Stabilizing Effect of Resistivity towards ELM-free H-mode Discharge in Lithium-conditioned NSTX

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Outline

- Motivation
- Review of NSTX Li-conditioned experimental results.
- Pre-lithium discharge analysis.
- Post-lithium discharge analysis.
- Summary and discussion.

Motivation

- In 2008 campaign, NSTX achieved completely ELM-free H-mode discharge after using Li-coated divertor and wall.

- The pedestal profiles of pressure, and the values of Z_{eff} have been noticeably changed.

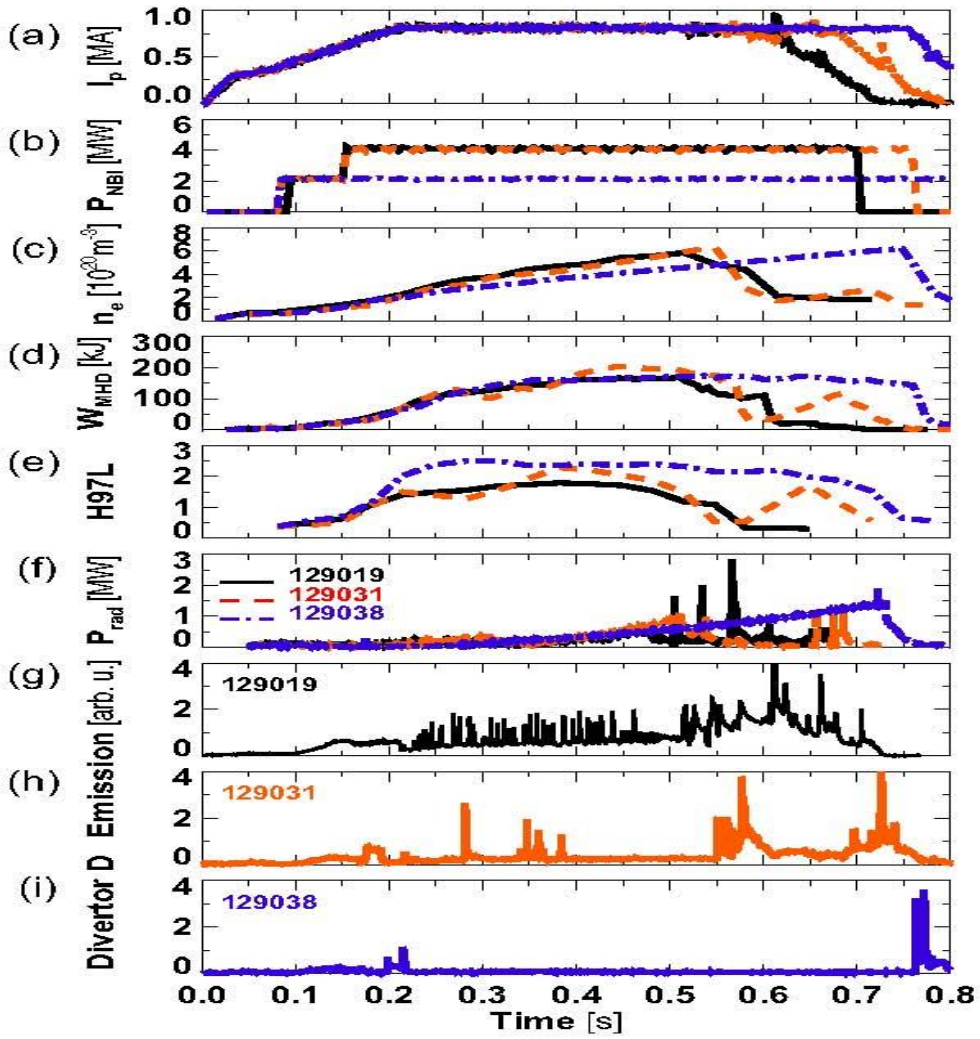
- The mechanism behind this ELM-suppression is studied in context of extended magneto-hydrodynamic (MHD) modeling.

Li Coating leads to ELM suppression in NSTX

ELMy H-mode - 129019 no. discharge (black) – NBI heating – 4 MW

ELM free H-mode – **129038** no. discharge (**blue**) – NBI heating – 2 MW

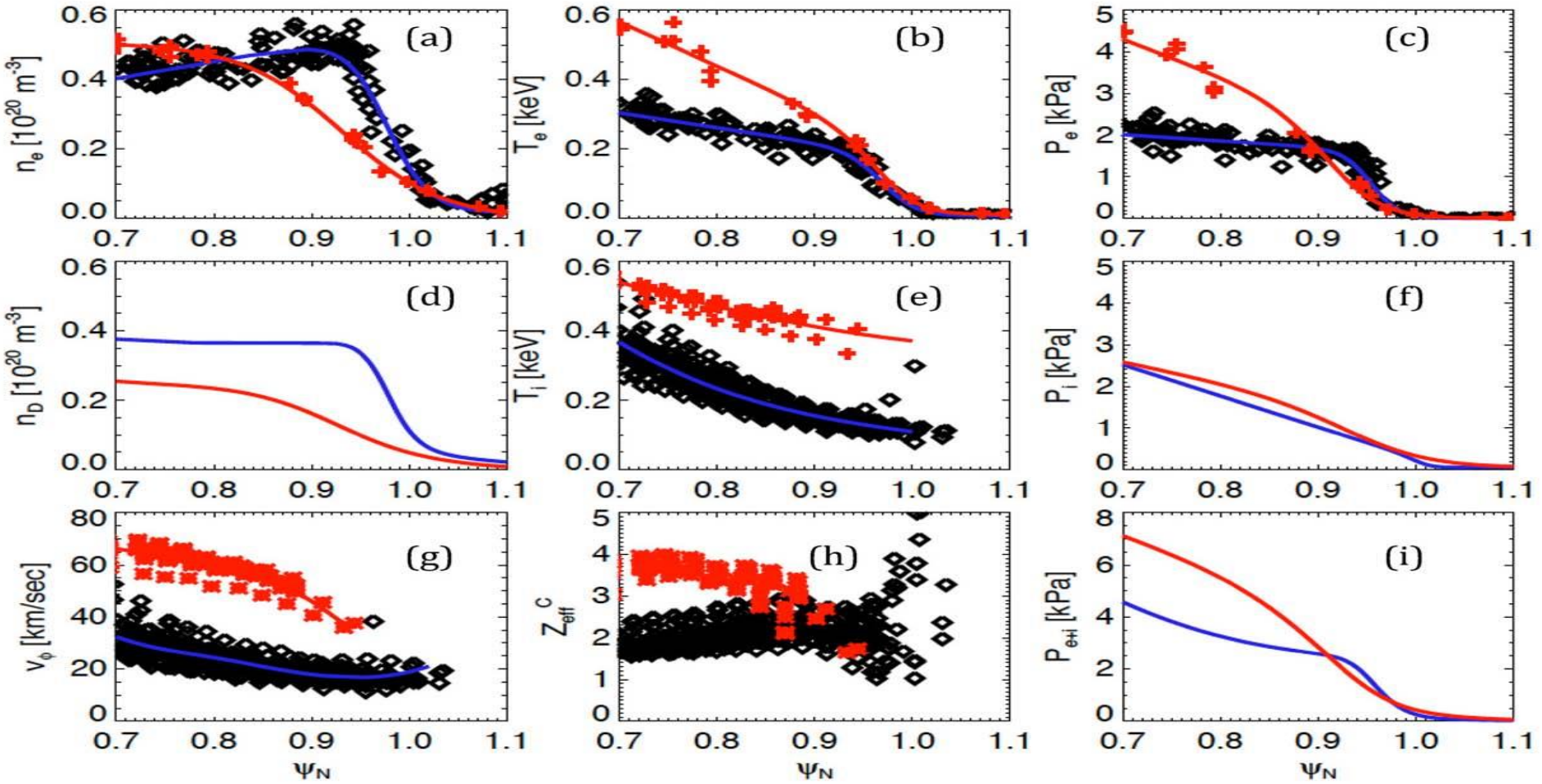
- NBI heating is reduced by 50 % but stored energy is same.
- H-mode confinement time is enhanced by 2 factor.
- Radiation in post lithium study is enhanced substantially.



D. P. Boyle et. al., Plasma Phys. Control. Fusion, 53, 105011 (2011).

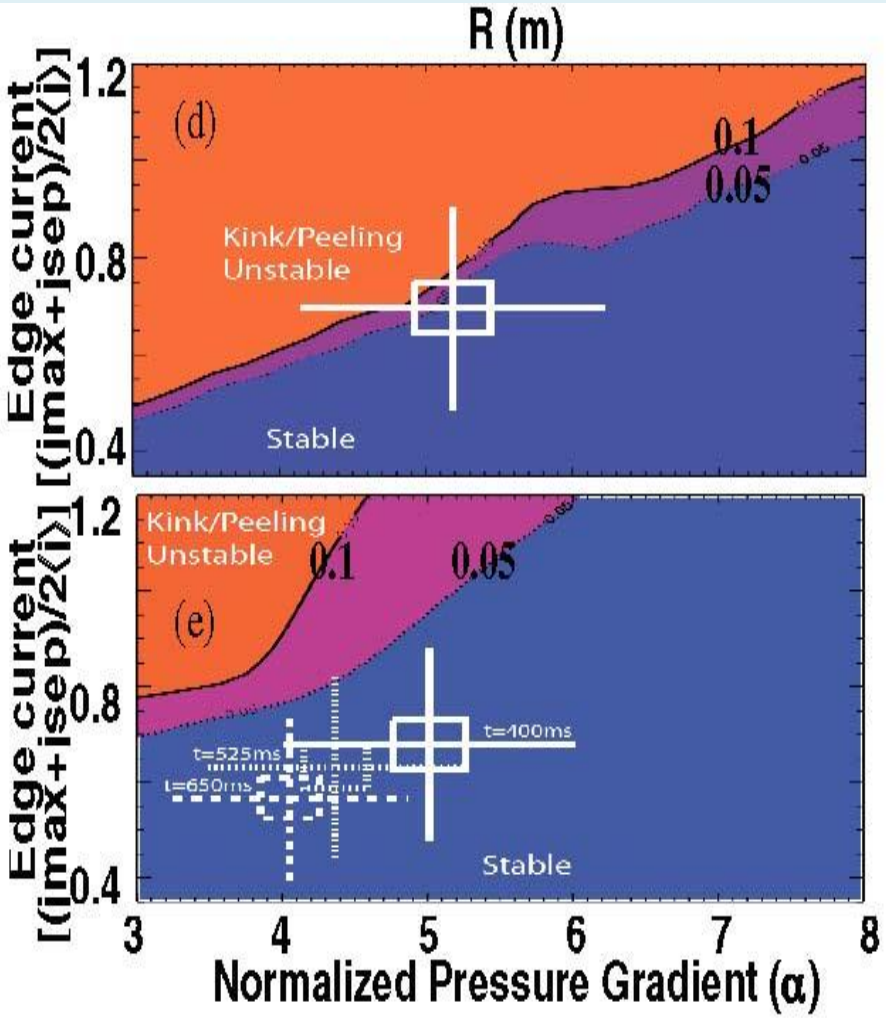
Changes in profiles and Z_{eff} value after Li-coating

(Red curve – Post-Lithium, blue curve-Pre-Lithium)



R. Maingi et. al., Nucl. Fusion, 52, 083001 (2012).

ELITE analysis indicates post-lithium NSTX pedestal more stable due to profile changes



- The crosshair is the position of experimental equilibrium.
- In post-lithium discharge, the pedestal equilibrium moves away from peeling-ballooning boundary into stable region.
- The stabilization was attributed to inward shifting of edge pedestal and increase of pedestal width.

R. Maingi et. al., Phys. Rev. Lett., 103, 075001 (2009).

The goal and Procedure of study

- Is profile modification alone sufficient to stabilize ELMs in NSTX?
- Or, are there any direct impurity effects (Z_{eff}, radiation, rotation) on ELMs?

Steps of Analysis:

- Ideal MHD analysis of Pre-lithium/Post-lithium discharge.
- Redo of this analysis including 2fluid-correction terms as Hall effect, electron diamagnetic effect and gyro-viscosity.
- Resistive extended MHD analysis with Spitzer model and scanning of Z_{eff} parameters consistent with NSTX experimental data.

NIMROD analysis: Extended MHD equation solver

Continuity Equation:

$$\frac{\partial n_D}{\partial t} + \nabla \cdot (n_D V) = \nabla \cdot (D \nabla n_D) \quad , \quad n_D = \text{Ion density} \, , \; n_e \approx n_D$$

Momentum Equation of MHD fluid:

$$\rho \frac{\partial V}{\partial t} + \rho (V \cdot \nabla) V = -\nabla (P_e + P_D) + J \times B - \nabla \cdot \Pi$$

Temperature Equations:

$$n \left[\frac{\partial T_{D,e}}{\partial t} + (V \cdot \nabla) T_{D,e} \right] = -(\gamma - 1) \left[n T_{D,e} (\nabla \cdot V) + \nabla \cdot q_{D,e} + Q_{D,e} \right]$$

Ampere's Law and zero divergence:

$$\nabla \times B = \mu_0 J \quad , \quad \nabla \cdot B = 0$$

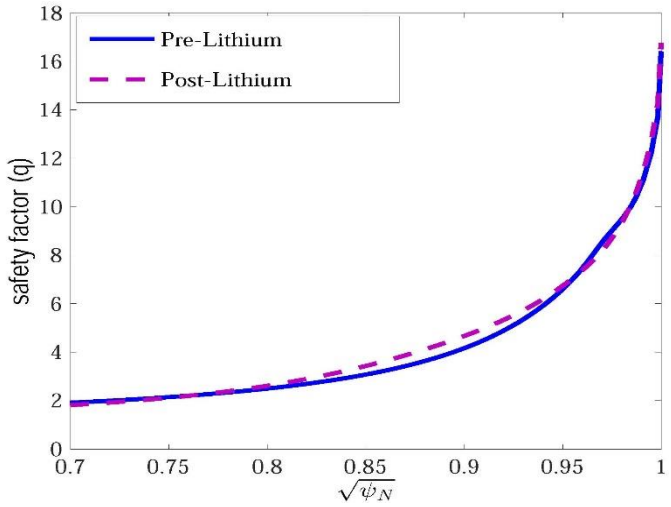
Faraday's law coupled with Generalized Ohm's Law:

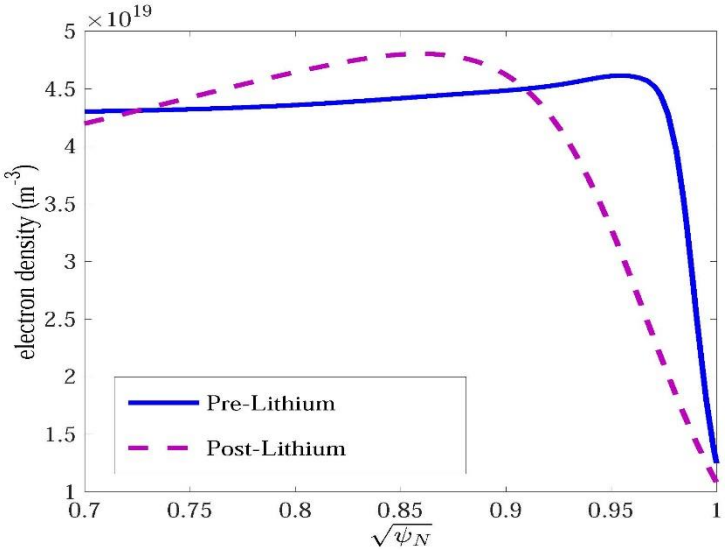
$$\frac{\partial B}{\partial t} = -\nabla \times \left[\eta J - V \times B + \frac{1}{ne} \left(J \times B - \nabla p_e + \frac{m_e}{e} \frac{\partial J}{\partial t} \right) \right]$$

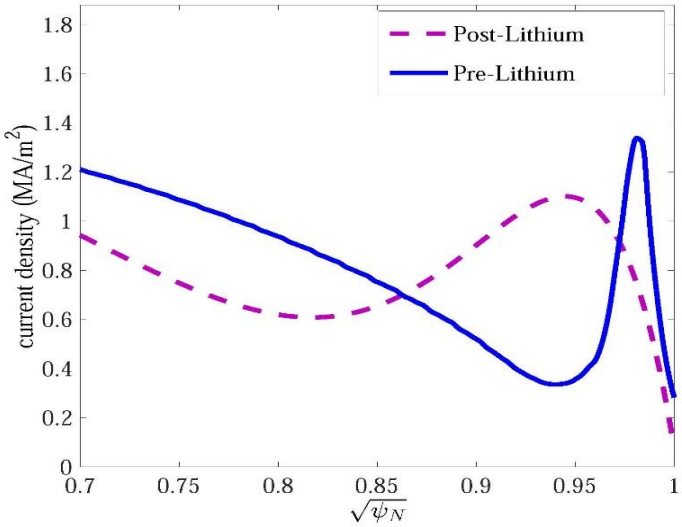
2-fluid effects

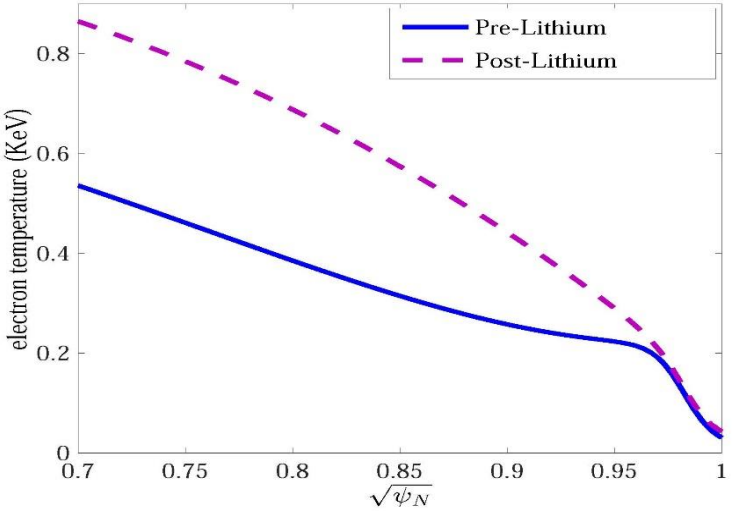
C. R. Sovinec and NIMROD team, J. Comp. Phys., 195, 355-386 (2004).

Profile Differences between Pre-Lithium and Post-Lithium

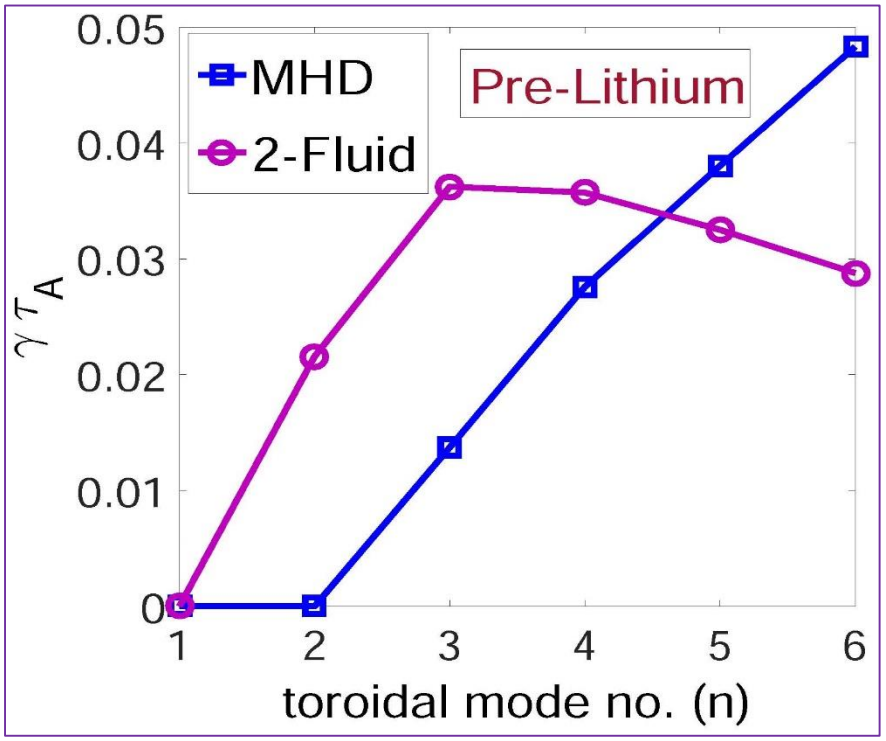


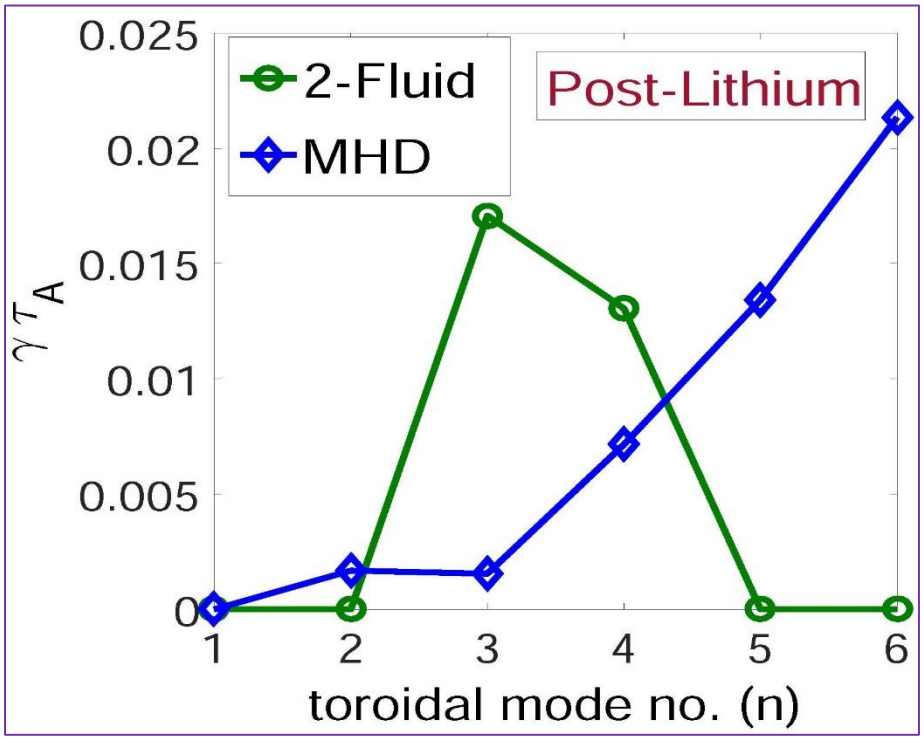






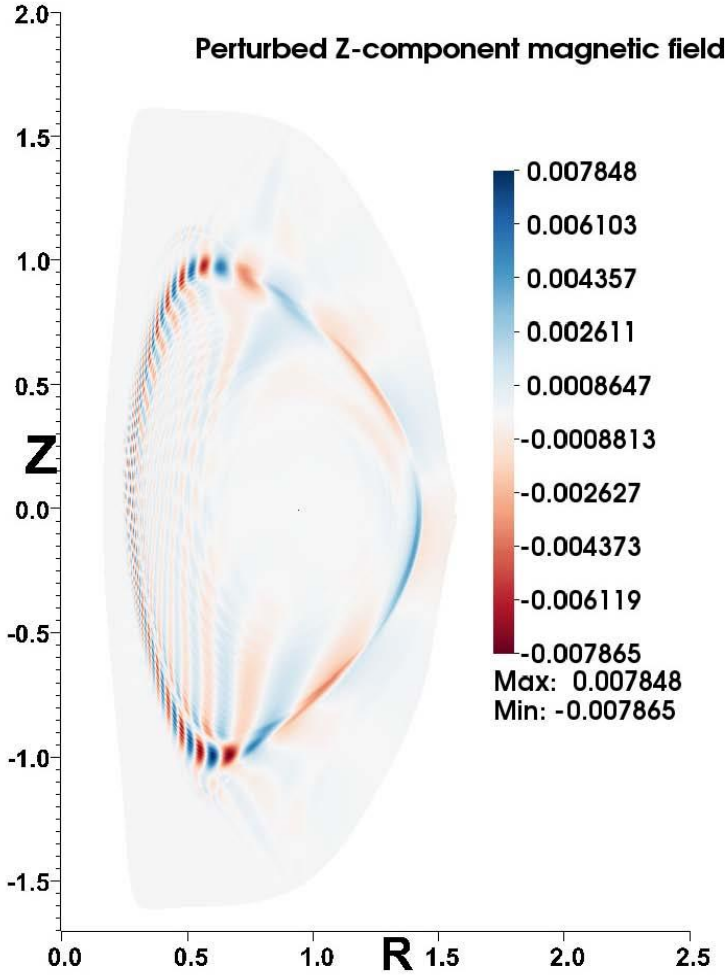
Ideal 2-fluid Model predicts both Pre/Post cases be unstable

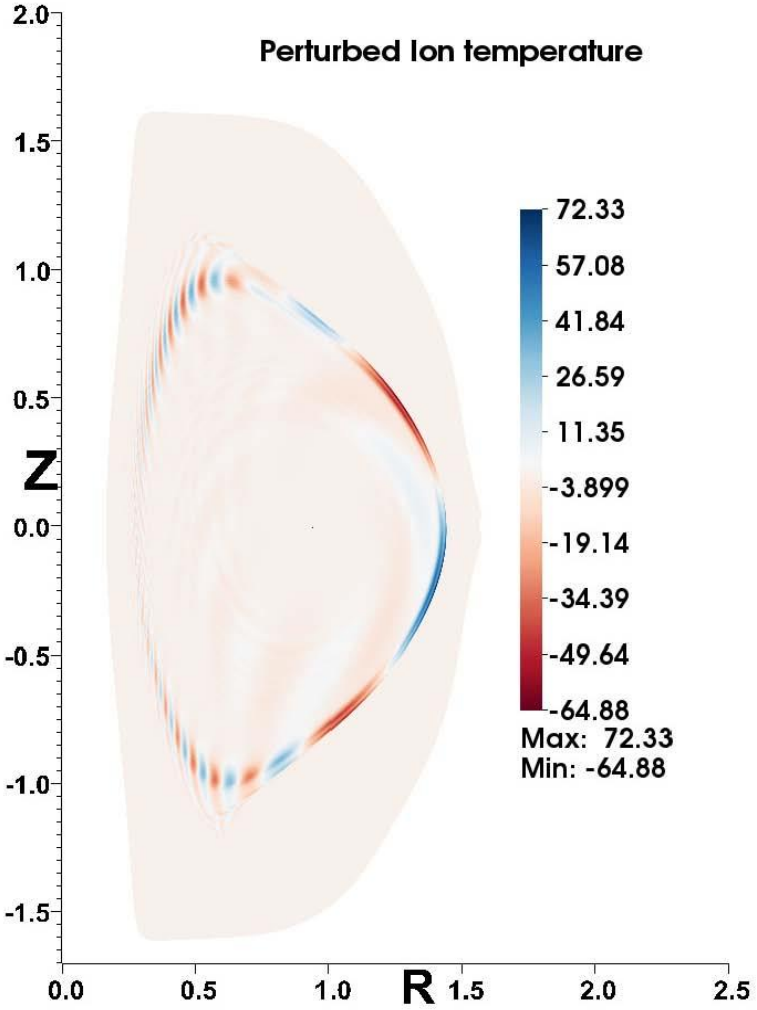




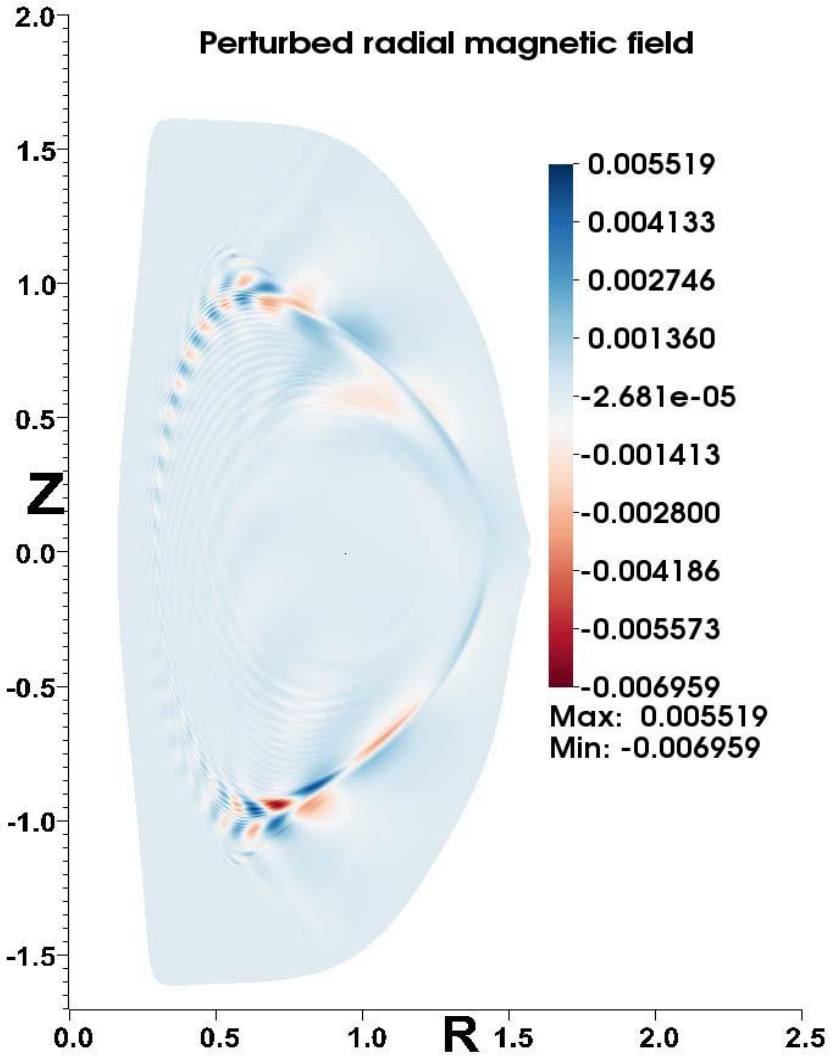
What else factor might play catalystic role behind stabilization?

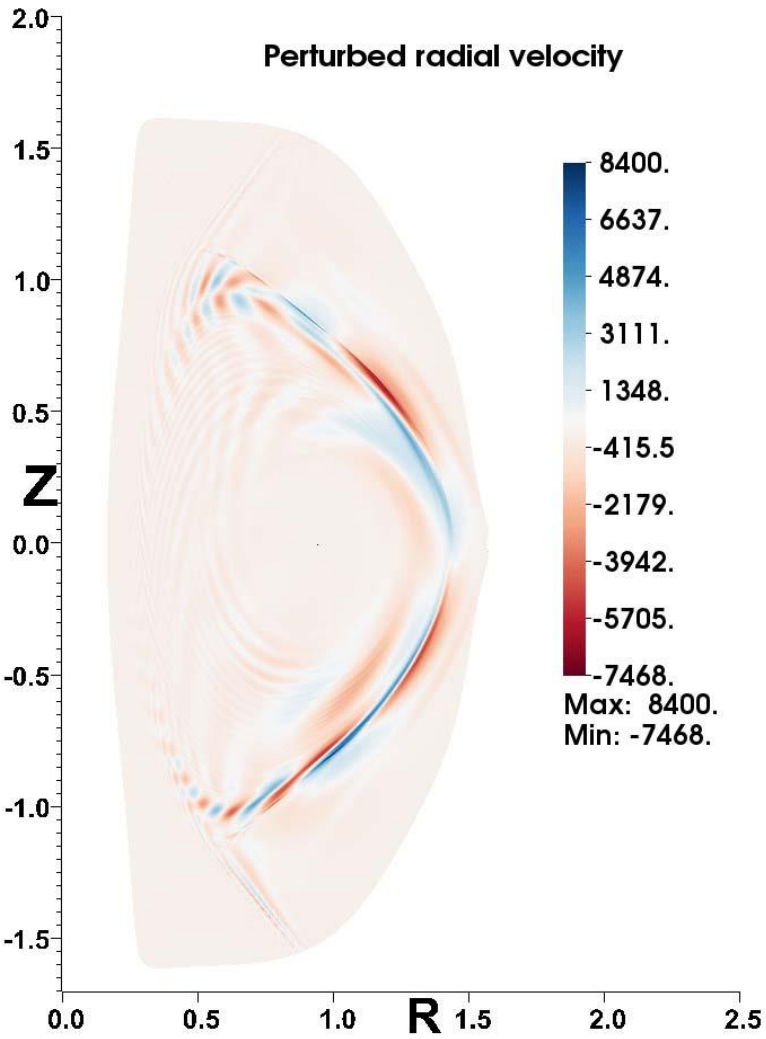
Edge localized modes have resolved structures



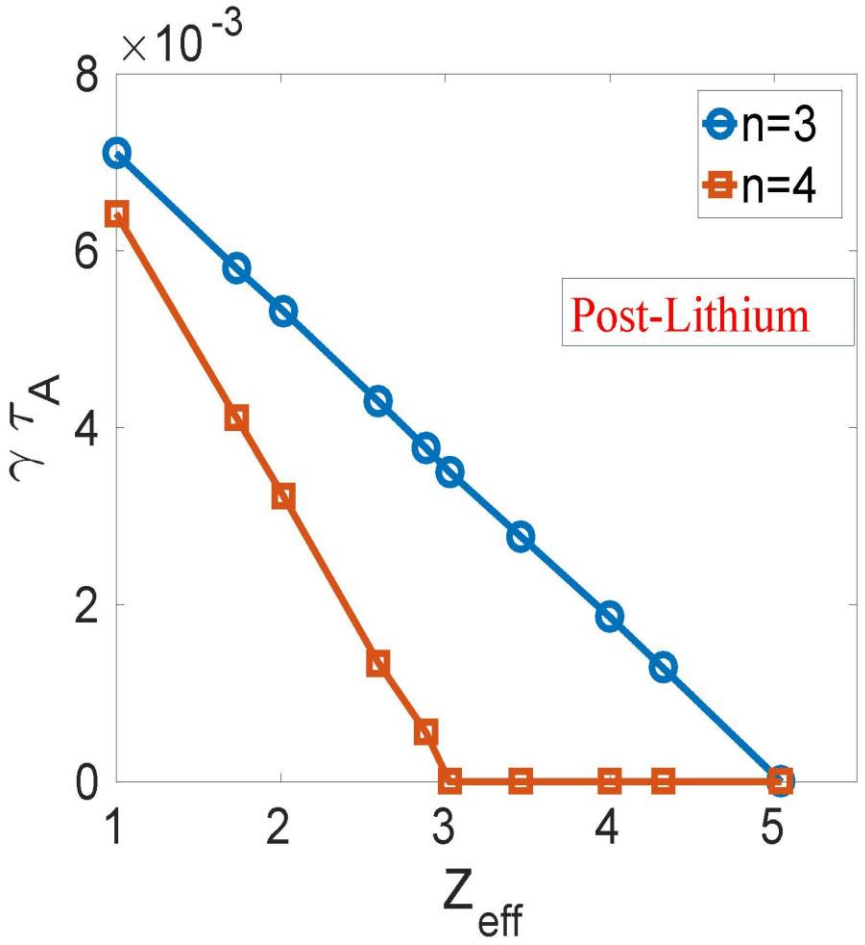


Edge localized modes have resolved structures





Enhanced resistivity causes stabilization of low-n modes



Spitzer Resistivity: $\eta(T_e) = \eta_0 \, Z_{eff} \left(\frac{T_{e0}}{T_e} \right)^{3/2}$

η_0 = resistivity at magnetic axis

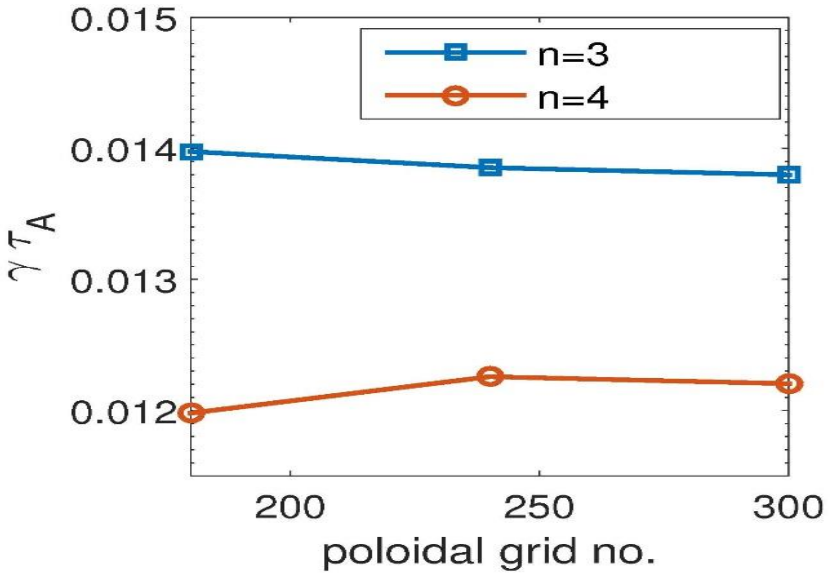
T_{e0} = electron temperature at magnetic axis

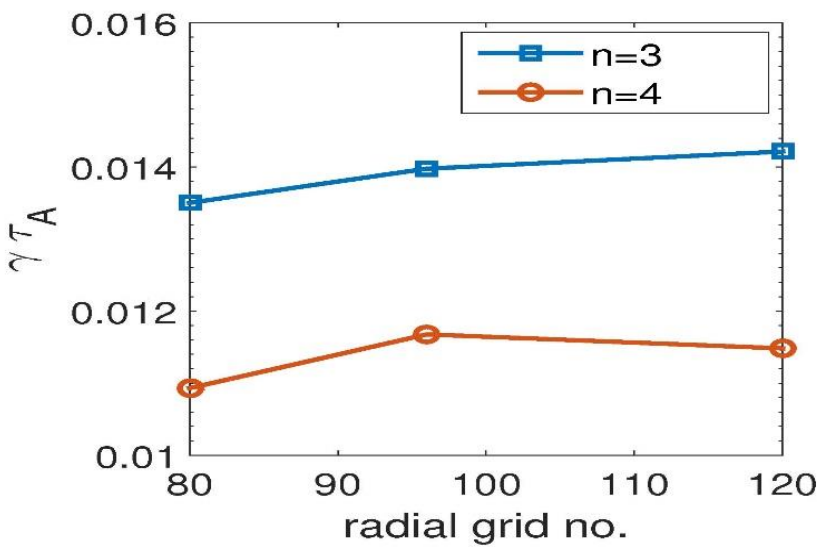
Z_{eff} = effective atomic number

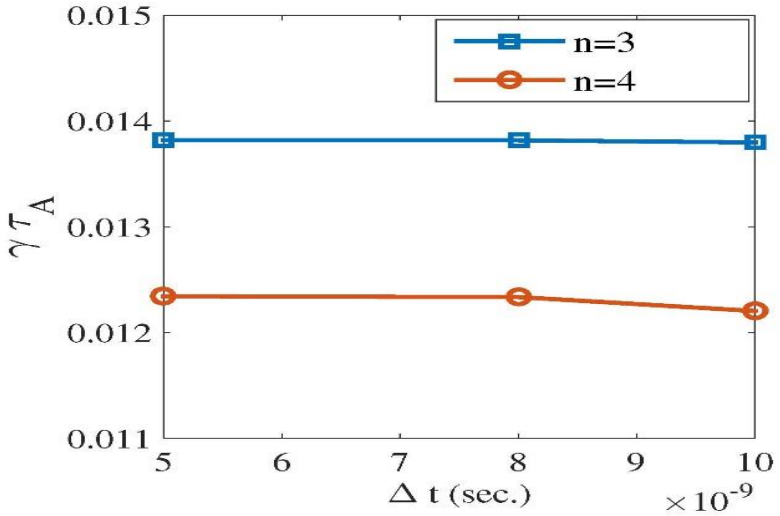
- The enhanced resistivity at edge pedestal corresponding to higher Z_{eff} provides complete stabilization.
- The required value of Z_{eff} is similar with the experimental measured value.

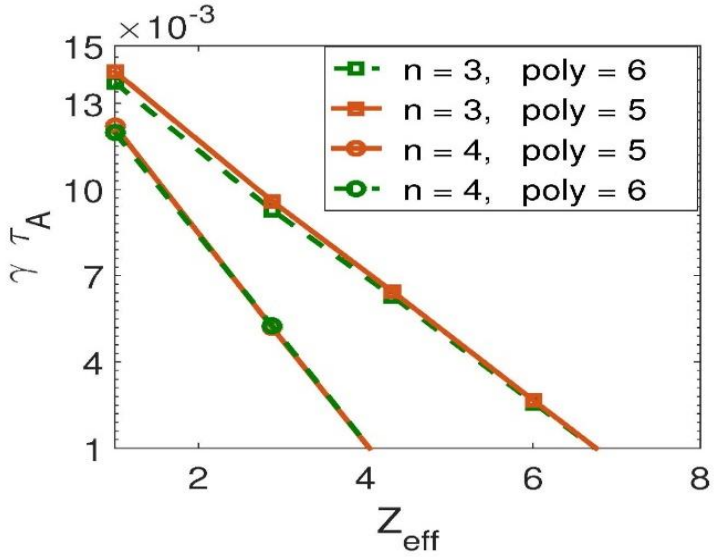
D. Banerjee, P. Zhu and R. Maingi, *Stabilizing effects of enhanced resistivity due to lithium-conditioning on low-n edge localized modes in NSTX*, **under review in Physical Review Letter**

The numerical results are well converged



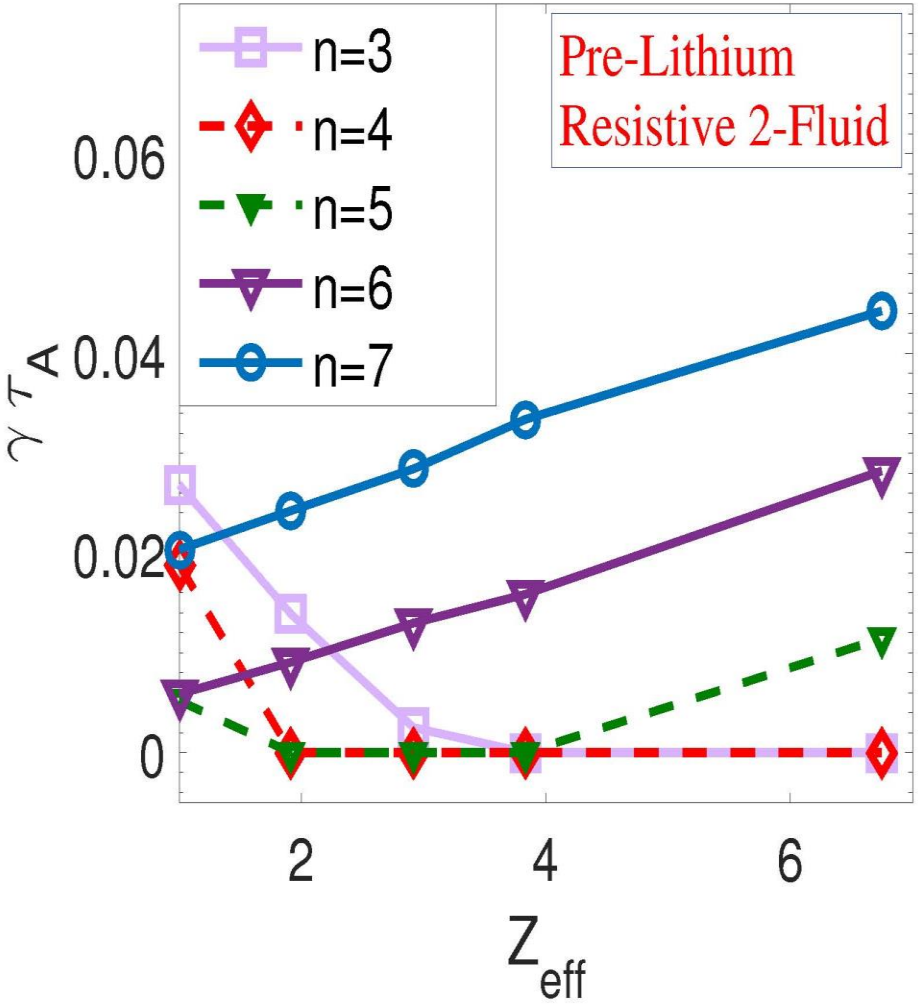






Resistive stabilization on low-n ELMs in NSTX is general!

- The value of Z_{eff} is varied in Spitzer model for pre-lithium case.
- The density and temperature profiles of electron and ion are unchanged.
- n=3,4 are reduced in growth rate and finally become stabilized.
- Growth rates of (n>5) modes are increasing with resistivity.



Summary & Conclusion

- Resistive stabilizing effects on low-n ELMs have been found in 2-fluid model using NIMROD calculations.
- The profile changes alone may not be sufficient for explaining the Li-induced ELM suppression in NSTX.
- Resistive stabilization of low-n ELMs due to the enhancement in Z_{eff} may explain the Li-induced ELM suppression in NSTX.

Acknowledgement

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  https://nimrodteam.org/team.html
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- ***University of Science and Technology of China super computer center's support on computational facility.***

Thanks for your Kind attention