradient and shift toward region of reduced magnetic shear responsible for stabilization of ELMs
  - Pedestal n_e profile shifts inward -> P_e profile broadens
  - Pre-lithium discharges unstable to n=3 (peeling-ballooning mode)
  - Post-lithium discharges stable
    - Instability growth rates reduced by 70-100% in post-lithium discharges

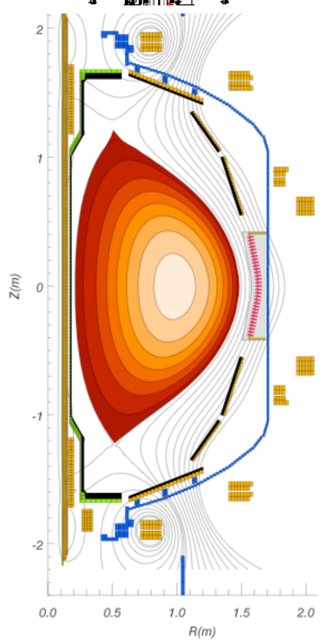
Quiescent phases (*) increase with increasing lithium coating (P_{NBI} = 4 MW)

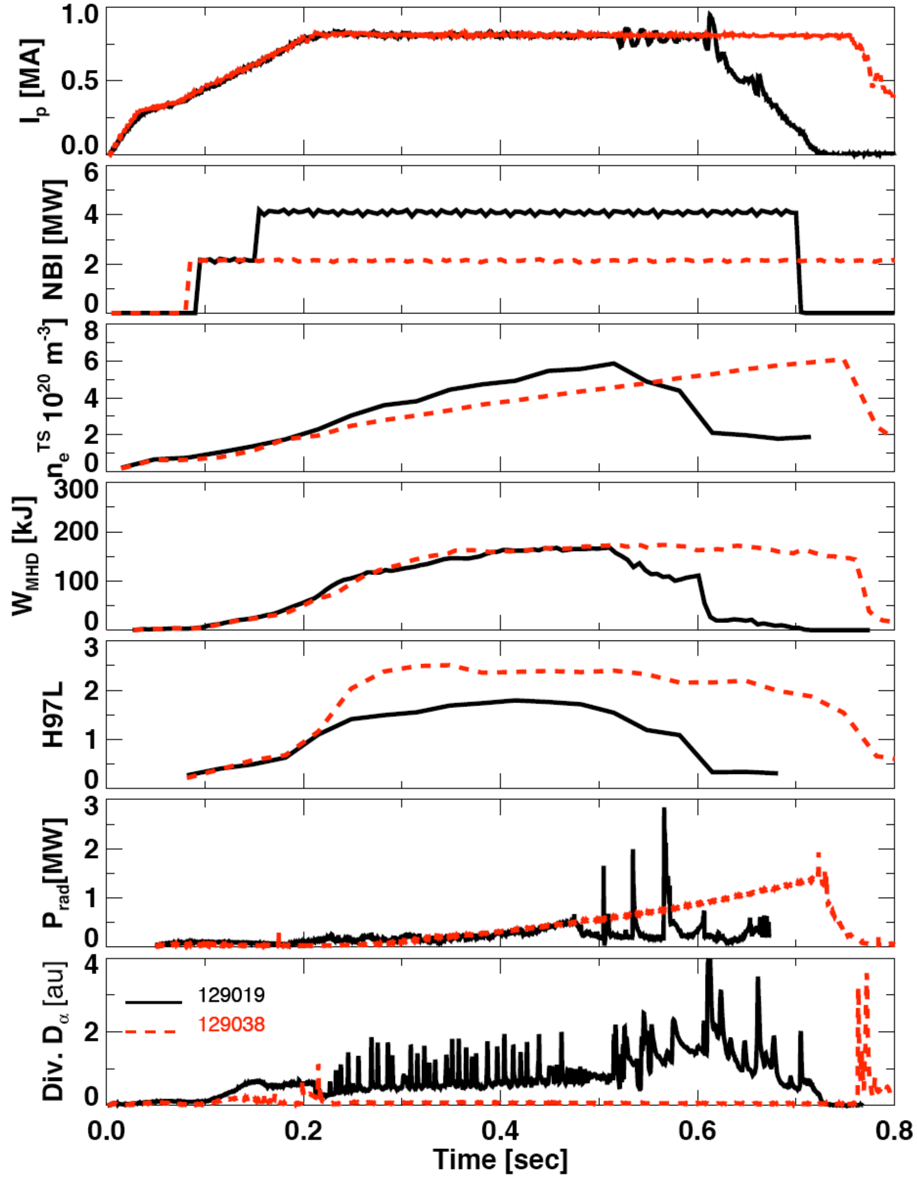


D. Mansfield, JNM 2009

ELM-free H-mode induced by lithium wall coatings

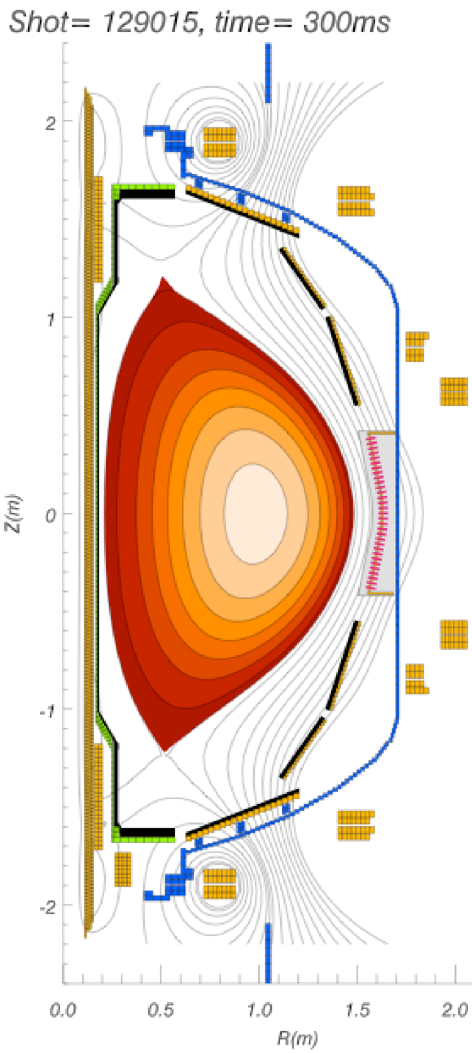


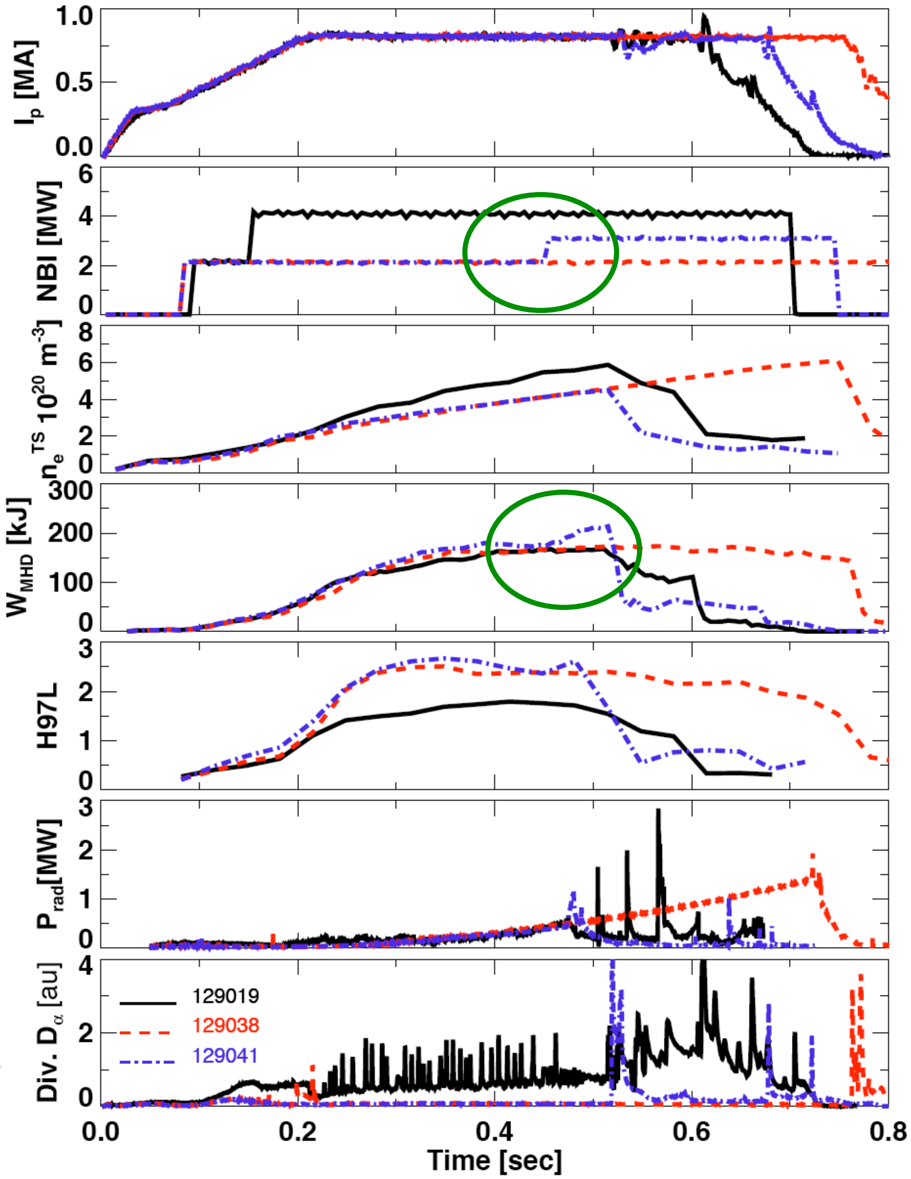




- Pre-Li, Post-Li
- Lower NBI to avoid β limit
- Lower n_e
- Similar stored energy
- H-factor 40%↑ (more than hi δ,κ)
- Higher P_{rad} /P_{heat}
- ELM-free, reduced divertor recycling

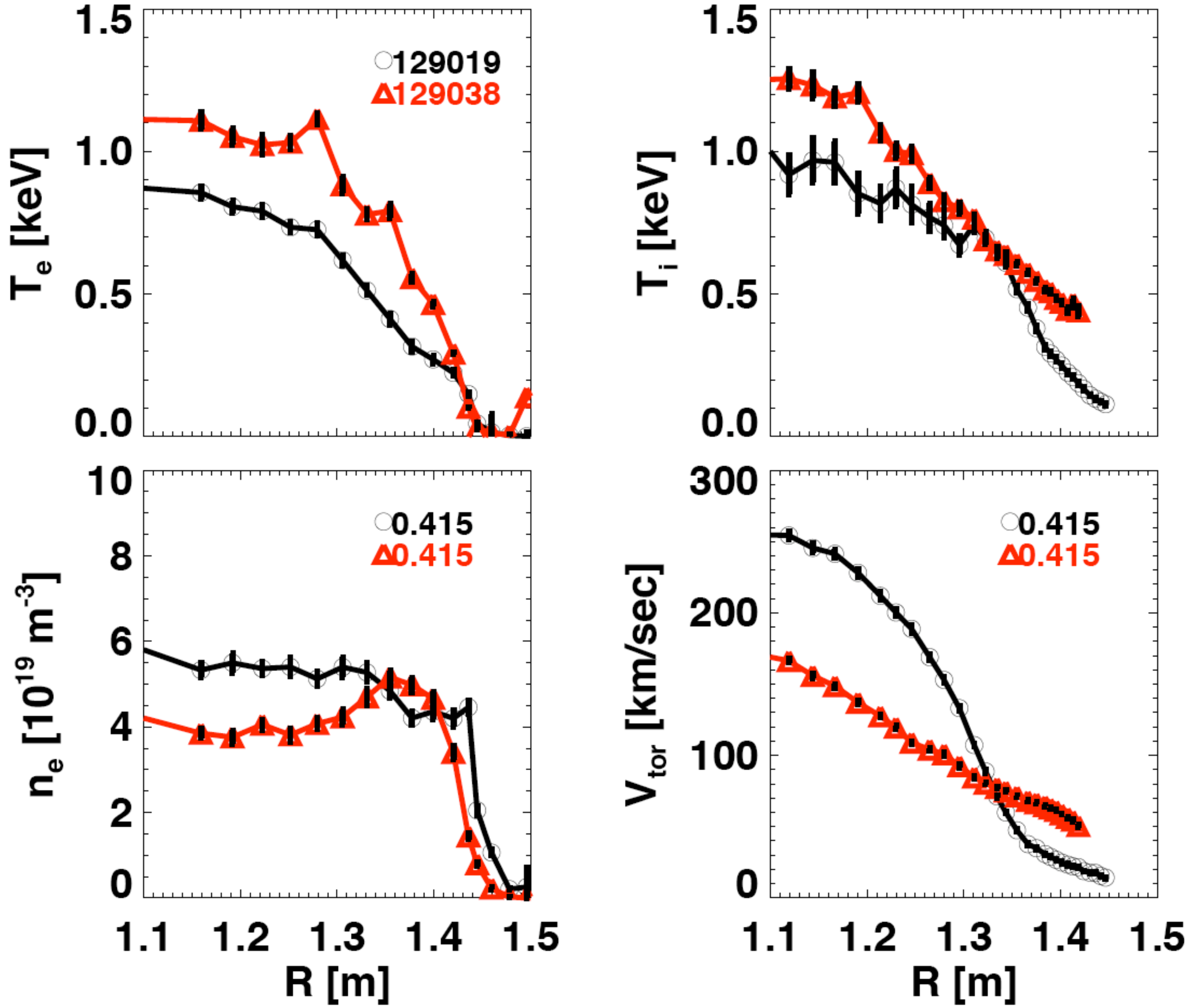
Global β_N limit encountered before edge stability limit with lithium coatings





- Pre-Li, Post-li, Post-li at β limit
- Intermediate NBI to probe β limit
- β limit at P_{NBI}=3 MW (β_N =5.5)

T_e, T_i increased and edge n_e decreased with lithium coatings



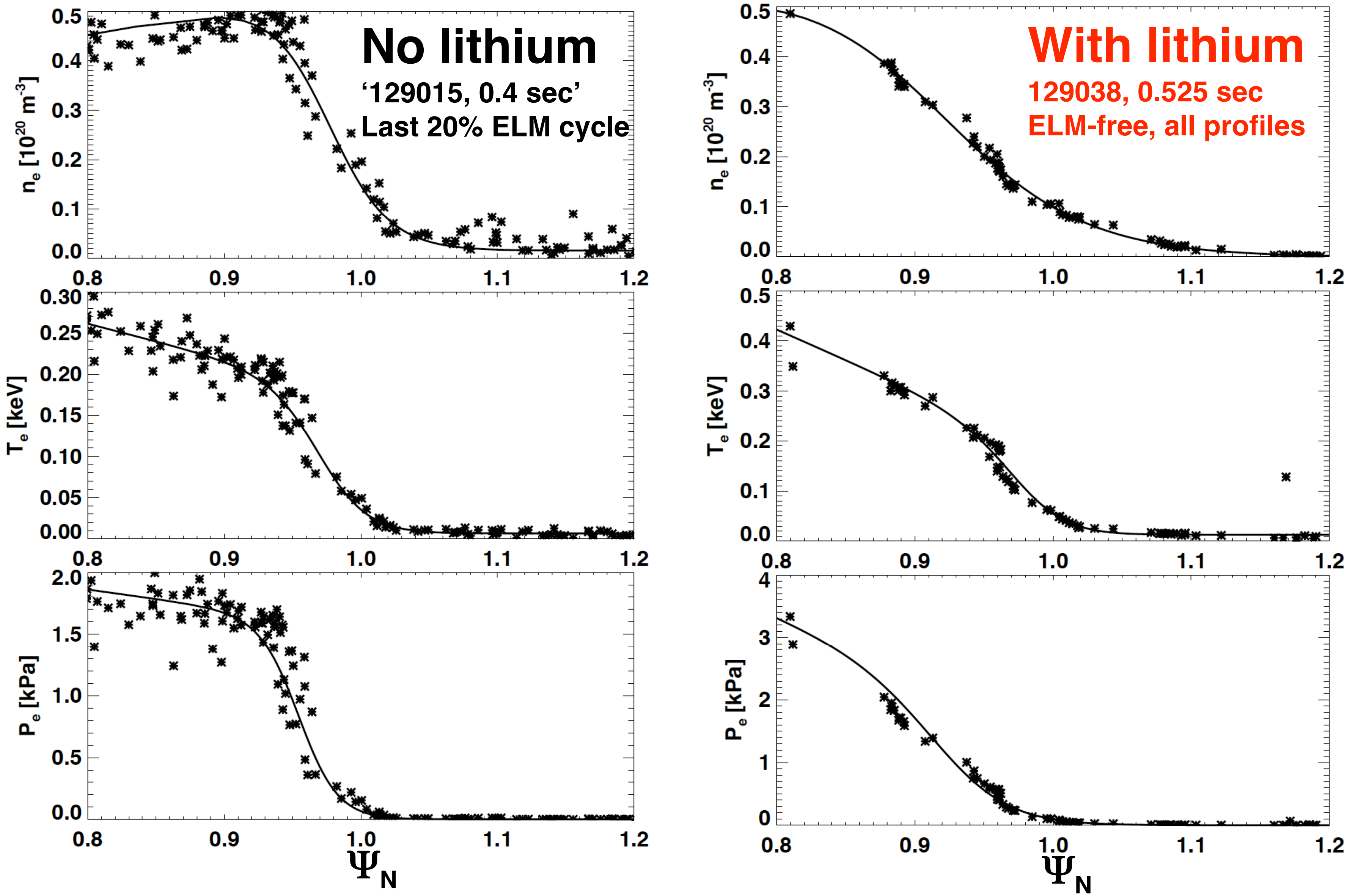
No lithium

With lithium

Edge stability analysis procedure

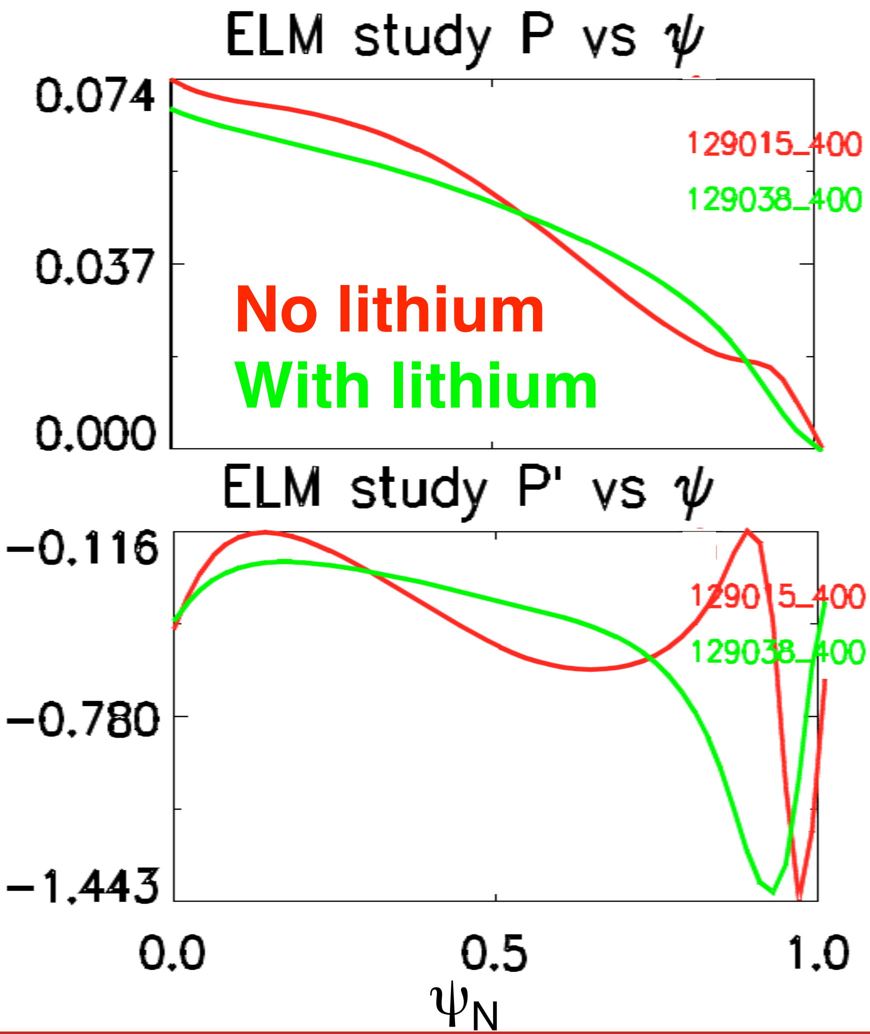
- EFIT run at Thomson profile times for ψ_N mapping
- Profile fitting of multiple time slices with standard procedures used as target for kinetic EFITs
  – Pre-lithium discharge profiles from last 20% of ELM cycle selected
  – Post-lithium discharge profiles used in 100-200 msec windows
- Free boundary kinetic EFITs run to match kinetic pressure profiles
  – Edge bootstrap current computed from Sauter model
  – Stability evaluated with PEST
- Fixed boundary kinetic EFITs run with variations of edge pressure gradient and edge current
  – Stability boundary evaluated with ELITE

Multiple time slices used to characterize profiles



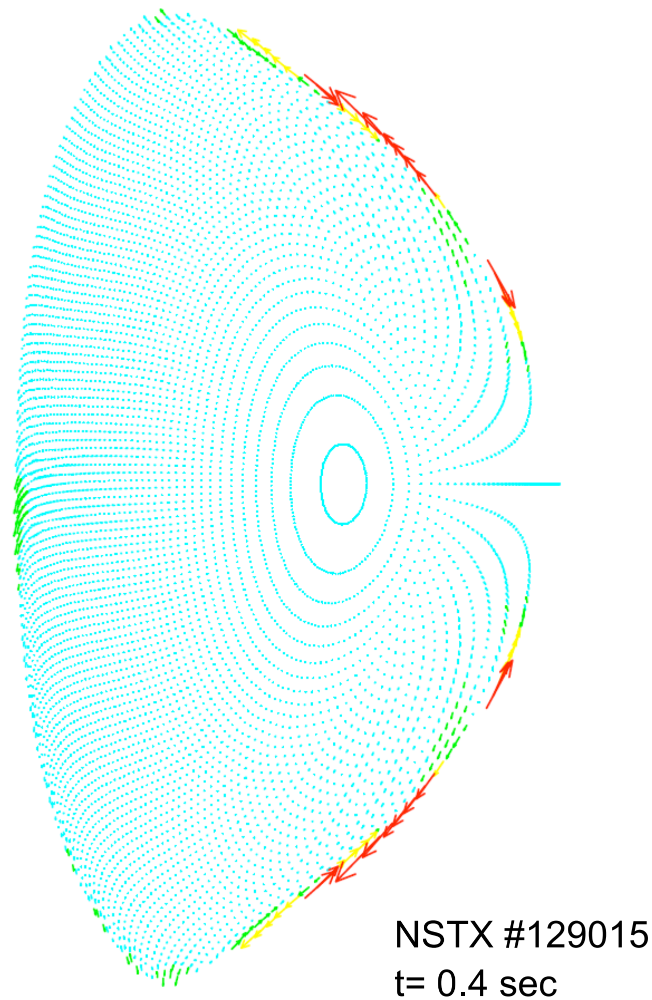
n=3 mode most unstable
(PEST analysis on kinetic EFIT)

Maximum pressure gradient shifted inward with lithium



No lithium: γ_{lin}/ω_A ~ 0.01-0.015

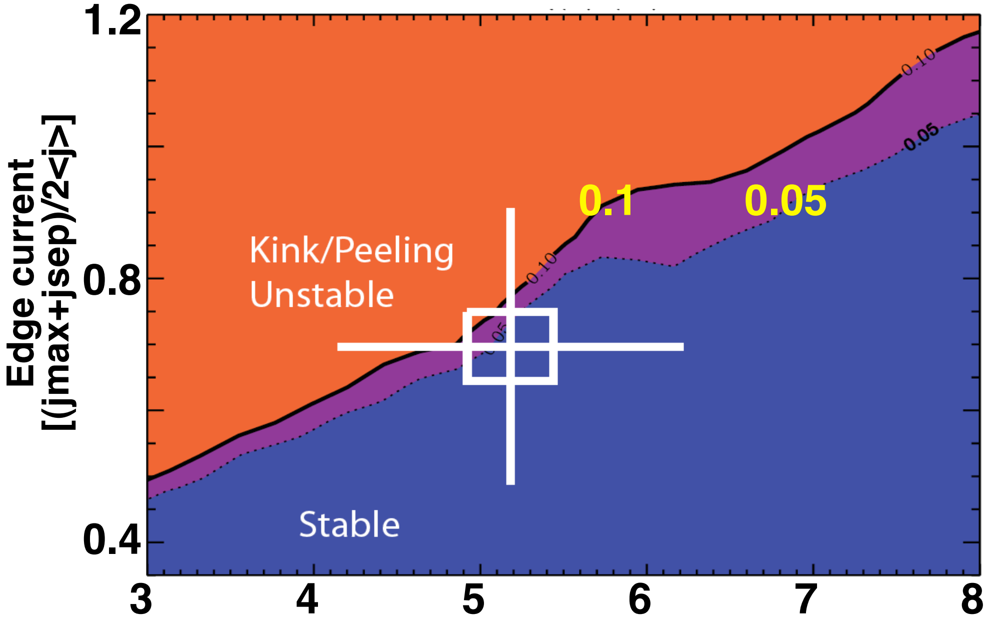
Projection of displacement ξ (n=3)

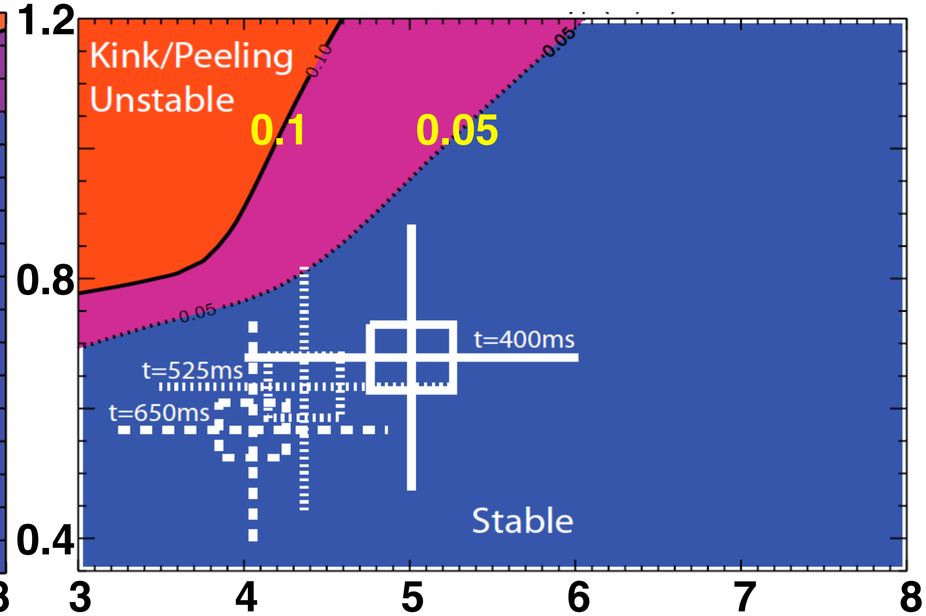


Pre-lithium edge profiles close to peeling/ ballooning instability threshold (ELITE)

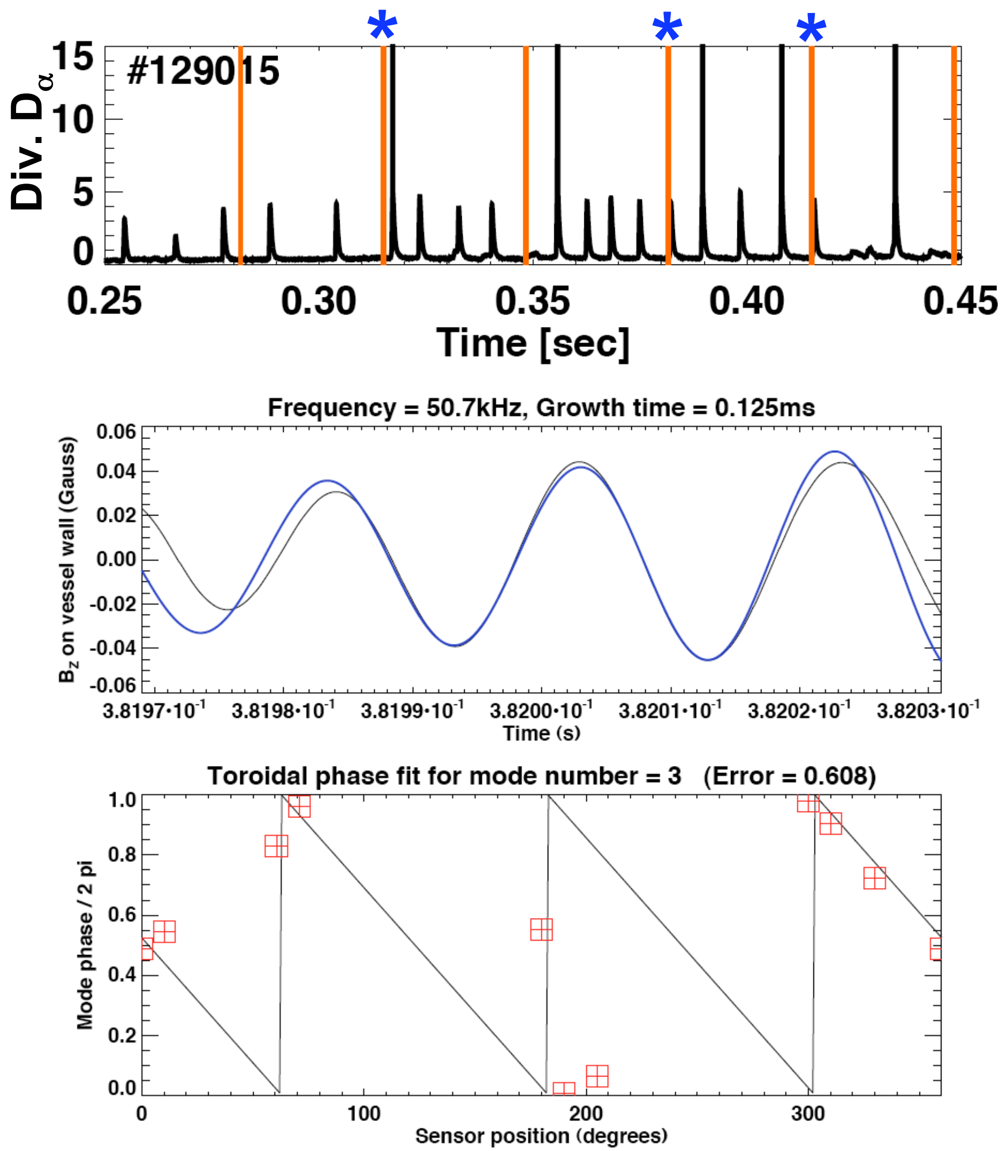
No lithium: $\gamma_{lin}/(\omega^*/2)$ becomes large at blue/purple/orange boundary ('varyped' EFITs)

With lithium: $\gamma_{lin}/(\omega^*/2)$ becomes large at blue/purple/red boundary ('varyped' EFITs)





Low-n ELM precursor observed in magnetics



- Discharge with optimal ELM timing relative to Thomson pulses chosen for stability analysis
  - 3 ELMs in last 20% of ELM cycle
- Magnetic fluctuation spectrum from 40-60kHz analyzed near ELM at t=0.382s sec
- n=3 pre-cursor oscillation shown here
  - Other ELMs: n=2-5

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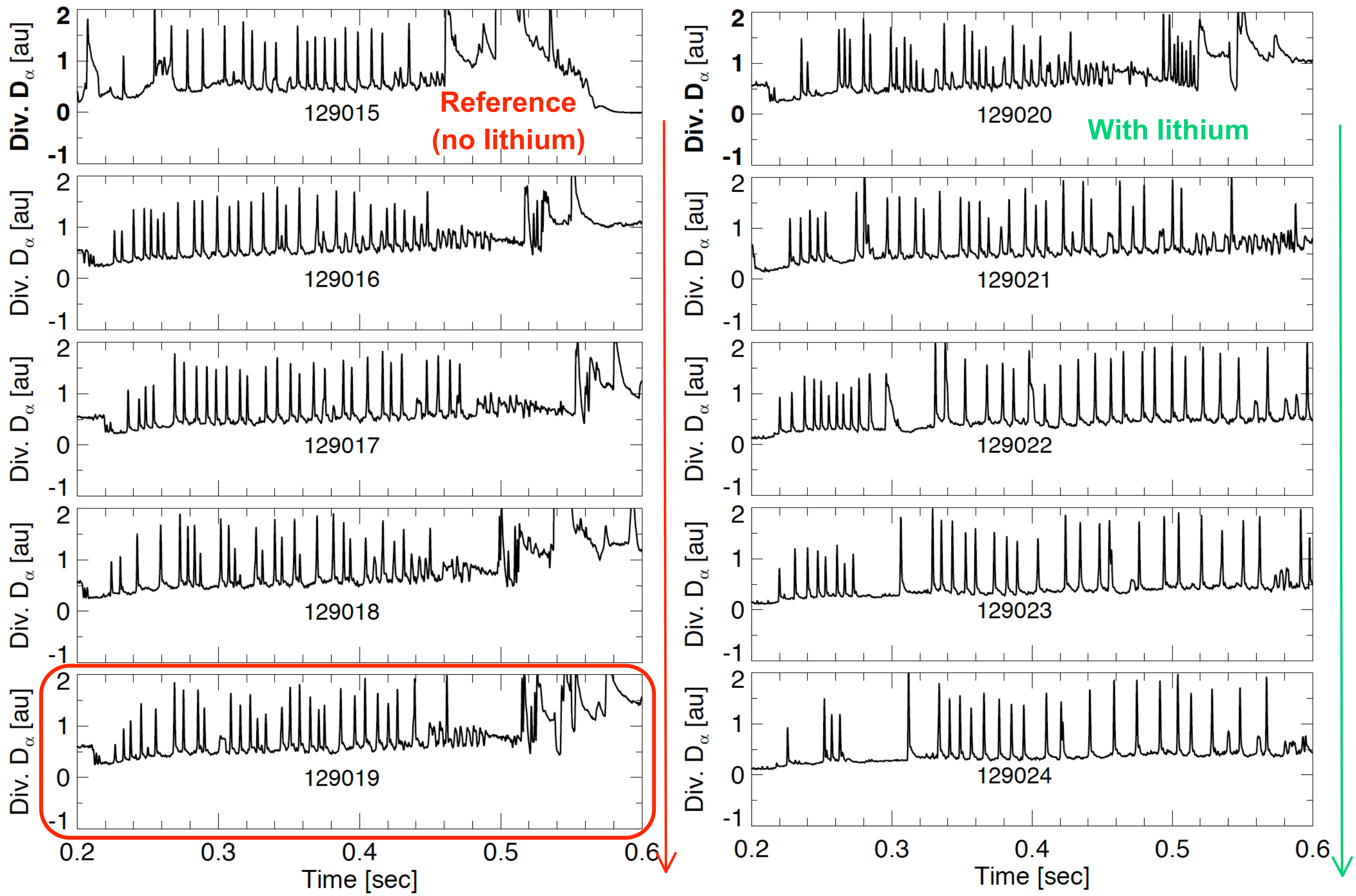
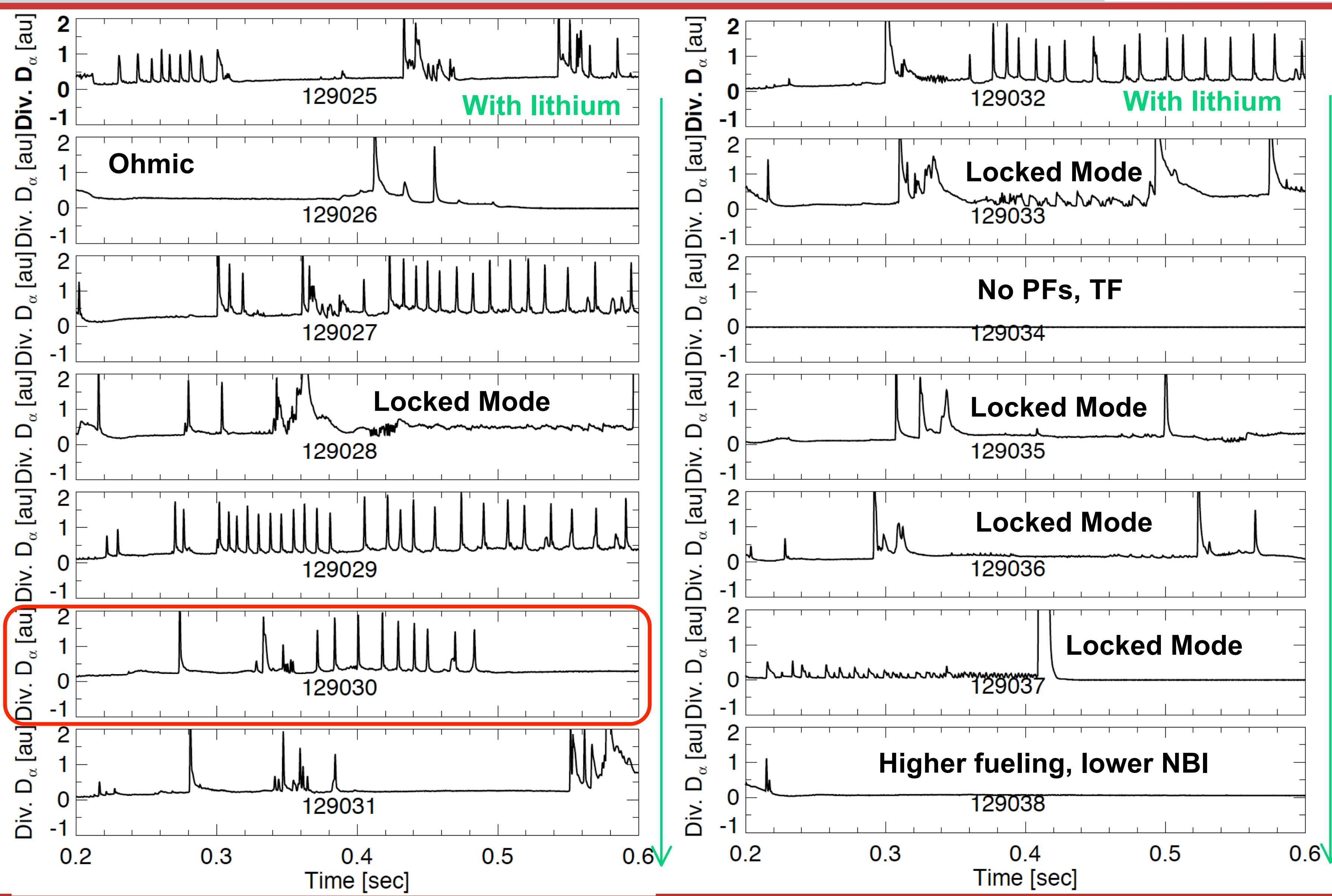
- What is the role of failed discharges/L-mode in observing ELMs on following discharges?

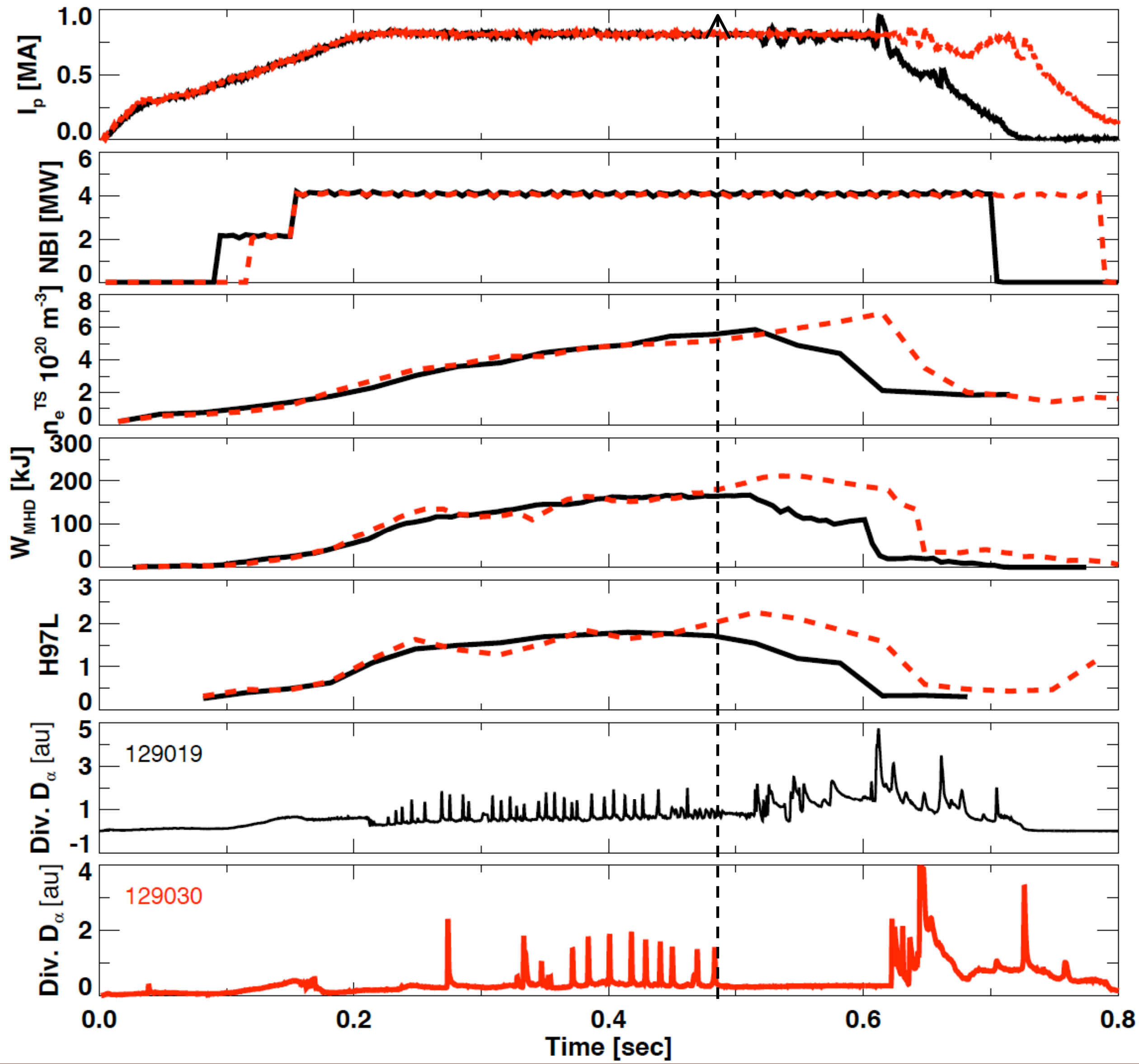
ELM evolution with shot number



ELM evolution with shot number



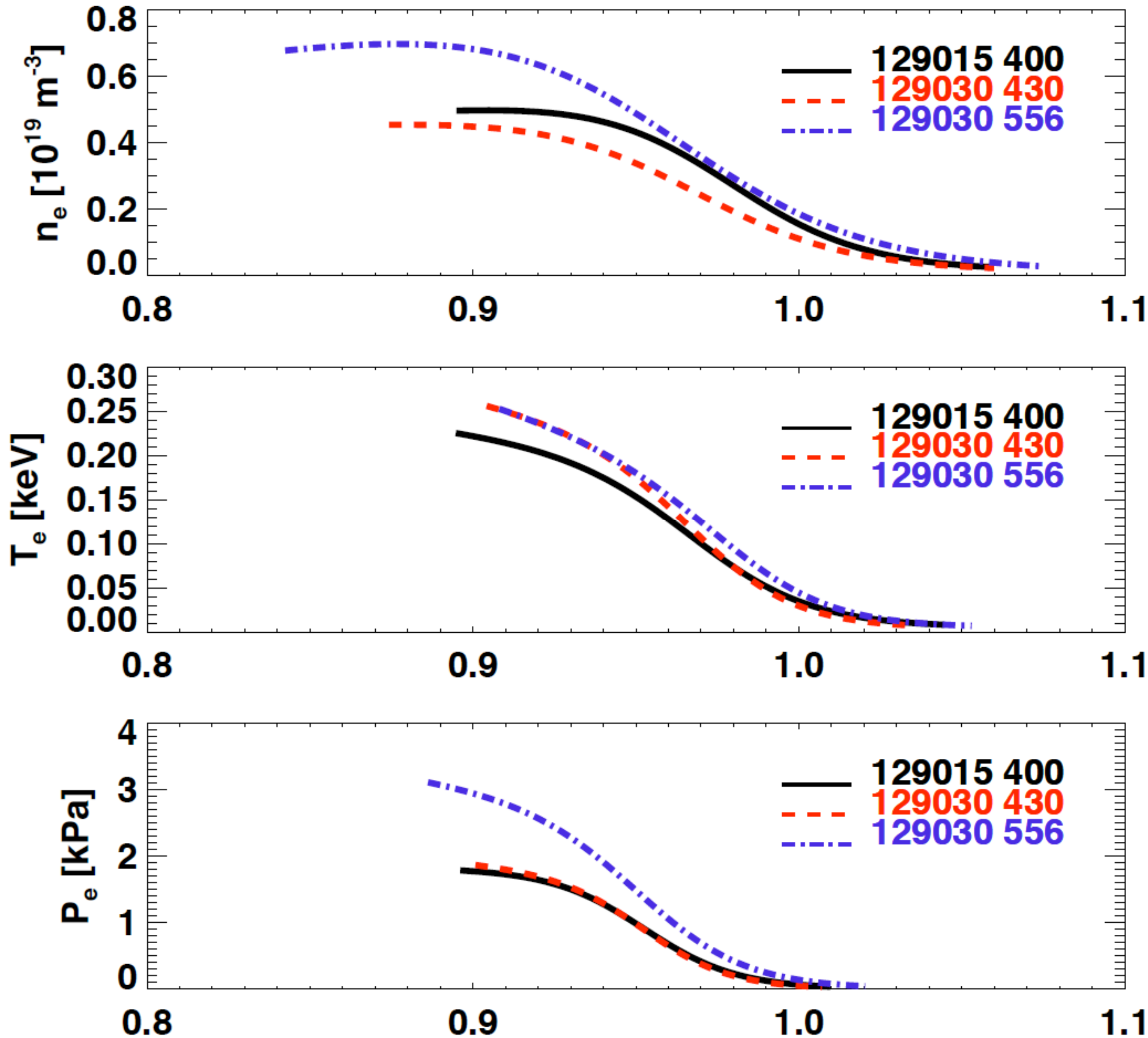
Stored energy increased after ELMs disappeared



No lithium

With lithium

P_e profile similar but n_e reduced before long quiescent phase in #129030



No Li

With Li - ELMy

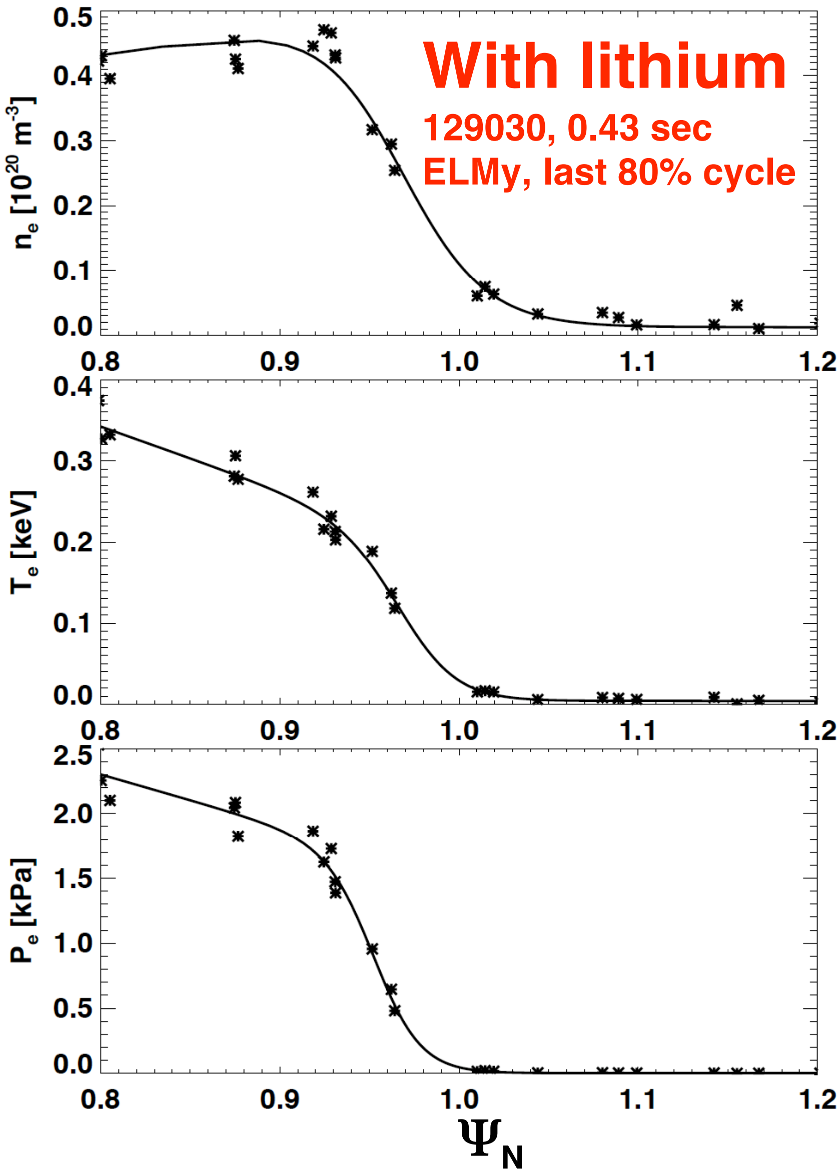
With Li - ELM-free

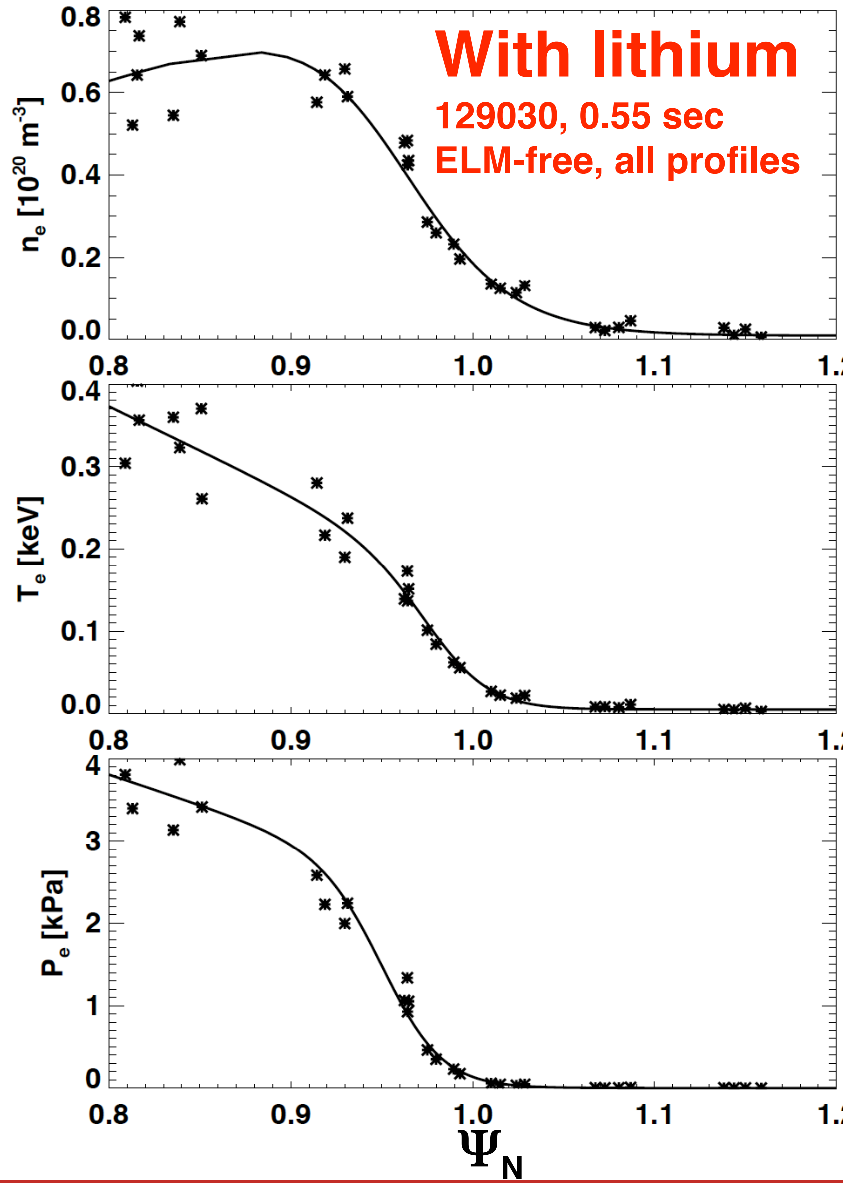
Modification of edge stability observed with lithium wall coatings

- Lithium wall conditioning induces ELM-free H-mode
  - H-factor increased by 50%
  - Global stability limits (β_N ~ 5.5-6) encountered before edge (ELM) stability limits
  - T_e, T_i increase and profiles change substantially
  - ELM-free phases increase gradually with lithium deposition, with discharges eventually becoming ELM-free
  - Impurities accumulate and radiated power increases with time
    - ➢ Present plan: use 3d fields to trigger ELMs to purge impurities
- Reduction of peak P_e (n_e) gradient and shift toward region of reduced magnetic shear responsible for stabilization of ELMs
  - Pre-lithium discharges unstable to low-n peeling-ballooning modes
    - Low-n pre-cursor found in magnetics data
  - Post-lithium discharges stable
    - Instability growth rates reduced by 70-100% in post-lithium discharges

Backup

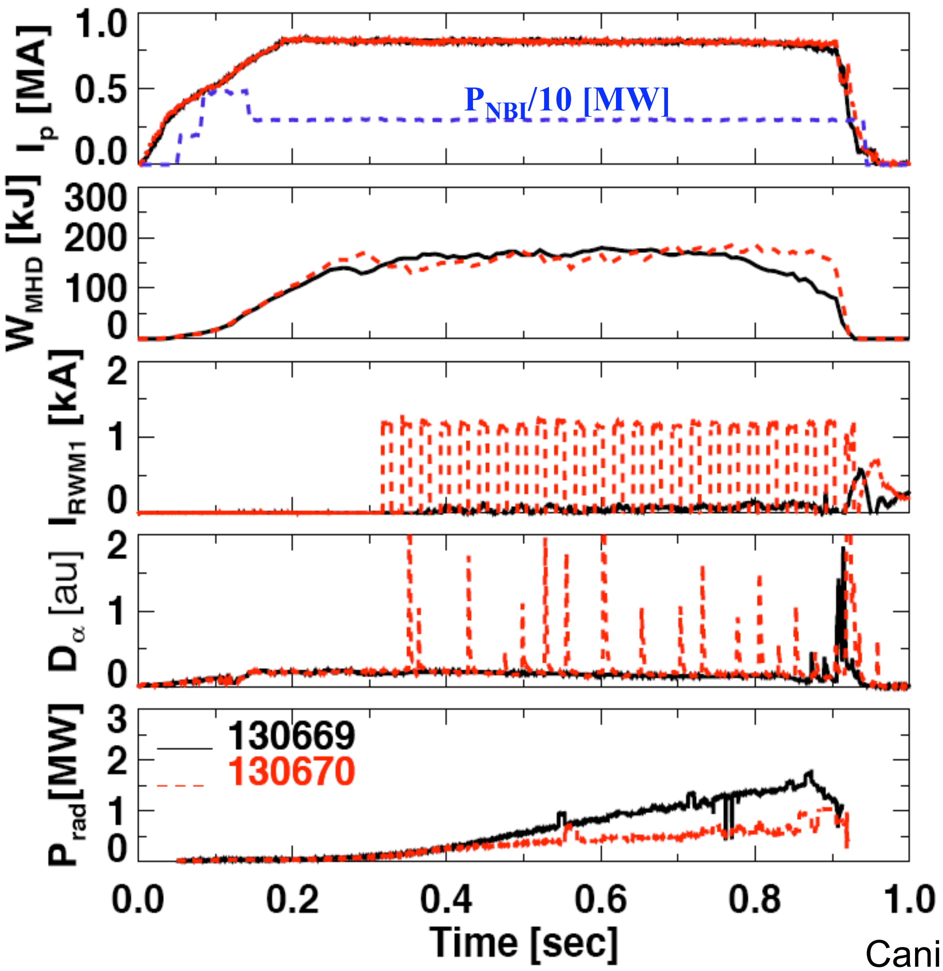
Multiple time slices used to characterize profiles



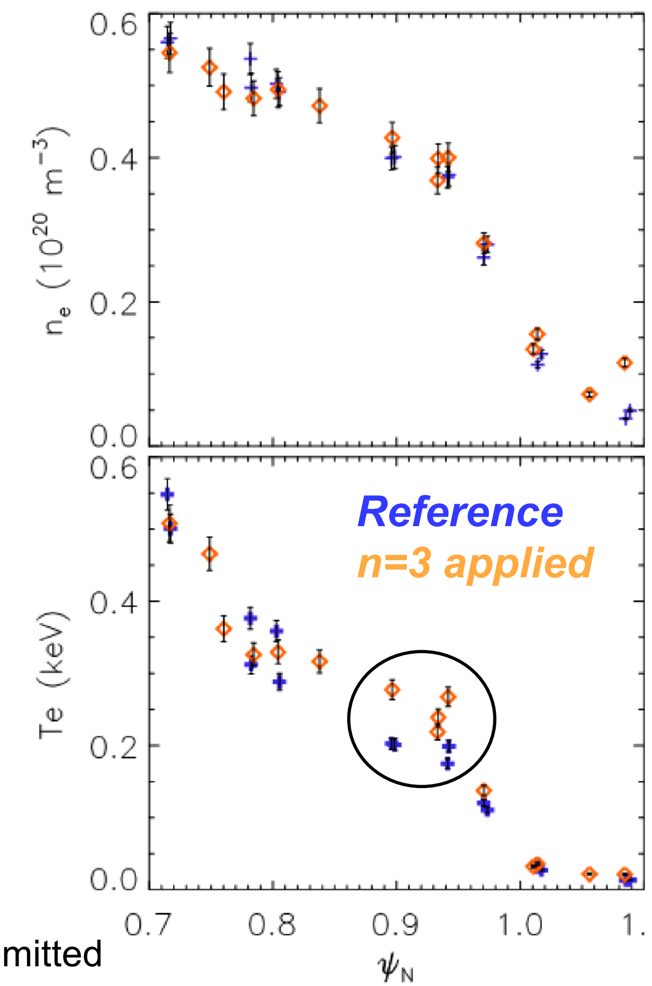


3-D fields used to alter ELM behavior - provides a possible scenario for impurity and radiation control of ELM-free Lithium discharges

Type I ELMs triggered for impurity control (post-lithium, n=3)

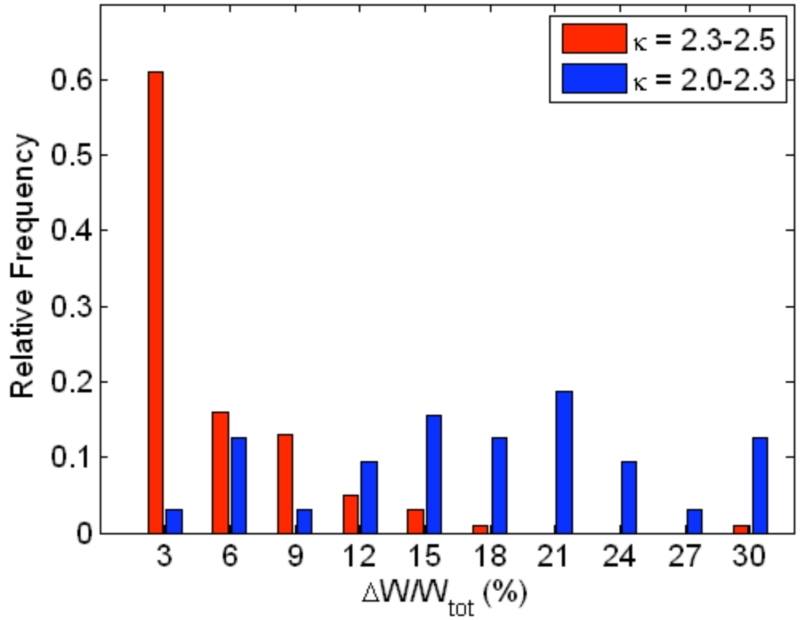


Edge T_e and dT_e/dr increased --> n=3 more unstable (PEST)



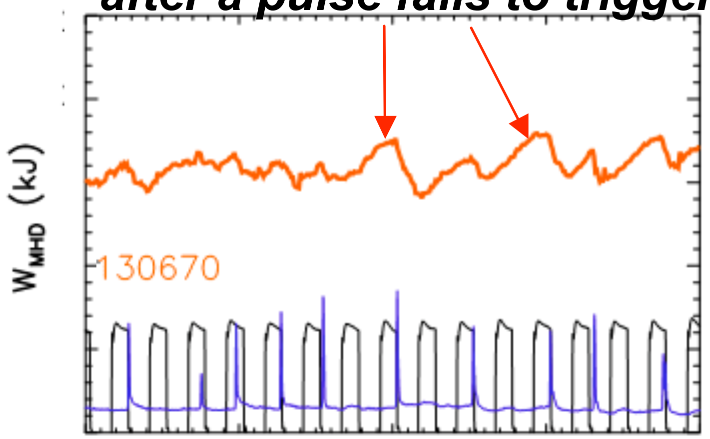
Canik, PRL submitted

Magnetic ELM pace-making may be improved at higher κ, with internal coils



•Largest ELMs occur

•after a pulse fails to trigger



- Triggered ELMs are large, but trends are promising
  - ELMs are much smaller at high κ
  - Optimization for small ELMs will be performed in future experiments
- Internal coils could greatly improve technique
  - Triggering requires 8-10 ms pulses, comparable to ~4 ms field penetration time
  - Internal coils -> faster triggering?
    - Higher frequency, smaller ELMs, better impurity control
    - More reliable triggering, smaller ELMs?