NSTX-U

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Changes to edge gyrokinetic stability with lithium coated PFCs in NSTX

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J.M. Canik, ORNL

W. Guttenfelder, R. Maingi, R.E. Bell, B.P. LeBlanc (PPPL), T.H. Osborne (GA)

and the NSTX Research Team

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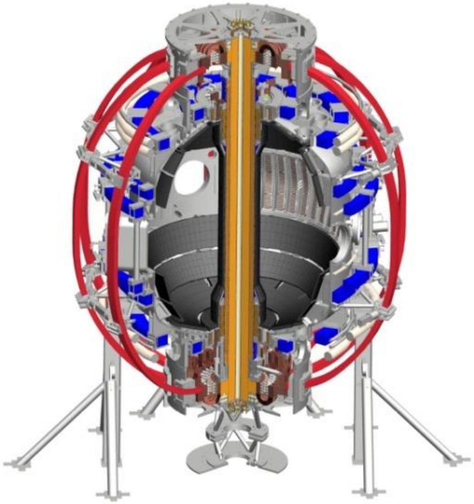
11/12/2013



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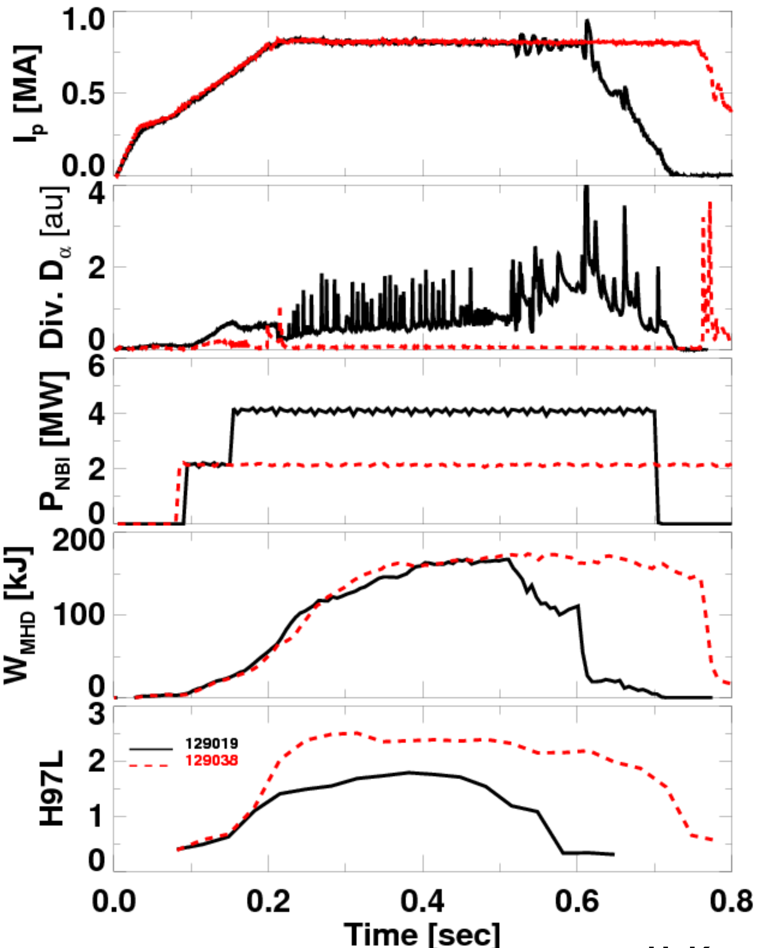
Outline

- Review of changes to edge plasma with lithium
- Gyrokinetic calculations of edge stability towards understanding the effects of lithium
- Pedestal-top is microtearing unstable without lithium, stable with
  - Stabilized by density gradient
- Near-separatrix region is unstable to ETG, more strongly with lithium
  - Nonlinear simulations suggest ETG may be experimentally relevant

Type I ELMs eliminated, energy confinement improved with lithium wall coatings



Without Li, With Li

ELM-free, reduced divertor recycling

Lower NBI to avoid β limit

Similar stored energy

H-factor 40%↑

H. Kugel, PoP 2008
R. Kaita, IAEA 2008
M. Bell, PPCF 2009

Top of pedestal (ψ_N~0.8-0.95)

n_e and T_e gradients increase with lithium

⇒Improvement in global confinement

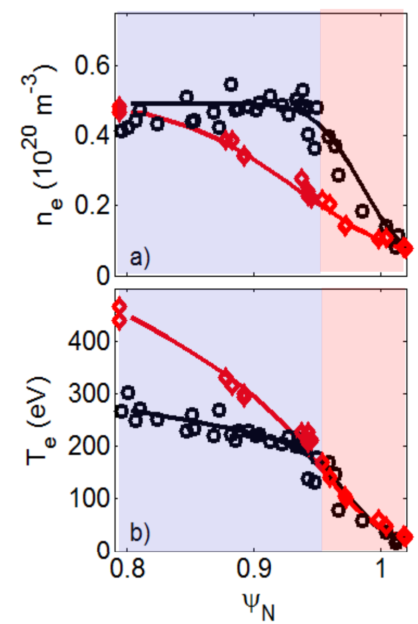
Near-separatrix (ψ_N~0.95-1)

n_e and its gradient are reduced with lithium

T_e profile is unchanged

⇒Reduced pressure gradient

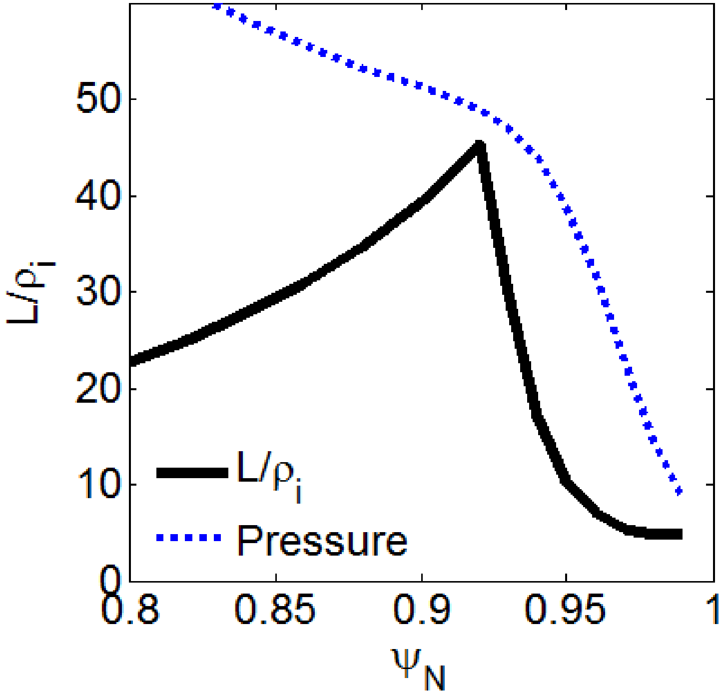
⇒ ELM stabilization



Microstability of the NSTX pedestal with/without lithium is studied with GS2*

- Local, linear microstability examined with GS2 code
  - Fully electromagnetic, with collisions (pitch-angle)
  - Kinetic electrons, D and C^{6+} ions
  - Kinetically constrained equilibria consistent with profiles & $J_{bootstrap}$

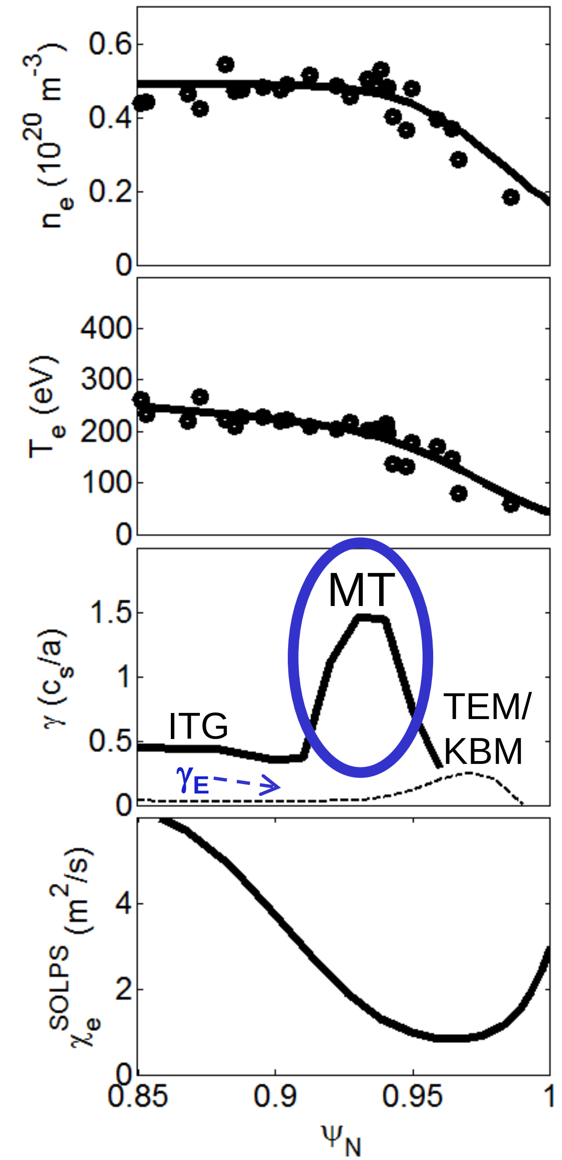
- Applicability of local approach is limited at edge
  - OK at pedestal top for ion scales, and everywhere for electron scales (L/ρ_e>>1)
    - $\Rightarrow$ Results presented here
  - Global simulations clearly needed in steep gradient region (L/ρ_i~5)



*M. Kotschenreuther et al, Comput. Phys. Commun. 88 (1995) 128.

Microtearing is dominant at pedestal top without lithium

- Mode type ID'd by eigenfunction structure, real frequency, parameter dependence
- Various low-k modes ($k_\theta \rho_s \leq 1$) are unstable across the edge
  - Core (ψ_N<0.9)
    - ITG dominant, γ_E small
  - Within pedestal (ψ_N~0.96)
    - γ reduced, ~ γ_E (TEM-like with KBM signatures)
  - **Pedestal top (ψ_N~0.93)**
    - **γ large, >> γ_E (Microtearing)**
- Microtearing unstable region corresponds to break in ∇T_e



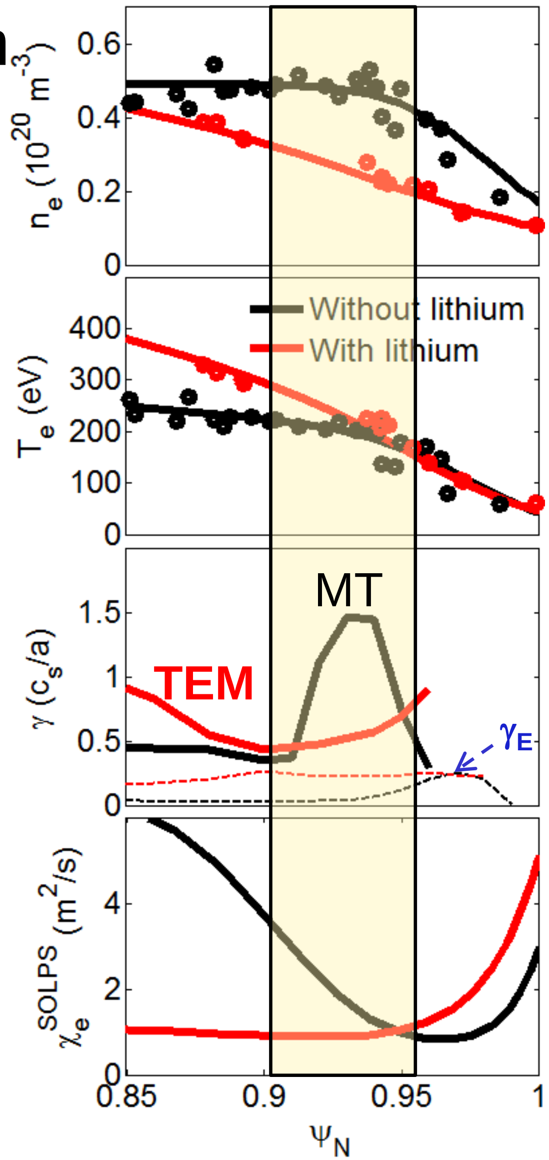
Canik, NF '13

Stabilization of pedestal-top microtearing modes with lithium correlates with reduced transport region in experiment

- From ψ = 0.8-0.95 ∇n_e increased with lithium
  - Increased ∇n_e stabilizing to MT (strongest parameter dependence)
  - TEM becomes dominant, reduced γ closer to γ_E

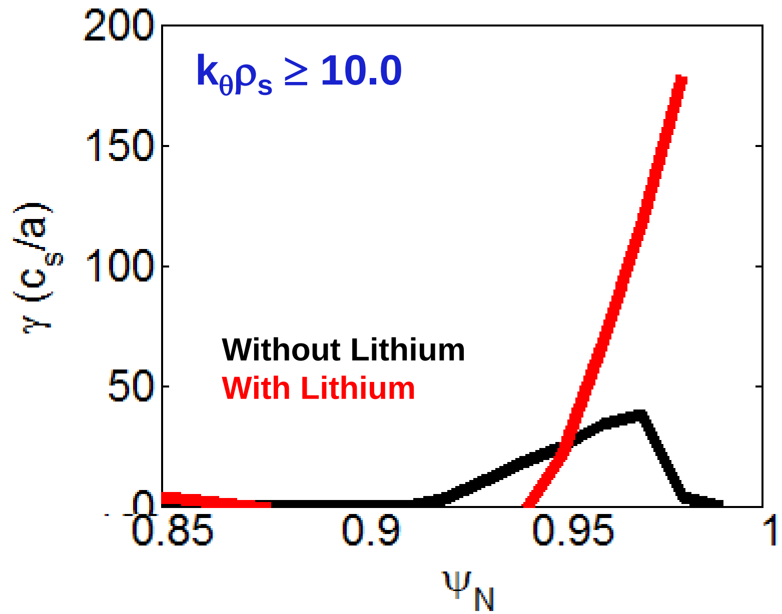
- χ_e inferred from SOLPS modeling[1] of experiment is reduced in this region
  - ⇒ ∇n_e stabilization of MT contributes to improved energy confinement with lithium?
  - Similar picture from MAST analysis[2]
  - Needs nonlinear simulations to quantify
  - Confinement improvement region is broader than where MT are stabilized
  - Physics behind change in n_e profile unknown

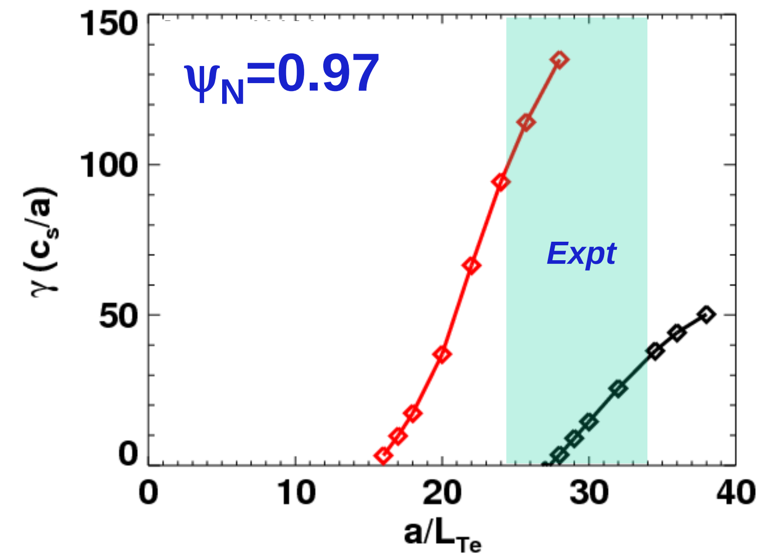
[1]Canik, PoP '11, [2]Dickinson, PRL '12



ETG modes are unstable near the separatrix

- ETG calculated to be unstable for ψ_N > 0.95 both without and with lithium
- Growth rates significantly higher with lithium
  - a/L_{ne} is reduced, while a/L_{Te} is unchanged
  - $\Rightarrow \eta_e$ increases from ~1.5 to ~2
- Could play a role in keeping T_e profile clamped at edge
  - Important for P-B stability
  - Linearly picture holds

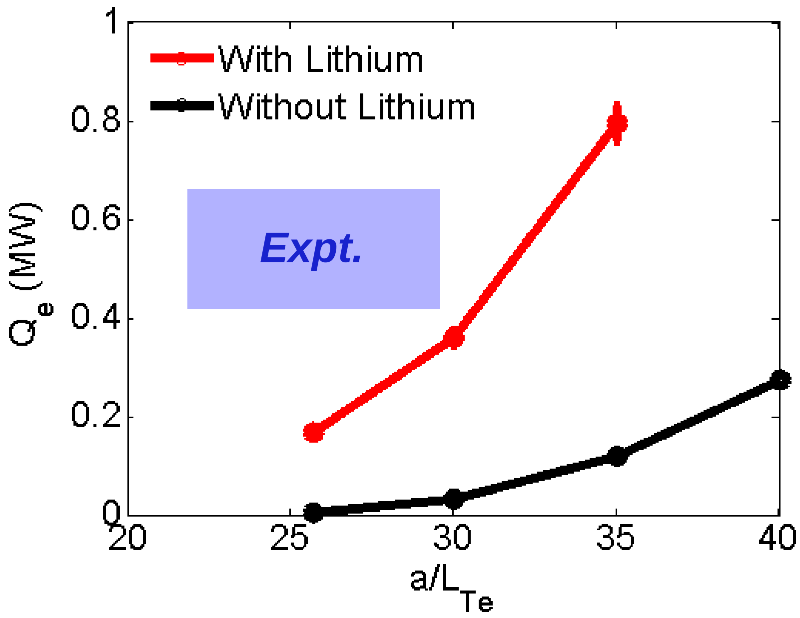


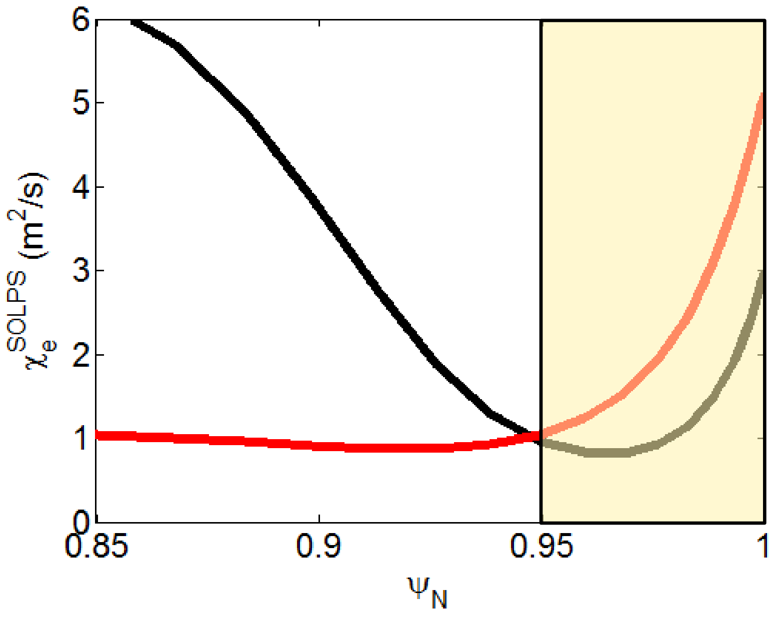


Nonlinear simulations indicate ETG heat flux may be significant with lithium

- Electrostatic, adiabatic ion simulations, including collisions and ExB
- Without lithium (high density gradient), ETG heat flux is very small
- With lithium, at nominal electron temperature gradient, ETG gives ~1/3-1/2 experimental electron heat flux
- With a/L_{Te} increased by ~20%, ETG can provide entire experimental flux
- Similar flux level found out to radius of ψ_N=0.99

ψ_N=0.97





Summary/conclusions/future work

- Two important edge regions identified by 2D interpretive modeling of NSTX discharges without and with lithium
  - Near-separatrix (ψ_N>0.95): T_e clamped⇒pressure gradient reduced with density when lithium is deposited (important for ELM stability)
  - Pedestal-top (ψ_N~0.8-0.95): transport reduced with lithium (contributes to energy confinement increase)
- Microtearing is dominant at pedestal-top without lithium
  - Stabilized by the increased density gradient with lithium
  - Could contribute to increased confinement with lithium->need nonlinear simulations
- ETG is destabilized near separatrix with lithium
  - Could play a role in observed T_e stiffness
  - Nonlinear simulations yield fluxes near experiment
- Changes to density gradient with lithium play key role

EXTRA SLIDES FOLLOW

Microtearing is dominant at pedestal top without lithium

- Mode type ID'd by eigenfunction structure, real frequency, parameter dependence
- Four spatial regions evident without lithium
  - Pedestal foot (ψ_N>0.98)
    - γ is large, >> γ_E (KBM-like)
  - Within pedestal (ψ_N~0.96)
    - γ reduced, ~ γ_E (TEM-like)
  - **Pedestal top (ψ_N~0.93)**
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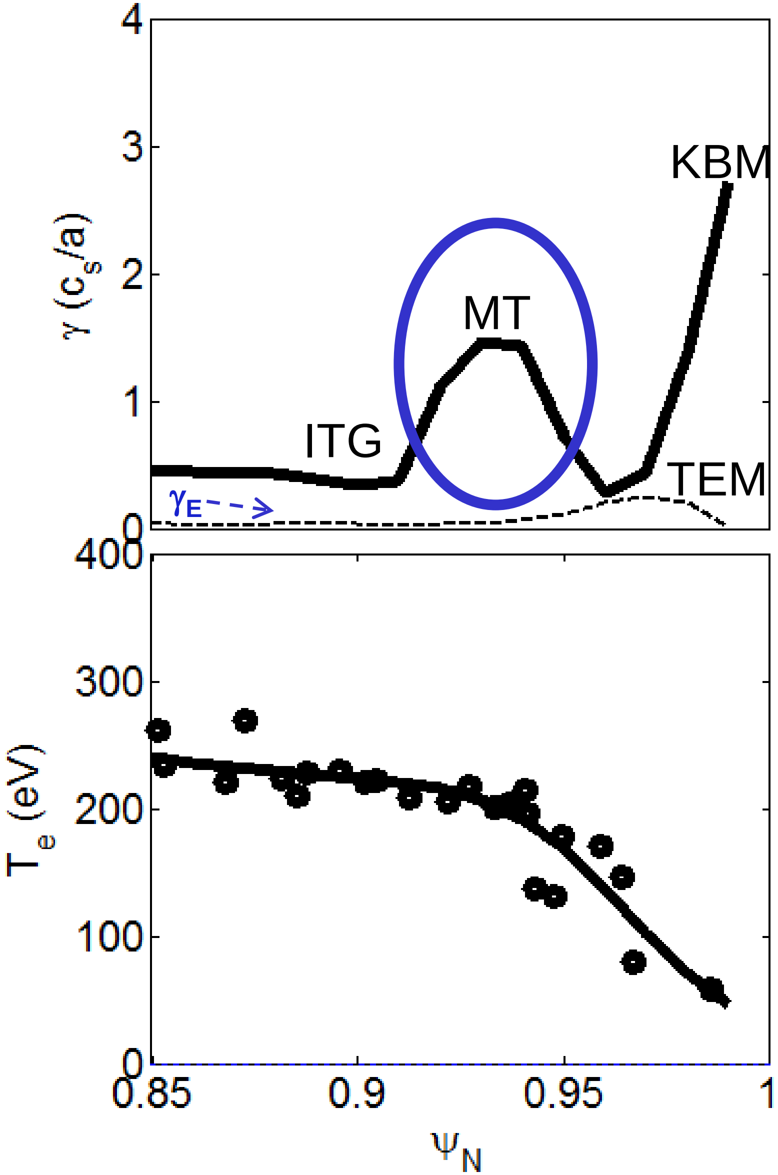
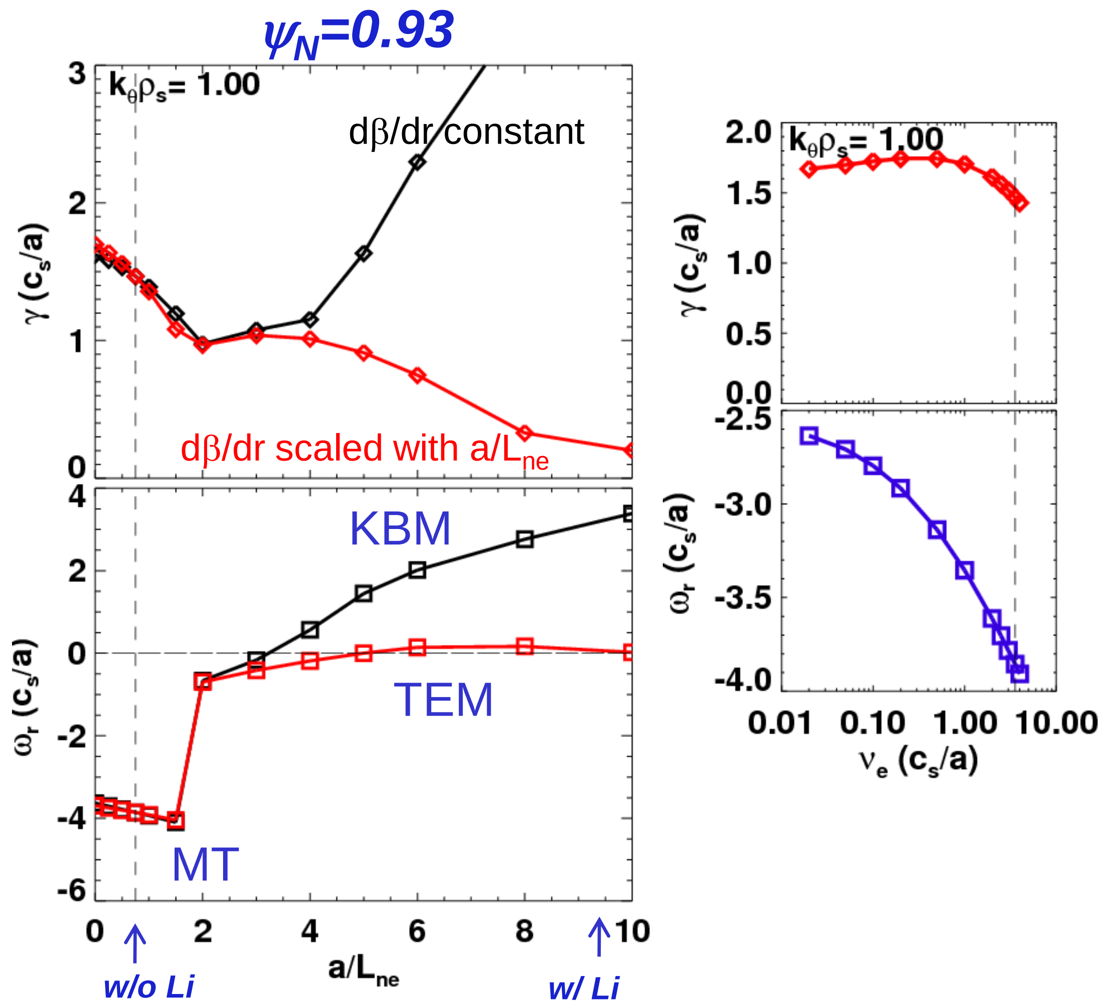
  - Core (ψ_N<0.9)
    - ITG dominant, γ_E small



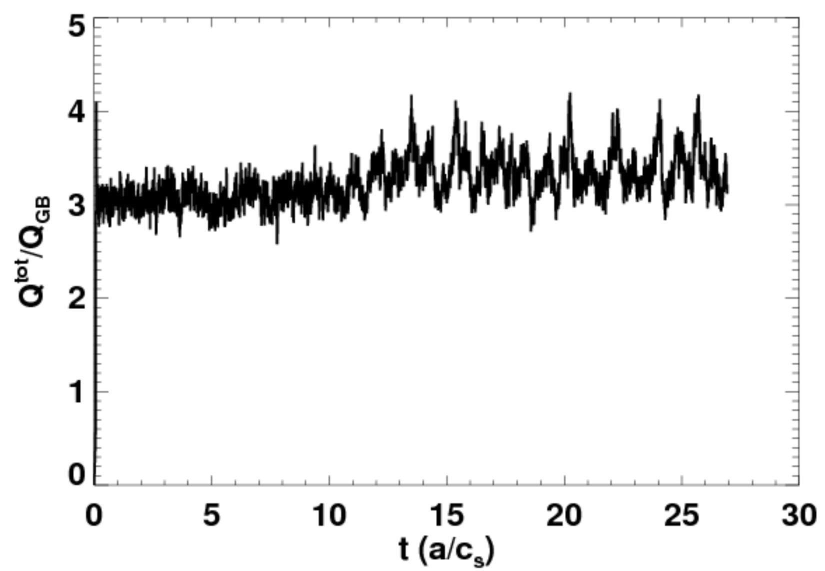
Density gradient is stabilizing to MT modes dominant at pedestal-top without lithium

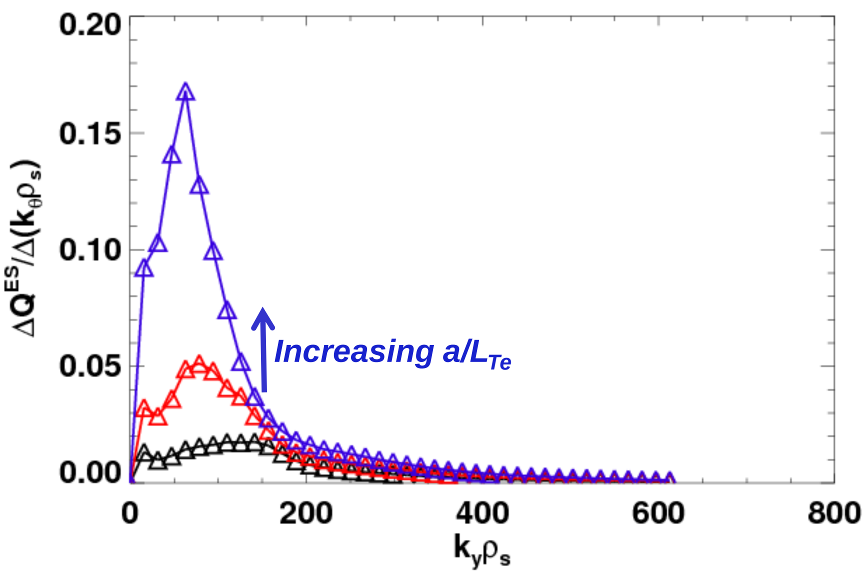
- Increasing a/L_{ne} stabilizes MT
  - TEM becomes dominant, with reduced γ
- If magnetic geometry is held fixed, KBM onset occurs at high a/L_{ne}
- With pressure gradient in geometry scaled consistently
  - No KBM onset
  - a/L_{ne} continues to be stabilizing
  - Growth rate strongly reduced at a/Lne of discharge with lithium
- Decreasing collisionality is weakly destabilizing at these parameters



Nonlinear calculations performed to test if ETG transport is significant near experimental parameters

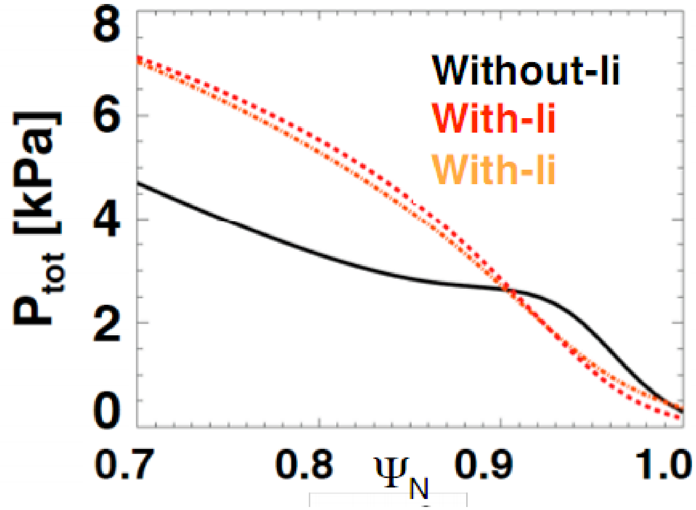
- Electrostatic, adiabatic ion simulations
- Collisions and ExB shear included
- Simulations run out to quasi steady state
- Resolutions checks performed to ensure heat flux is converged
- Transport peaks at rather high ky due to distortion of flux tube near separatrix

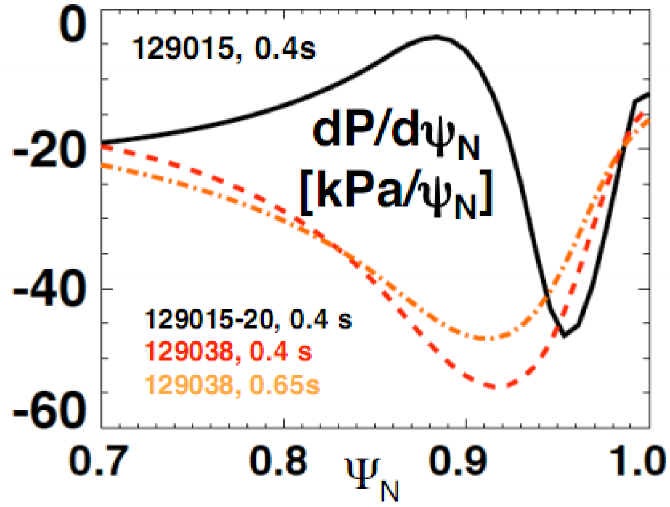


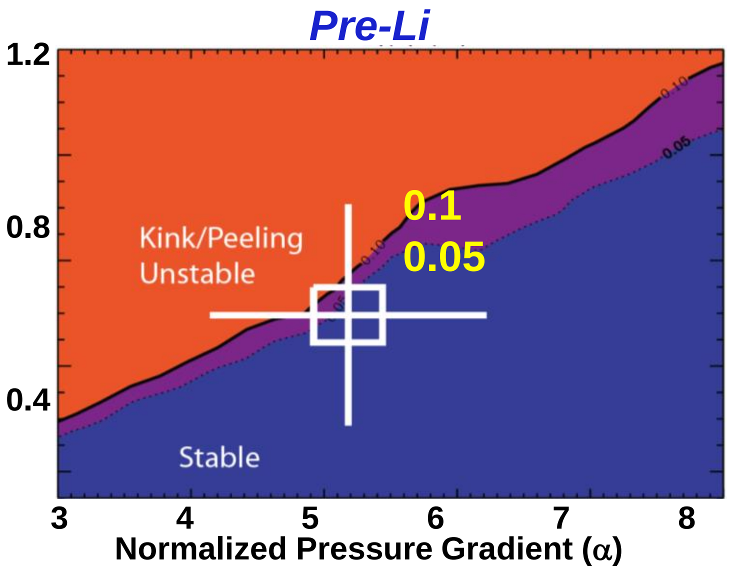


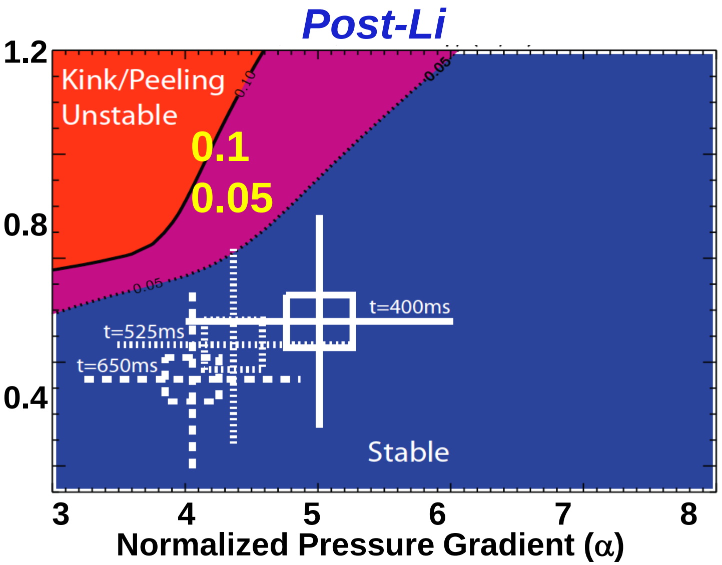
Peak pressure gradient moves inwards, p' and j reduced outside ψ_N~0.95

R Maingi, PRL 2009





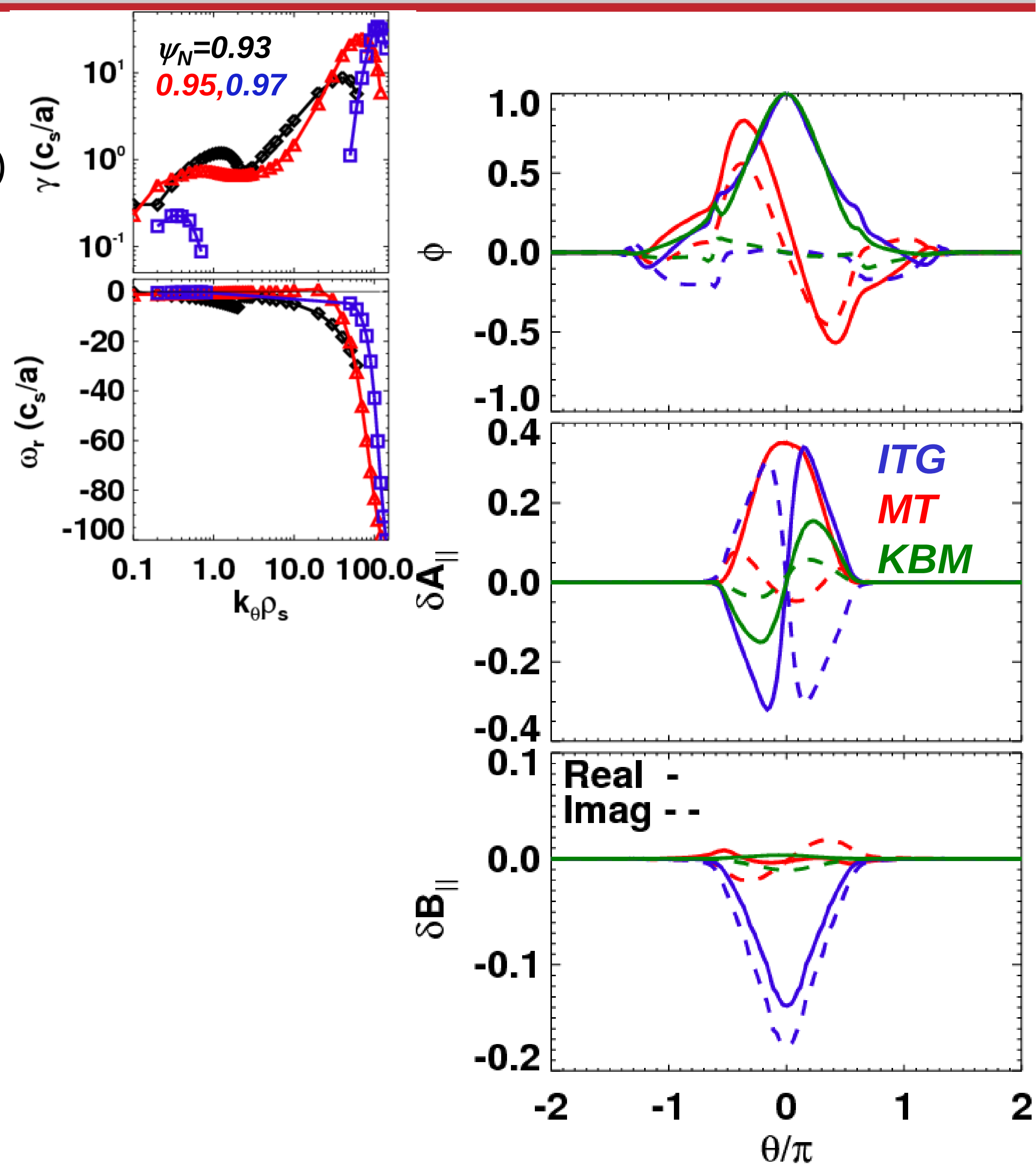




Mode type identified by eigenfunction structure and real frequency

- Instabilities calculated over wide range of $k_\theta\rho_s$
  - For now focus on ion scales ($k_\theta\rho_s \leq 1$)
  - Identify most unstable mode at each radius
- ITG/TEM
  - Twisting parity ($\delta A_{||}$ odd)
  - Re[$\delta A_{||}$] and Im[$\delta A_{||}$] have opposite sign
  - Real frequency determines ITG vs TEM
- Microtearing
  - Tearing parity ($\delta A_{||}$ even)
- KBM
  - Twisting parity ($\delta A_{||}$ odd)
  - Re[$\delta A_{||}$] and Im[$\delta A_{||}$] have same sign

- Mode ID has been confirmed via parameter scans to test for expected scaling



Radial profile of maximum low-k growth rate, freq

- Four spatial regions evident without lithium
  - Pedestal foot (ψ_N>0.98)
    - γ is large, >> γ_E (KBM-like)
  - Within pedestal (ψ_N~0.96)
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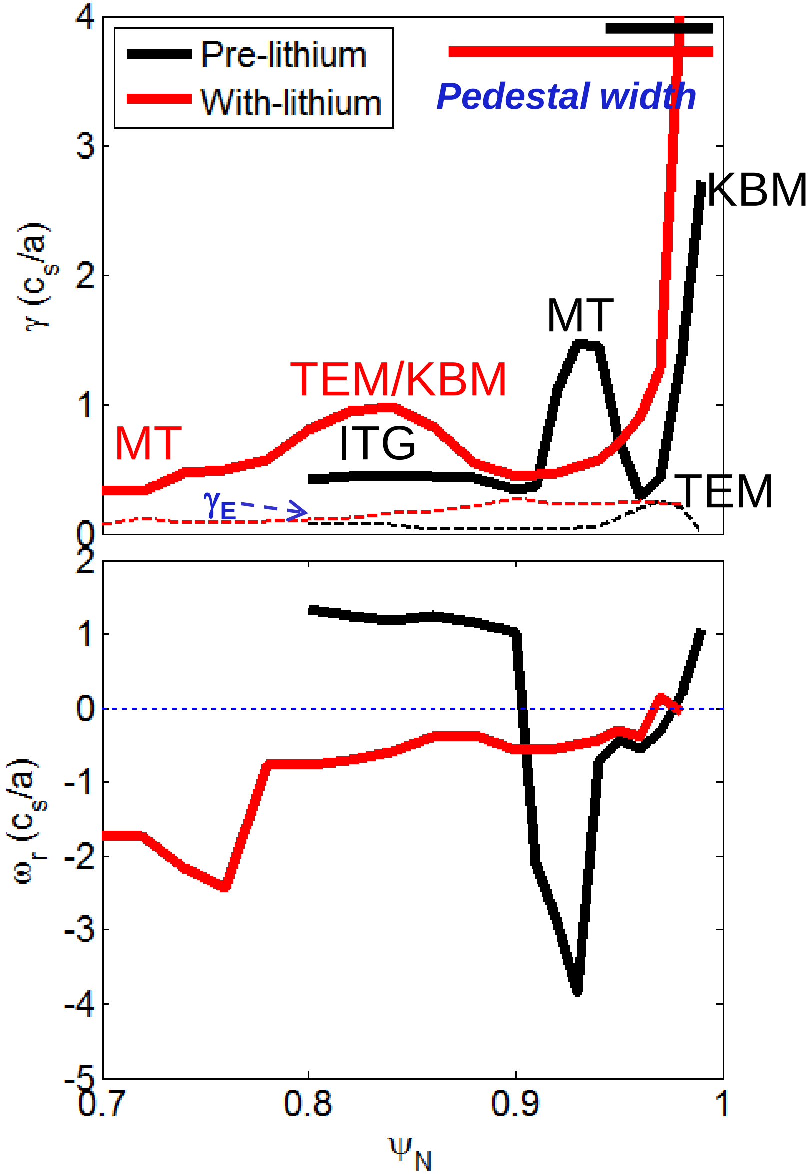
  - Core (ψ_N<0.9)
    - ITG dominant, γ_E small
- γ profile has similar structure with lithium
  - Regions are broader (pedestal widens)
  - Edge modes are always TEM/KBM hybrid



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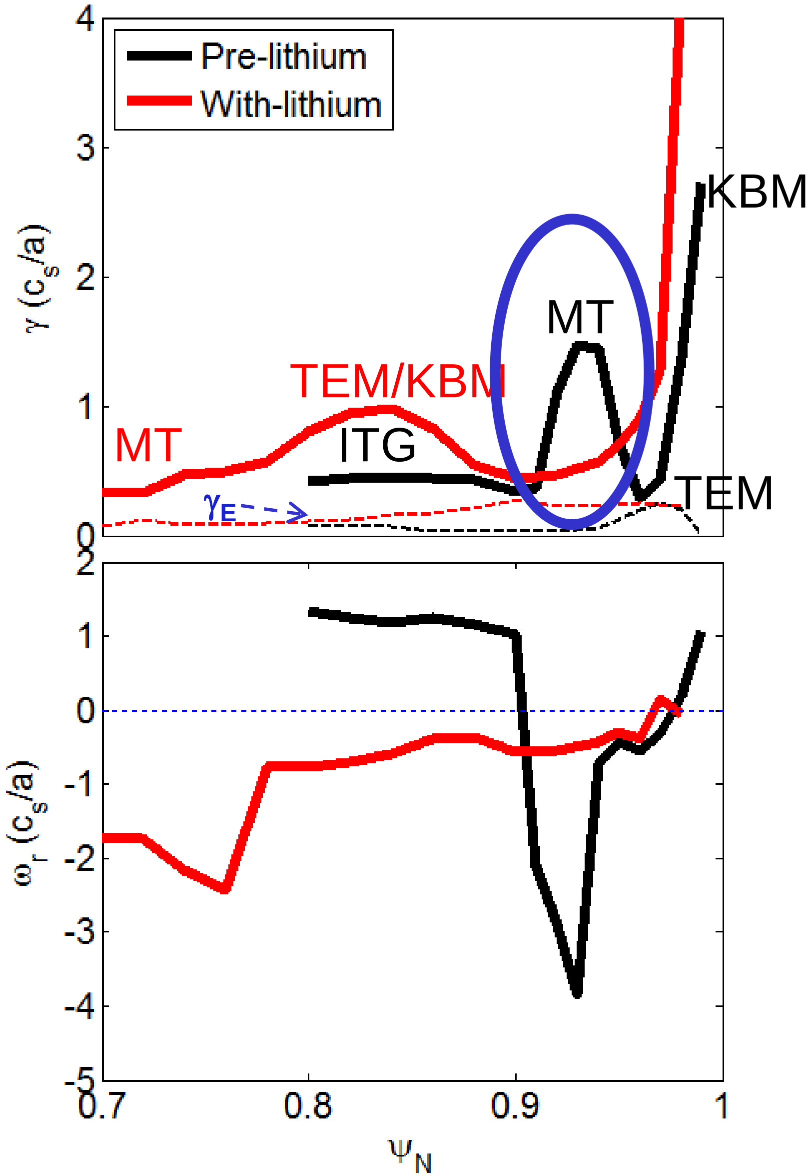
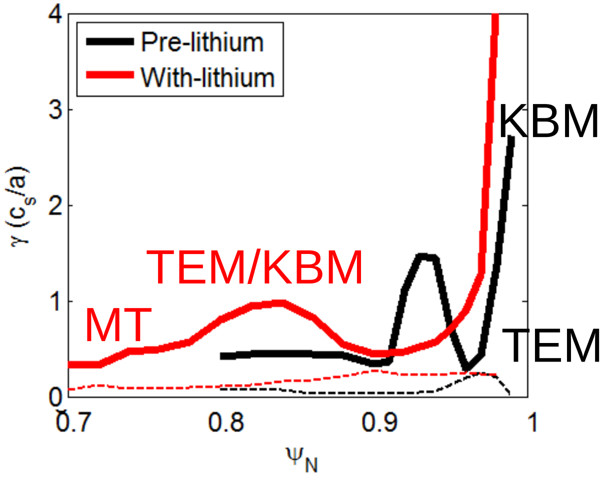
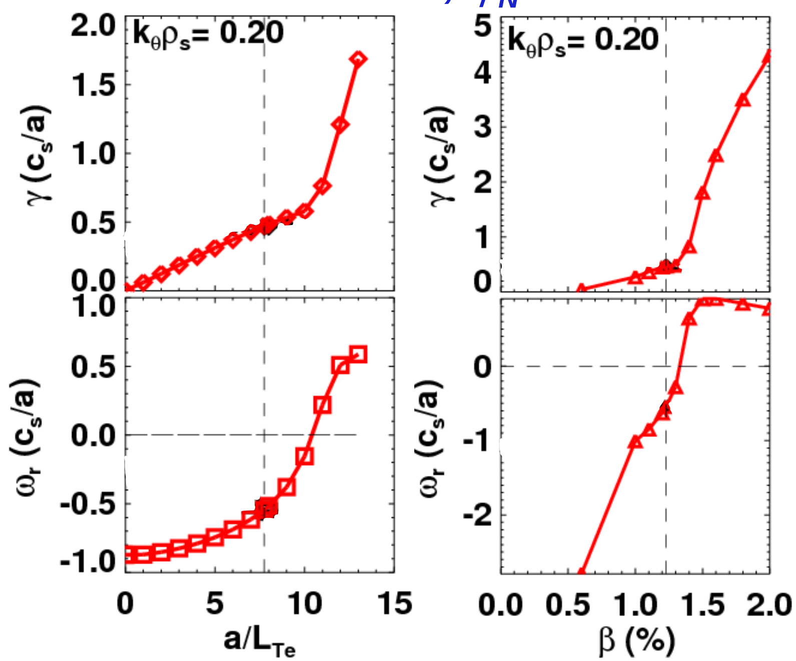


Hybrid TEM/KBM mode is dominant in steep-gradient-region

- a/LTe and ν scan shows TEM-like behavior
  - γ increases with a/LTe
  - γ decreases with ν
- β scan is KBM-like
  - Sharp increase in γ at high β
  - Weaker increase even below this knee, where ω_r is negative
- 'Hybrid' TEM/KBM w/ smooth transition between negative and positive ω_r
- Consistent with pedestal being near KBM onset



With lithium, ψ_N=0.92



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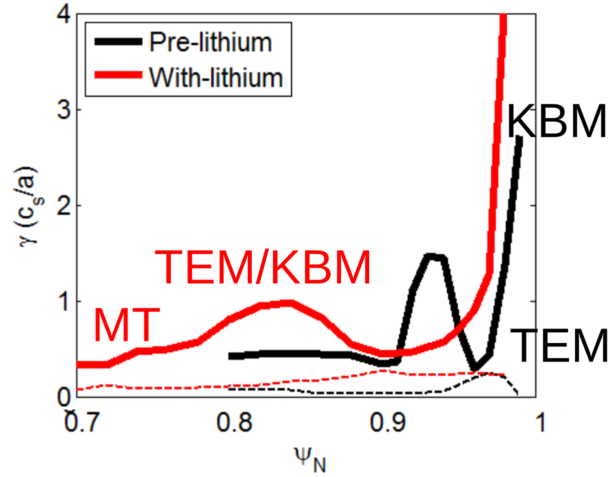
  - γ decreases with ν
- β scan is KBM-like
  - Sharp increase in γ at high β
  - Weaker increase even below this knee, where ω_r is negative
- 'Hybrid' TEM/KBM w/ smooth transition between negative and positive ω_r
- Consistent with pedestal being near KBM onset
  - Except that increasing β' in the MHD equilibrium is strongly stabilizing
  - When equilibrium β' is scaled-self consistently higher β reduces γ
    - No stiff ∇P limit at KBM onset?



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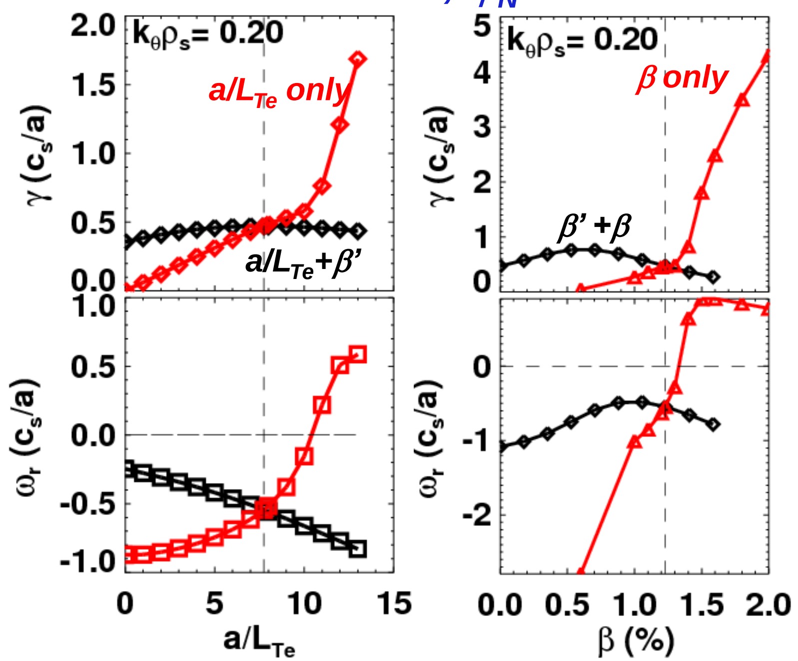
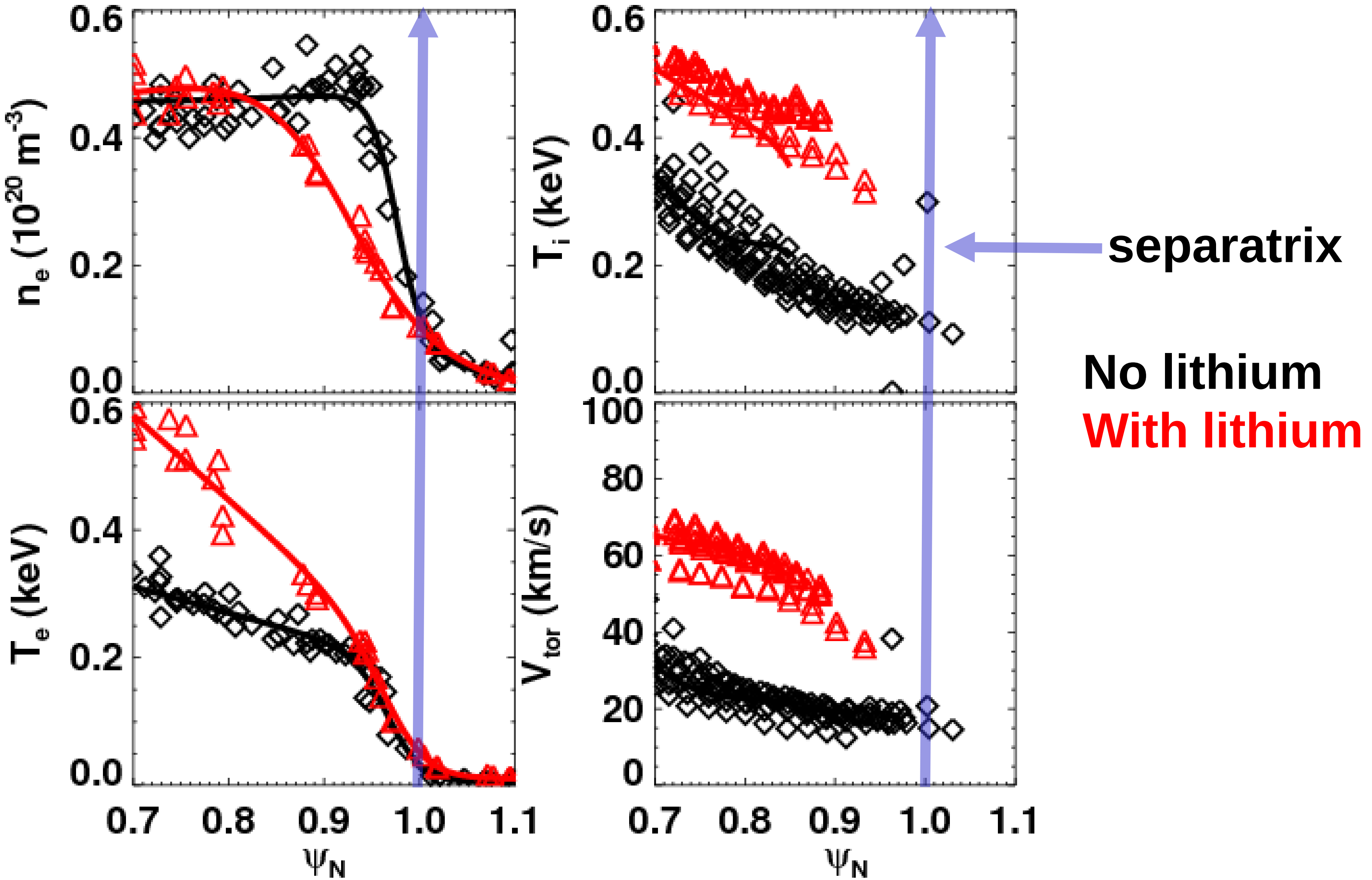
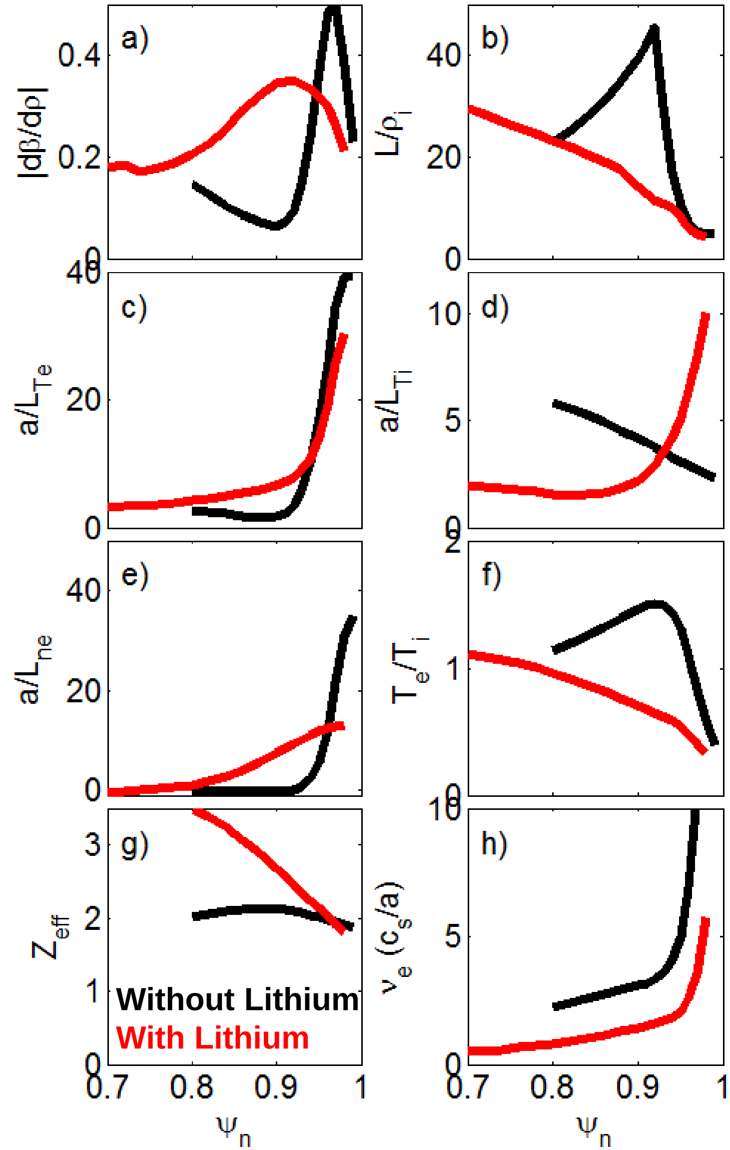


T_e, T_i increased and edge n_e decreased with lithium coatings



Summary of profiles used in calculations

- Peak pressure gradient moves inward from ψ_N=0.96 to ψ_N=0.9 with lithium
  - Pressure pedestal broader with lithium
- Collisionality reduced with Li
- Outside ψ_N~0.95
  - a/L_{Te} similar with/without lithium
  - a/Ln_e decreased with lithium
    - η_e increases
- Inside ψ_N~0.95
  - a/L_{Te}, a/L_{ne} increase with lithium
  - a/L_{Ti}, T_e/T_i decrease with lithium



Pre-lithium E×B shear is determined from measured V_t, P_{C6+} profiles

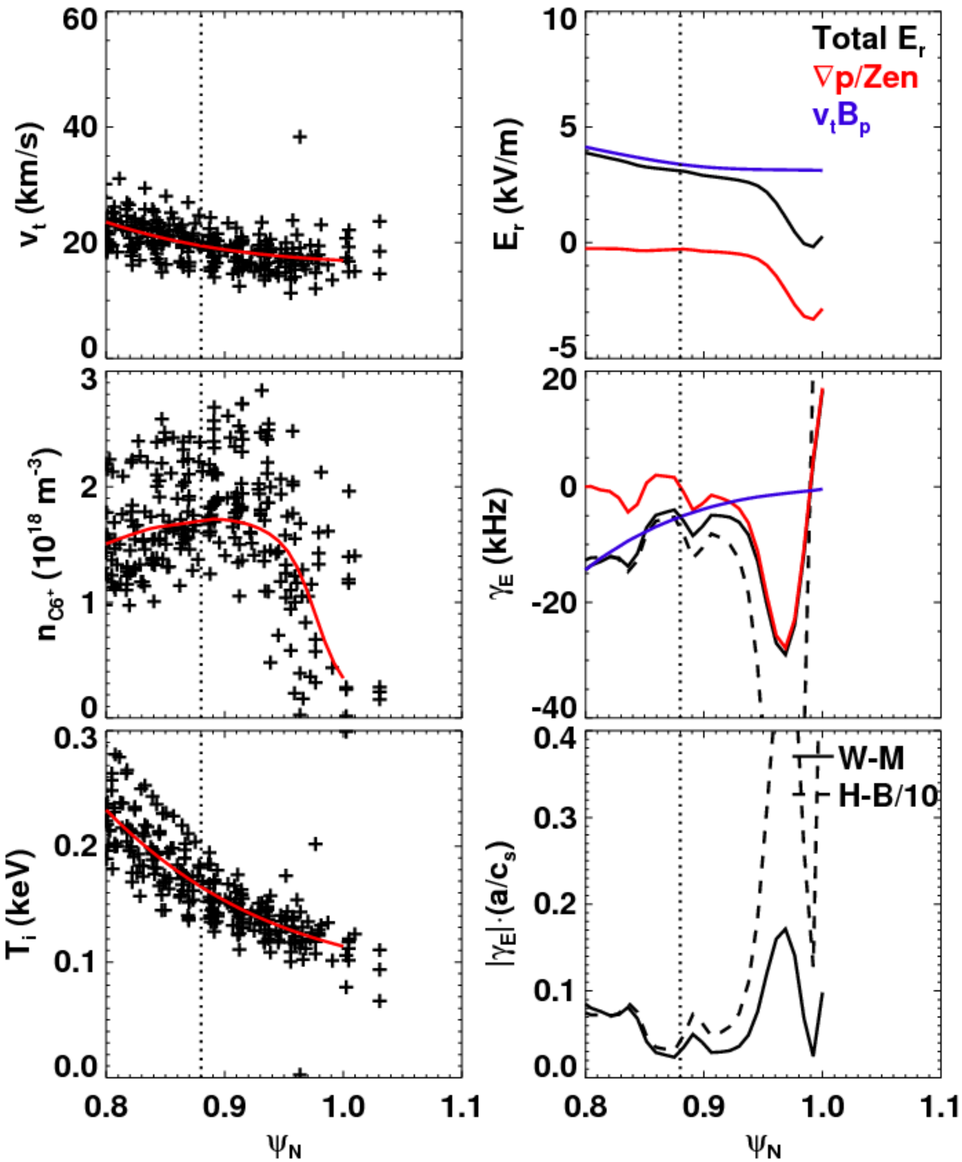
- Carbon toroidal rotation, pressure profiles used to estimate E_r
  - Poloidal rotation contribution small in other discharges (B_t~B_p) (Maingi, PRL '10)
- Shear rate calculated using two expressions
  - Waltz-Miller

$$\gamma_E = \frac{r}{q}\frac{\partial}{\partial r}\frac{E_R}{RB_p}$$

  - Hahm=Burrell

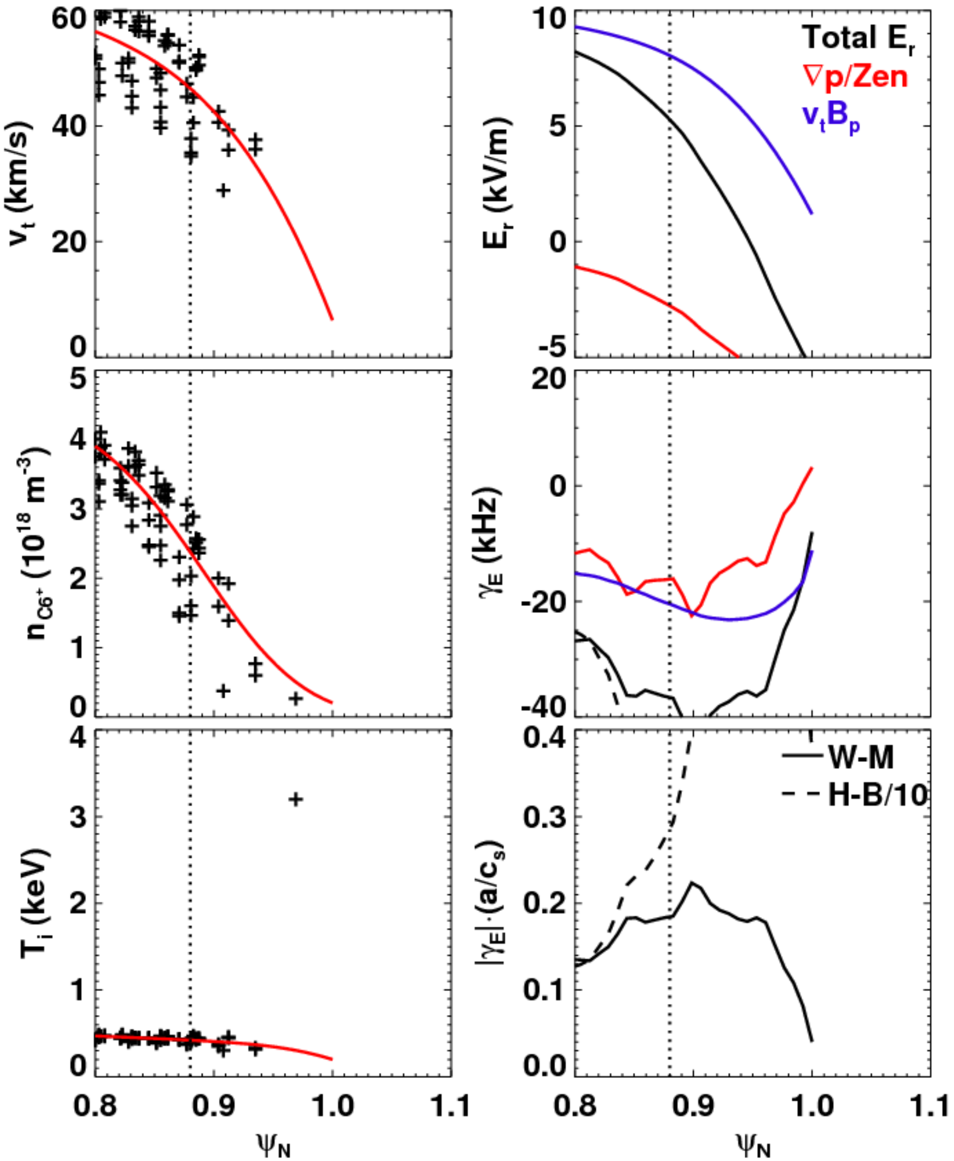
$$\gamma_E = \frac{(RB_p)^2}{B}\frac{\partial}{\partial \psi}\frac{E_R}{RB_p}$$

- Shear rate is largest within pedestal region
  - Narrow region with substantial pressure contribution



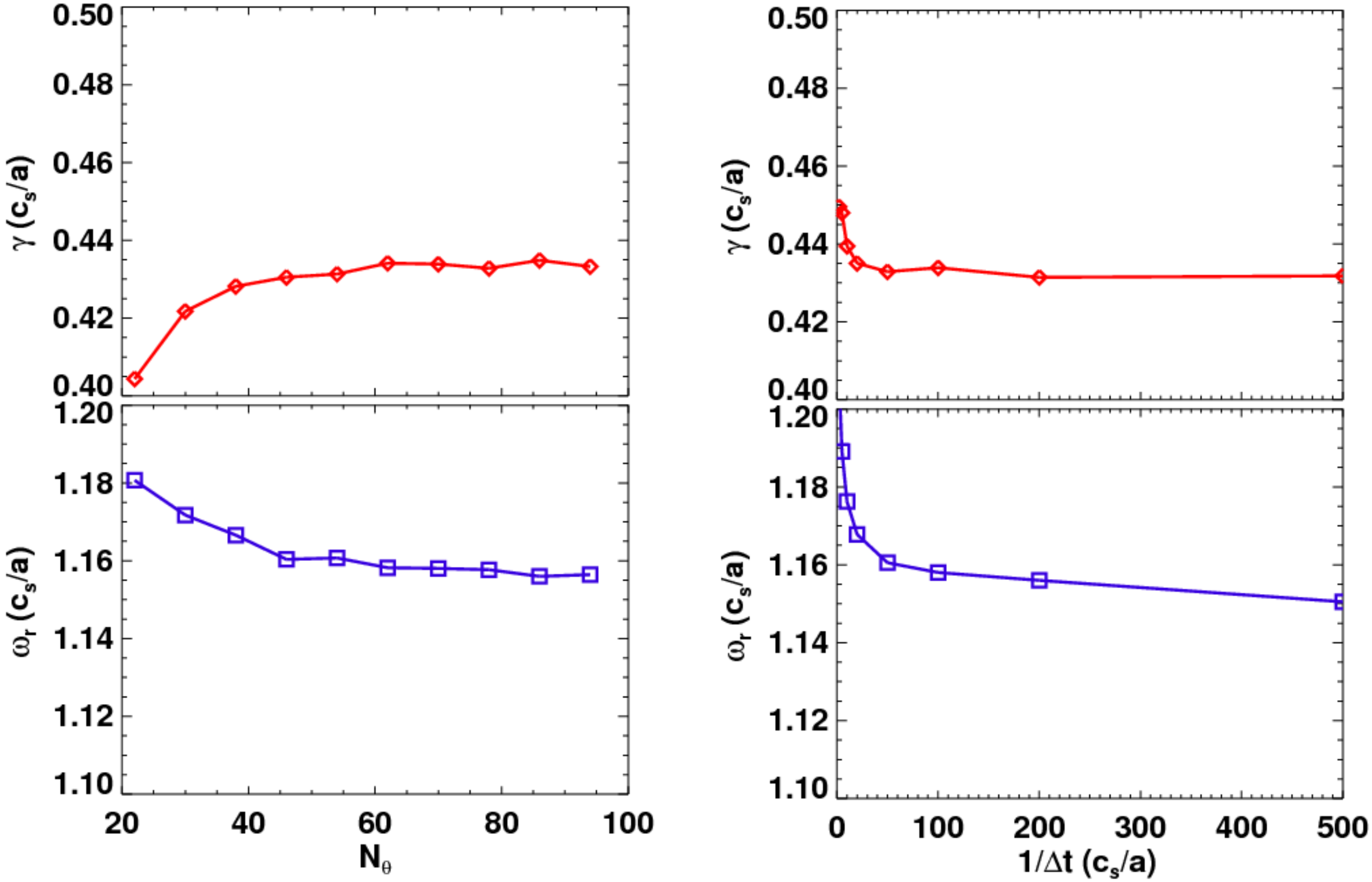
Region with large E×B shear becomes wider with lithium

- Values outside ψ_N~0.95 are extrapolations
- V_t, dV_t/dr are larger than pre-lithium case
- Pressure gradient gives significant contribution to γ_E over a wider radial range



Results are converged with grid size and time step

- N_θ = 72 works well in all cases
- $\Delta t \leq 0.01$, depends on radius (varies with γ, ω_r)
  - Also converged for dominance of two competing modes



N_E=16

N_λ=41