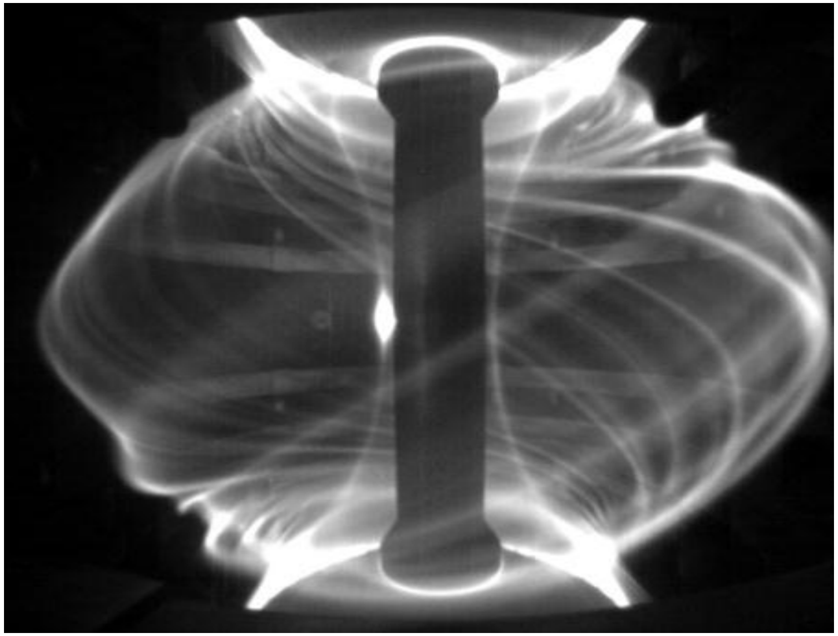
Gyrokinetic Instabilities near an Evolving Tokamak H-Mode Pedestal



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Acknowledgements:
J W Connor, R J Hastie + computer access to HECToR, HPC-FF and Helios.

Outline

1. Need for Gyrokinetics to Improve Pedestal Models
2. Plasma Profile Evolution between Type I ELMs in MAST
3. Local GK analysis of ELM cycle, $k_y\rho_i$~O(1)
   - microtearing (MTM) and kinetic ballooning (KBM)
4. MTM/KBM Transition at Pedestal Top
   - inward advance of pedestal?
5. Drive Mechanism for Microtearing at MAST Edge
6. Conclusions

1. Need for Gyrokinetics in Pedestal Models

Understanding the Edge Pedestal will help:
- optimise confinement in the core
- develop strategies to tame the ELM

State-of-the Art Model is EPED: [1]
- kinetic ballooning+MHD peeling ballooning $\Rightarrow$ predicts P_{ped} , Δ_{ped} prior to ELM
- EPED agrees with many measurements from prior to type-I ELMs
- EPED does NOT describe:
    - full details of how pedestal profiles evolve
    - T_{ped}, n_{ped} as required by core transport models

More Complete Model:
- must describe all edge transport processes

Role for Gyrokinetics:
- unveil microinstability mechanisms influencing pedestal evolution
- determine turbulent fluxes

[1] P B Snyder et al, Phys. Plasmas **16**, 056118 (2009)

1. Gyrokinetics at Edge is Challenging

Extensive physics required for high fidelity in edge GK:

- **δB** , collisions, strong shaping, impurities, flow

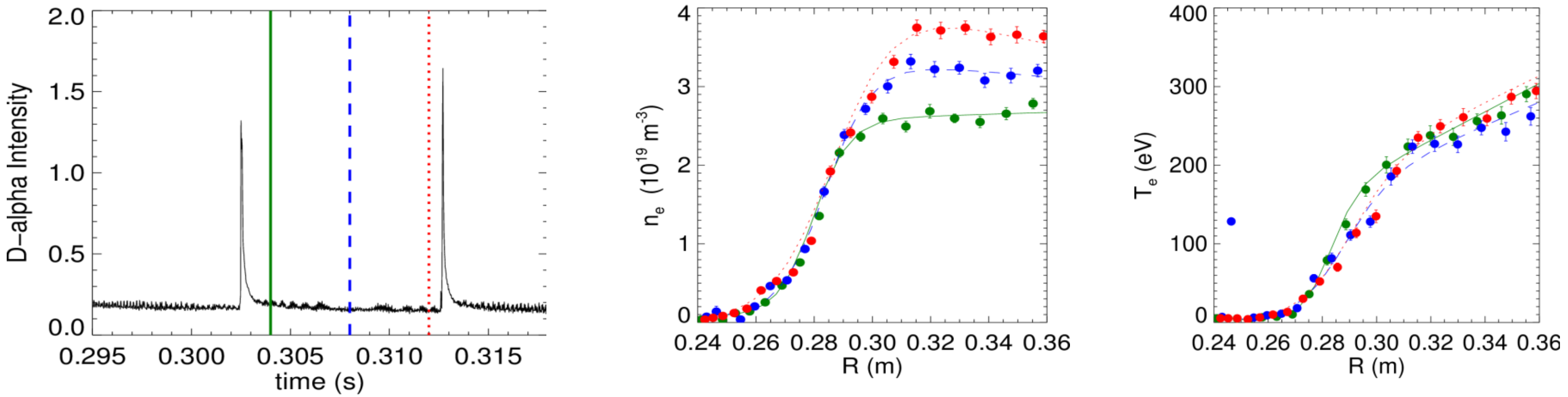
GK expansion parameter ρ_i/L_{eq} larger than in core, i.e. weak separation between turbulence and equilibrium length scales

…

L_{eq} varies across radial turbulence correlation lengths
$\Rightarrow$global simulations desirable

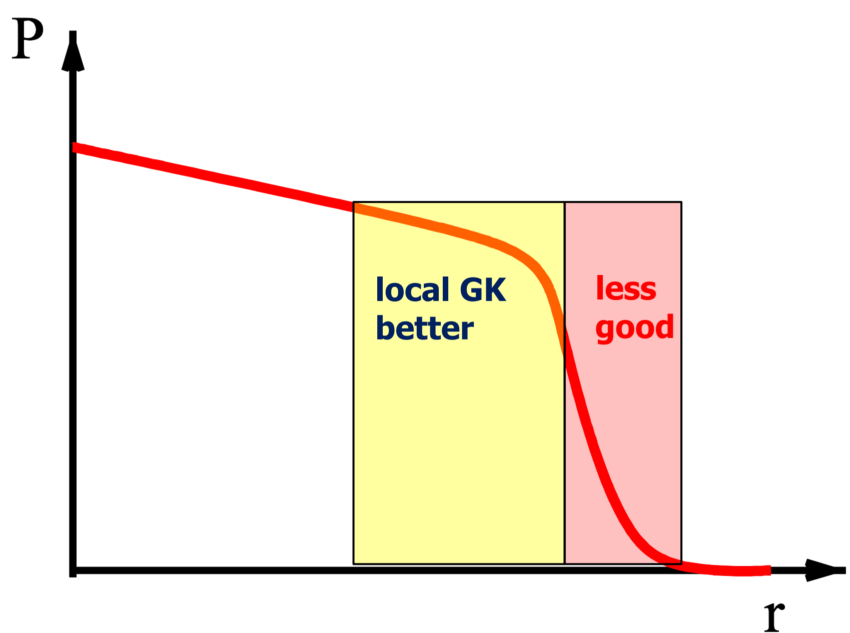
Neutrals influence edge plasma, and not included in GK.

1. MAST Plasma Evolution Measured over ELM cycle



* More MAST edge TS data in **R Scannell et al, EX/P7-22 (Friday)**

"What can we learn by Pushing Local GK to the Limit?"



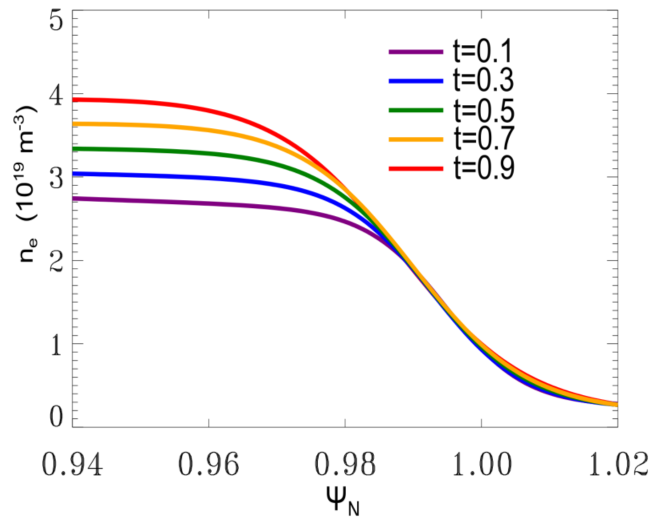
2: MAST ELM cycle Profile Evolution: low T_e^{ped}

T_e^{ped}~150eV
$\upsilon_{*e}(\psi_N=0.94)$~1.1

50 TS profiles from reproducible MAST discharges with periodic type I ELMs

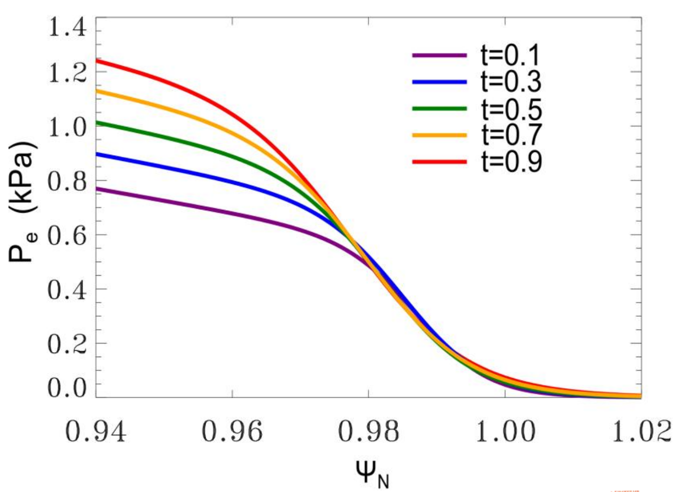
- sort profiles in elapsed time since last ELM

  $t = (\text{time}-\text{time}_{\text{lastELM}})/\tau_{\text{ELM}}$
- 5 bins: t=**0-0.2**, **0.2-0.4**, **0.4-0.6**, **0.6-0.8**, **0.8-1.0**
- fit mean binned profiles (mtanh)



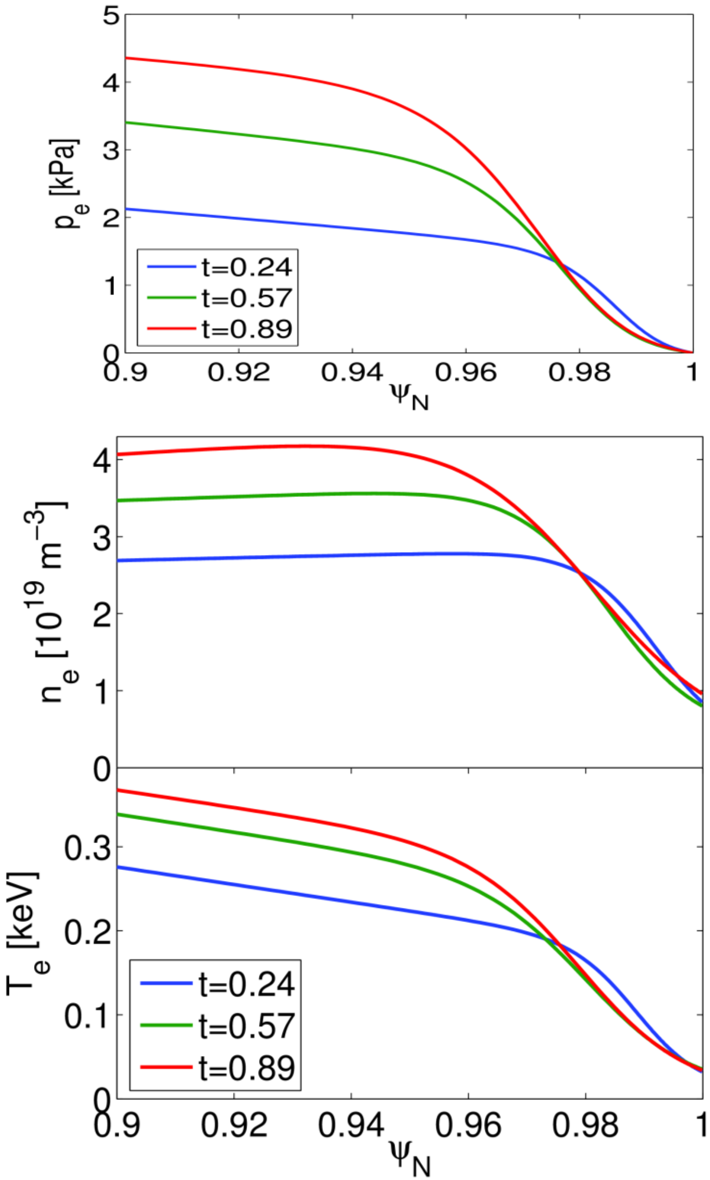
Evolution over ELM cycle:

- n_e, P_e have similar evolution
  - T_e evolution modest
- high dP_e/dr, dn_e/dr at separatrix after ELM then expand inwards with Max(gradient) staying ~constant



[1] Dickinson et al, PPCF **53**, 115010 (2011)

2: Profiles during MAST ELM cycle: high T_e^{ped}



T_e^{ped}~300eV
$\upsilon_{*e}(\psi_N$=0.94)~0.5

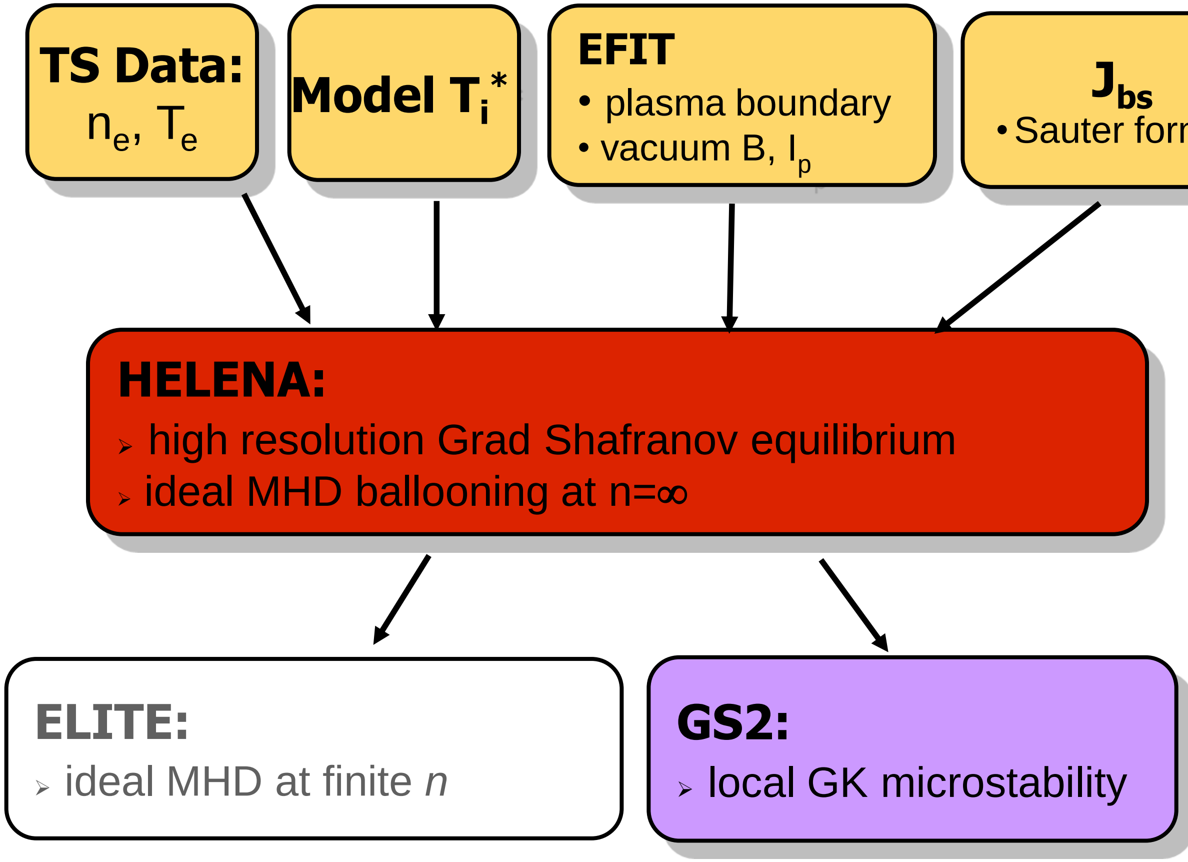
Lower gas puff:

- reduces collisionality in edge

ELM cycle profile evolution similar to low T_e^{ped} :

- pedestal in $\mathbf{T_e}$ also expands inwards

2: MAST Equilibria for Stability Analysis



*** Ion Model:**
-- T_i=T_e everywhere
-- $dT_i^{ped}/dr = dT_e^{core}/dr$
carbon impurity, Z_{eff} =2

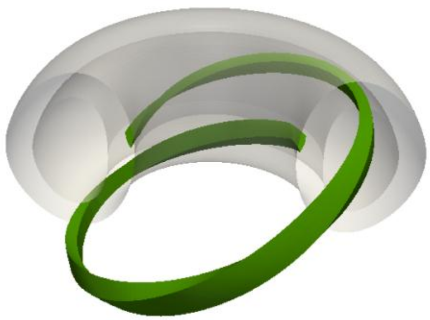
Equilibria +MHD analysis for **low T_e^{ped}** discussed in **[1]**

[1] Dickinson et al, PPCF **53**, 115010 (2011)

2: Local GK Analysis

Local linear GK analysis using GS2 [1]

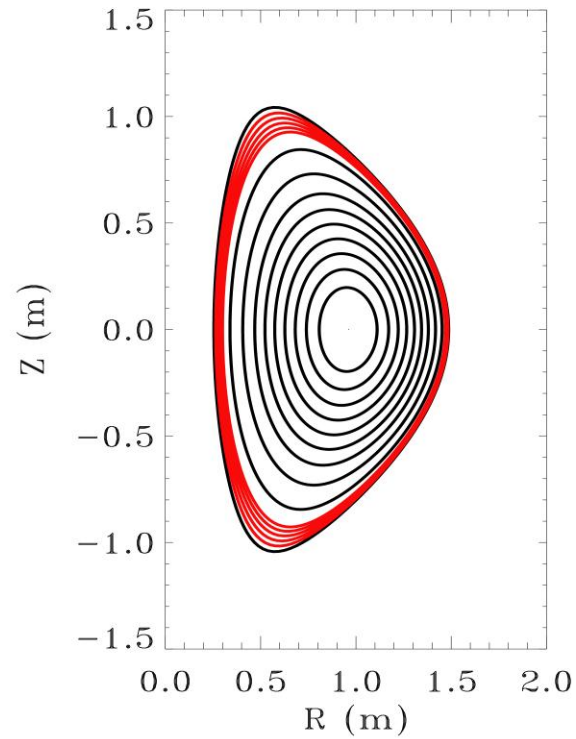
- full δ**B**, general shaping, collisions [2]
- neglect flow (may be important in pedestal)



[1] Kotschenreuther *et al*, Comp Phys Comm **88** 128 (1995)
[2] Barnes *et al*, Phys Plasmas **16** 072107 (2009)

Microstability analysis on surfaces spanning plateau/pedestal:

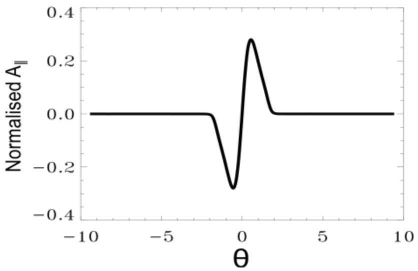
- focus on ion scales: $0.1 < k_y\rho_i < 5$



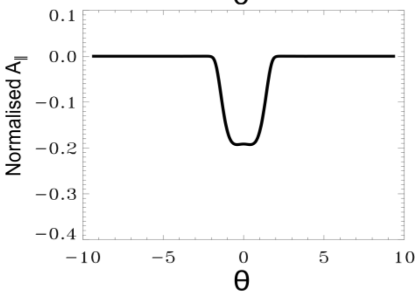
3: Local GK Results at Low T_e^{ped} [1],[2]

δB crucial for dominant microinstabilities (β scans)

$A_\parallel$ eigenfunctions in ballooning space.

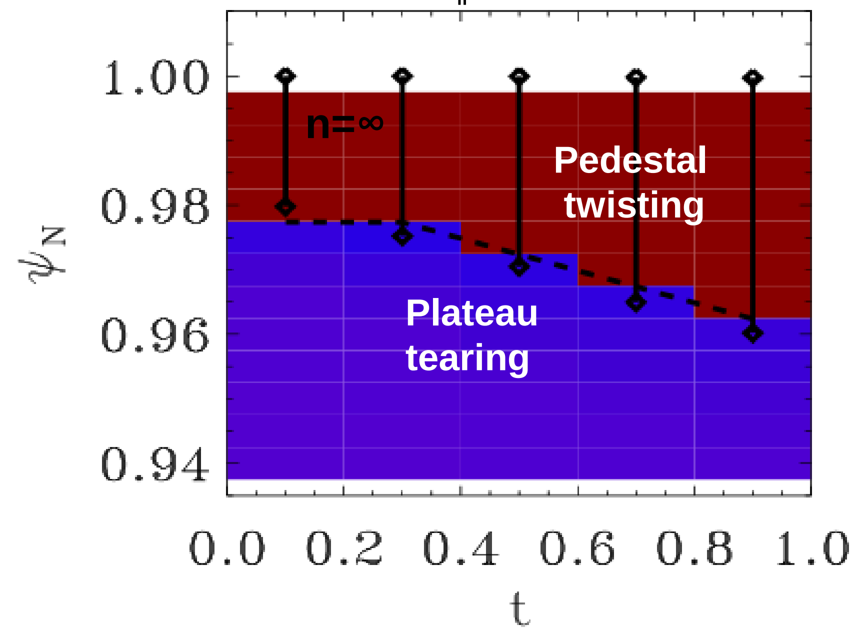


$A_\parallel$ odd, twisting
($k_y\rho_i$=0.22, ψ_n= 0.98, t=0.5)



$A_\parallel$ even, tearing
($k_y\rho_i$=3.3, ψ_n= 0.95, t=0.5)

Parity in $A_\parallel$



- **Pedestal: Kinetic ballooning modes (KBMs)** **(**$k_y\rho_i$ < 1, ω > 0)
  - NB ideal MHD *n*=∞ ballooning modes also unstable
- **Plateau: Microtearing modes (MTMs) *** ($k_y\rho_i$ > 1, ω < 0)

* similar MTMs unstable in JET plateau
Saarelma et al, TH/P3-10 (Wednesday)

[1] Dickinson et al, PPCF **53**, 115010 (2011)
[2] Dickinson et al, PRL **108**, 135002 (2012)

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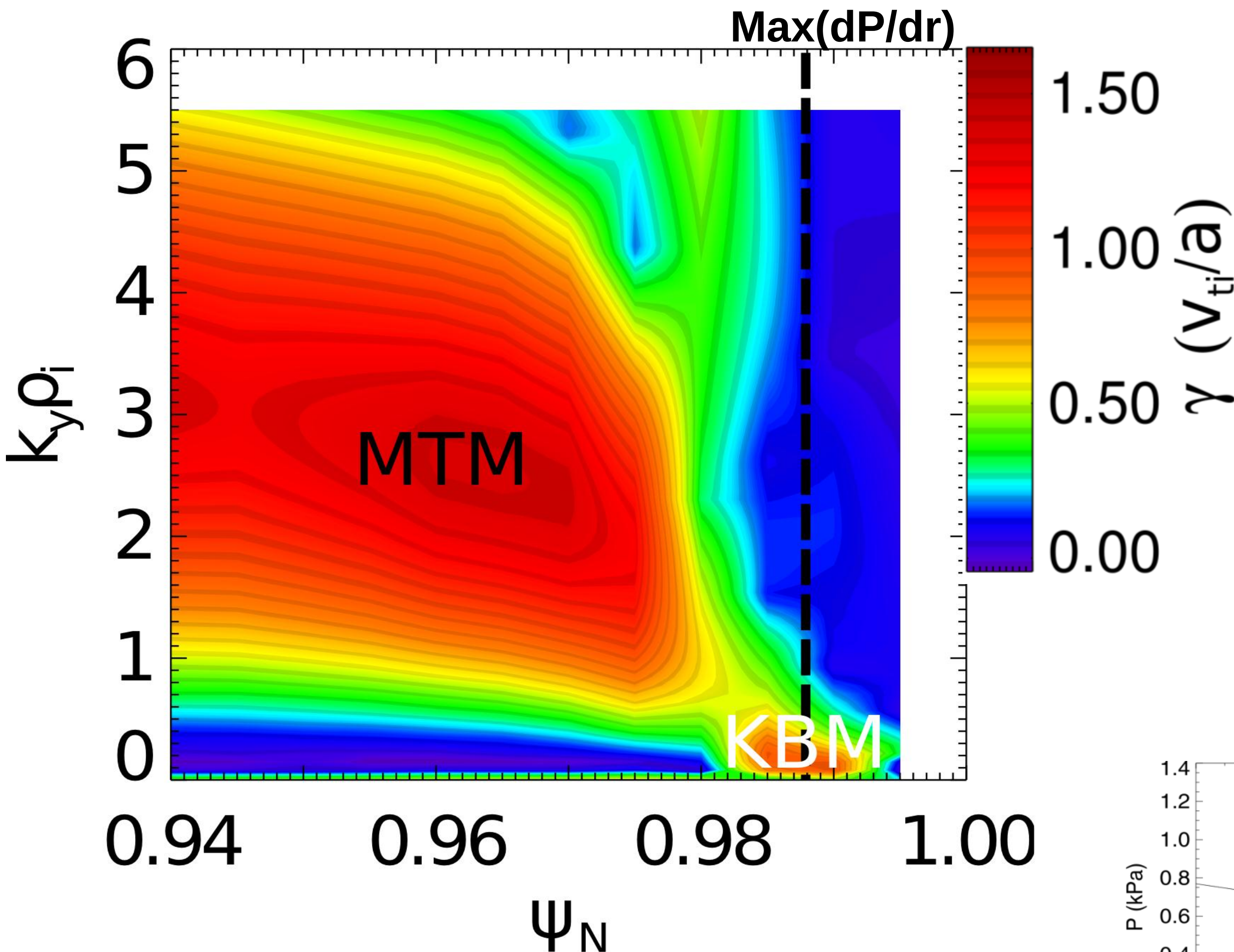
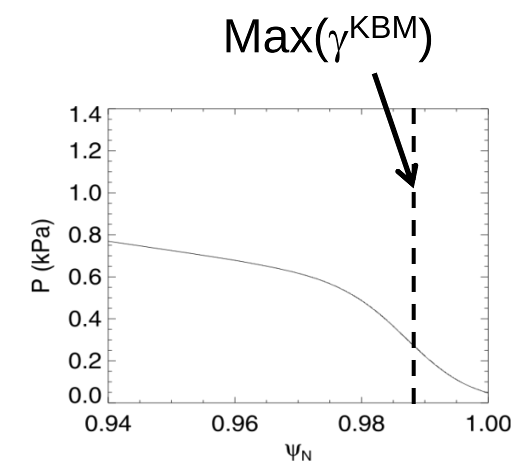
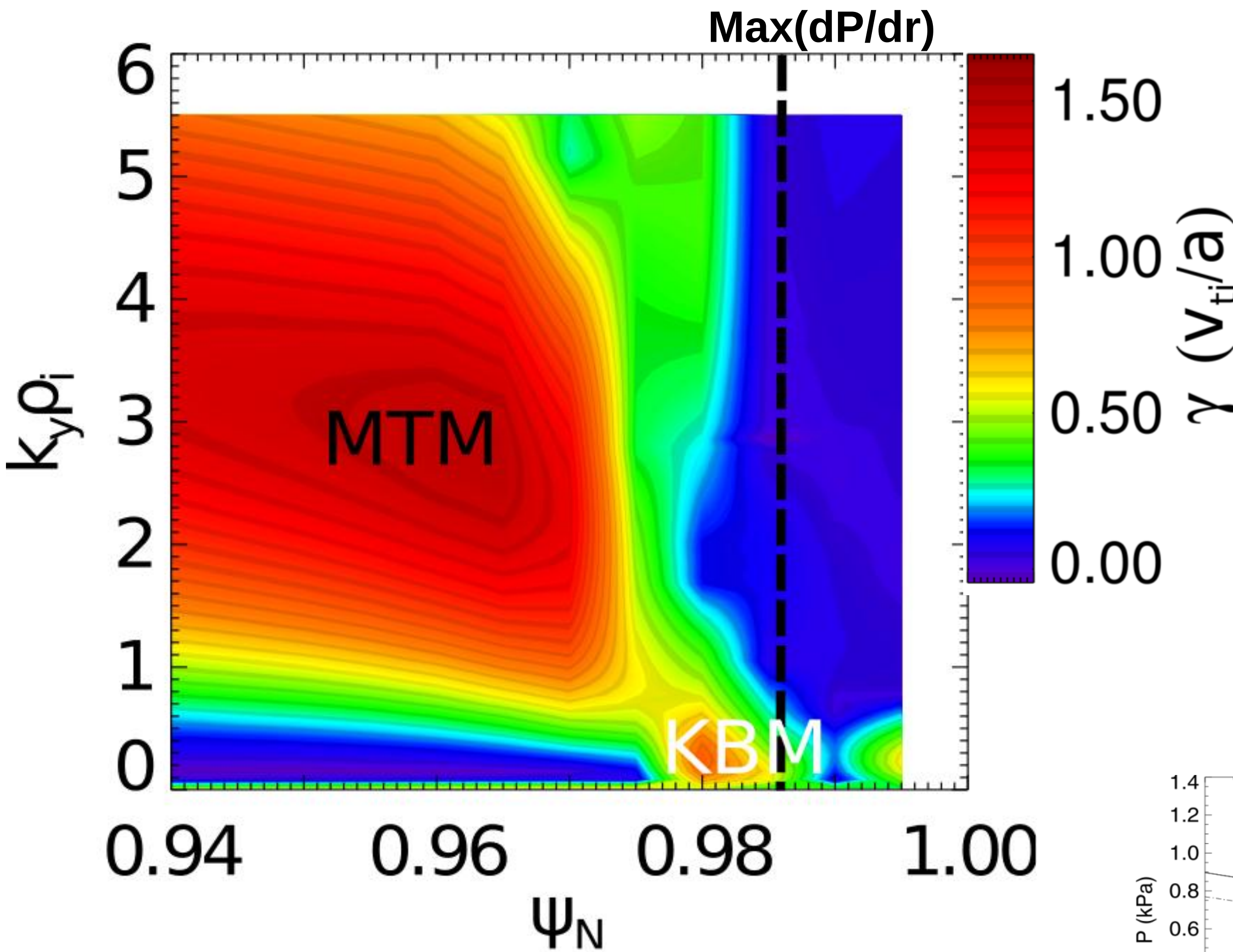
3: Microinstability Evolution Low T_e^{ped} t=0.1

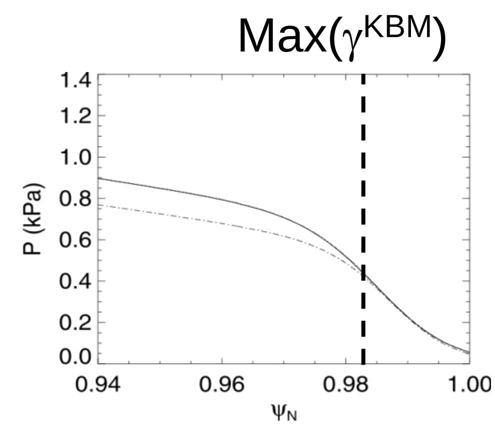




Max(γ_{KBM}) initially close to Max(dP/dr)

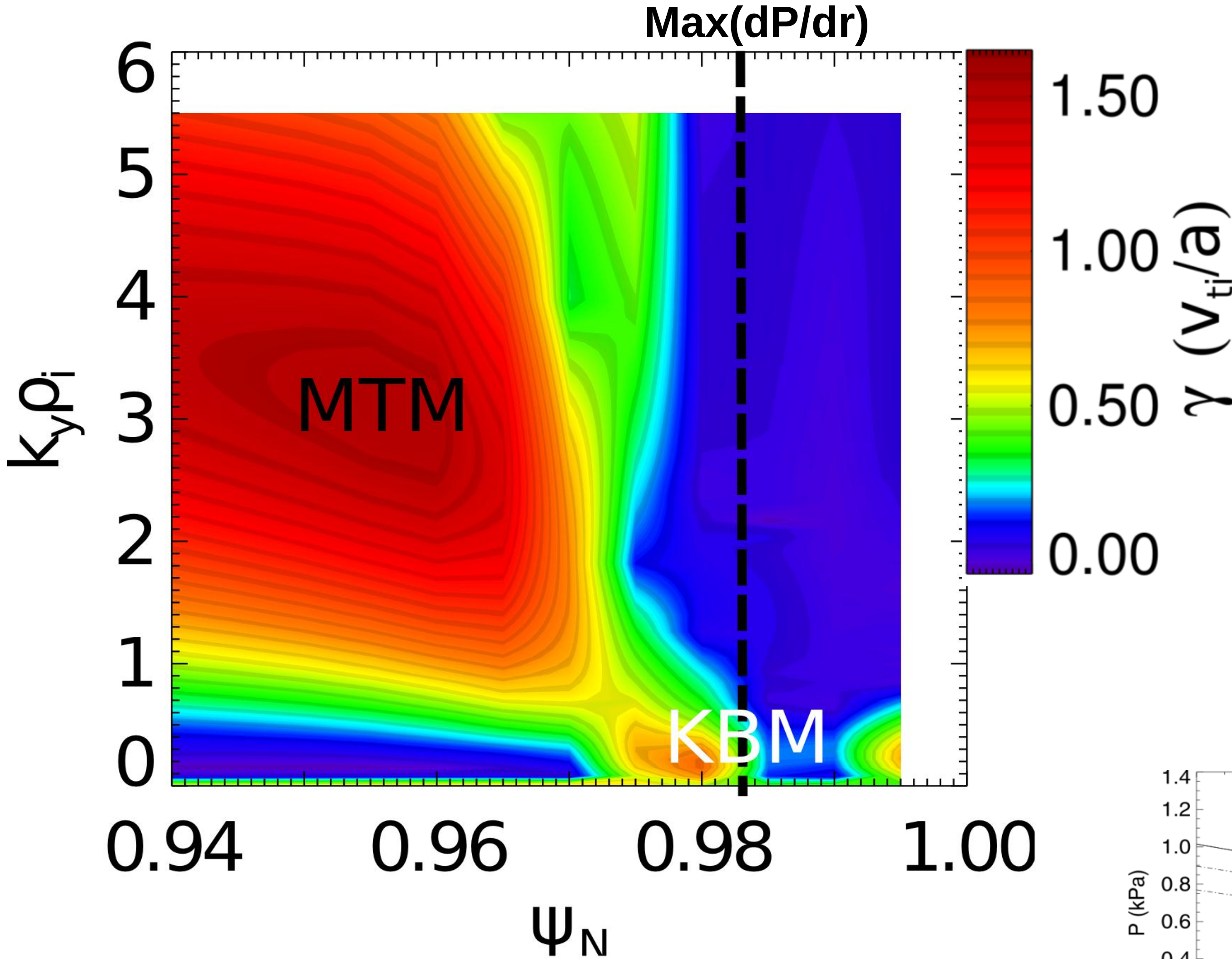
3: Microinstability Evolution Low T_e^{ped} t=0.3

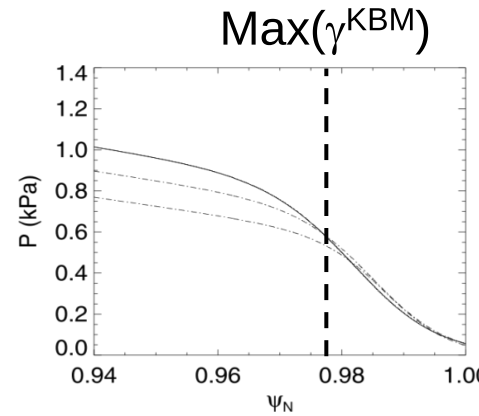




γ_{KBM} increases at ψ_N=0.98 as joins pedestal.

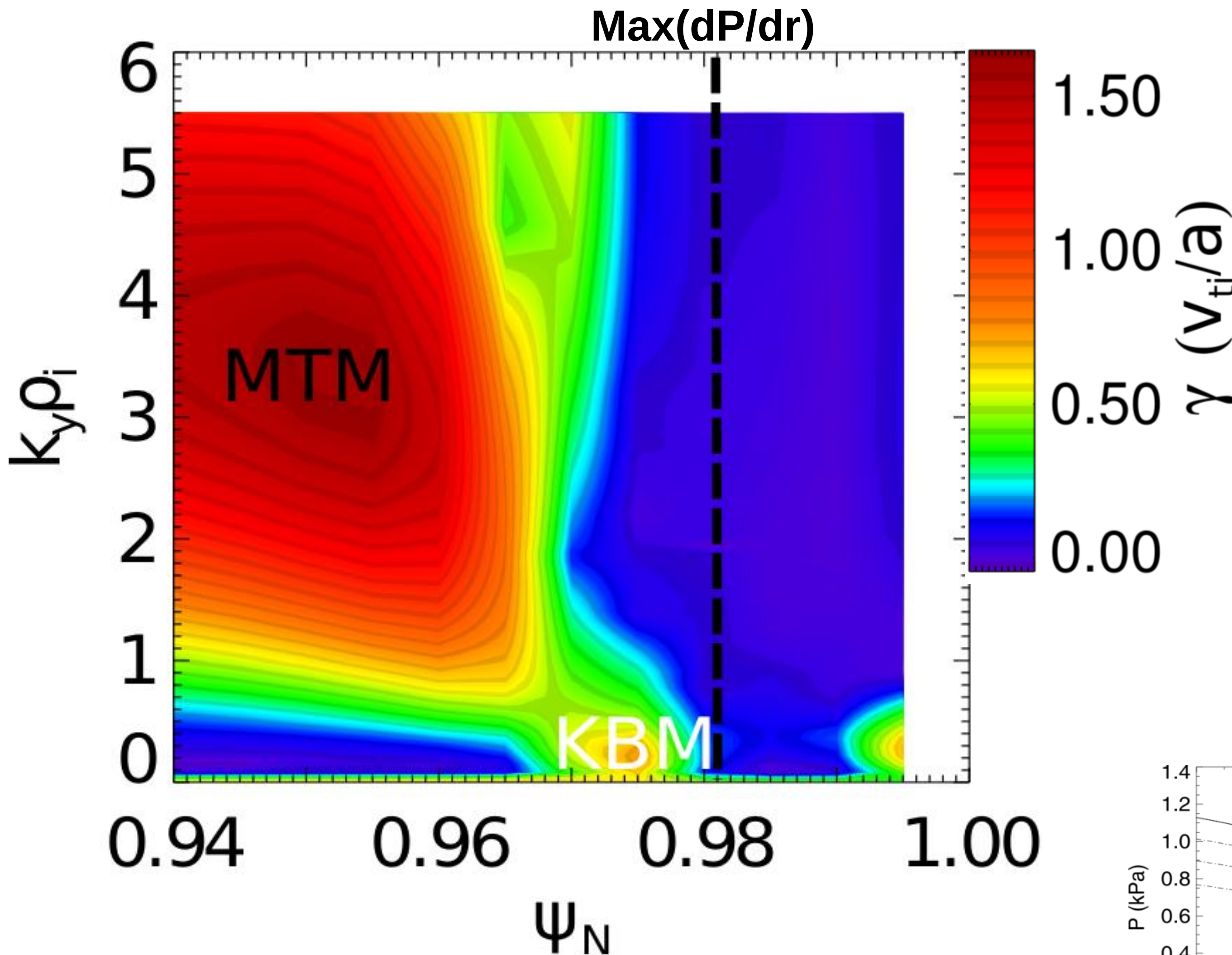
3: Microinstability Evolution Low T_e^{ped} t=0.5

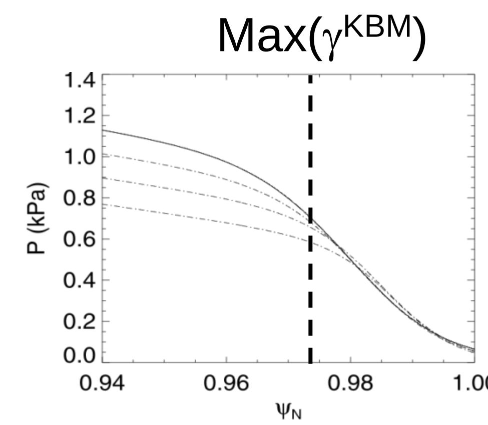




γ_{KBM} **falls at heart of the pedestal, e.g. ψ_N~0.985.**

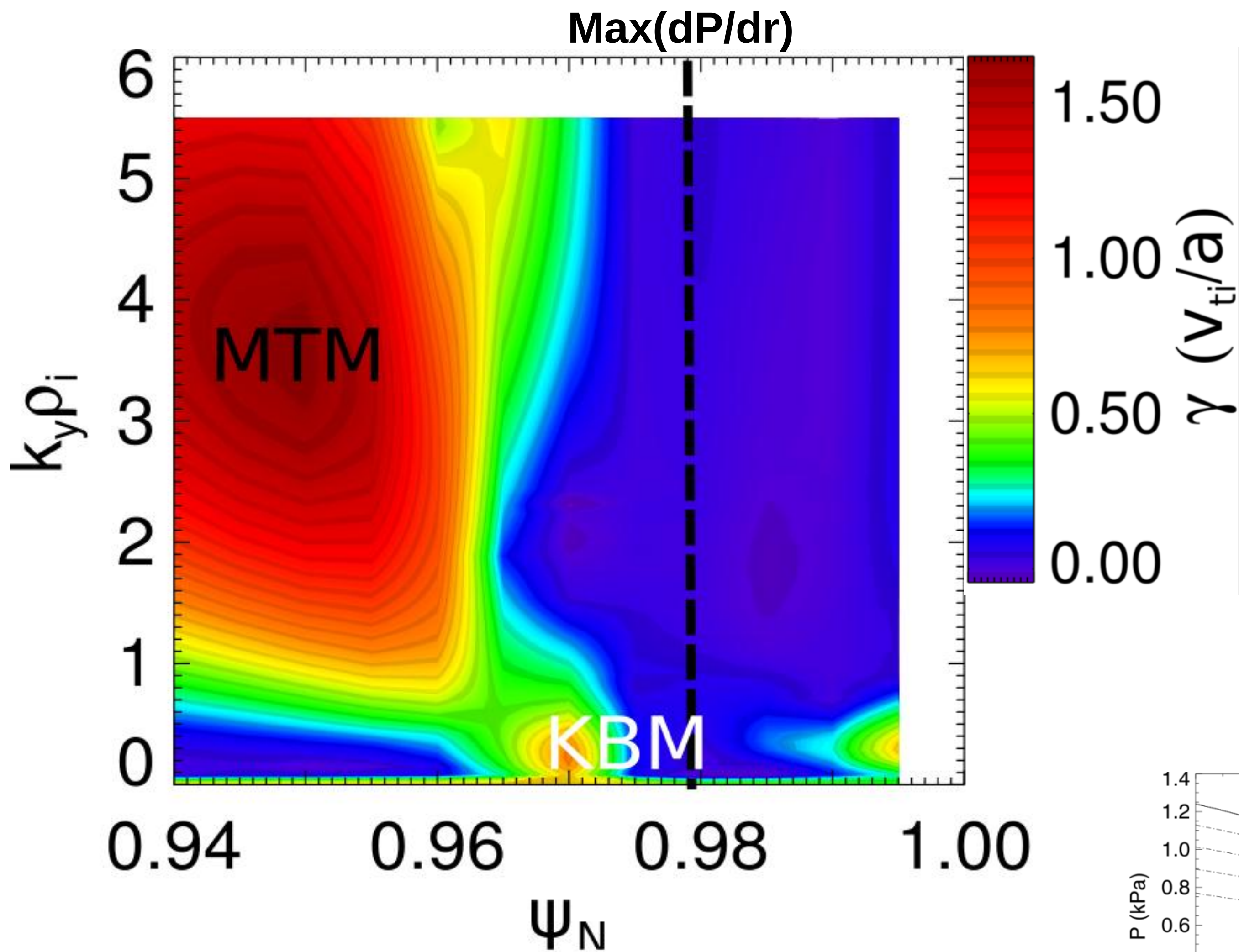
3: Microinstability Evolution Low T_e^{ped} t=0.7

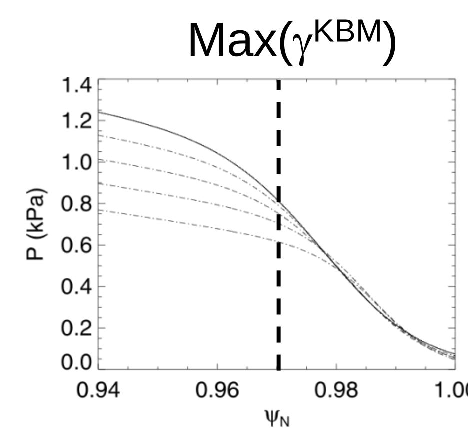




MTM stabilised at ψ_N=0.97 on joining pedestal

3: Microinstability Evolution Low T_e^{ped} t=0.9





Max(γ_{KBM}) increasingly inboard of Max(dP/dr)

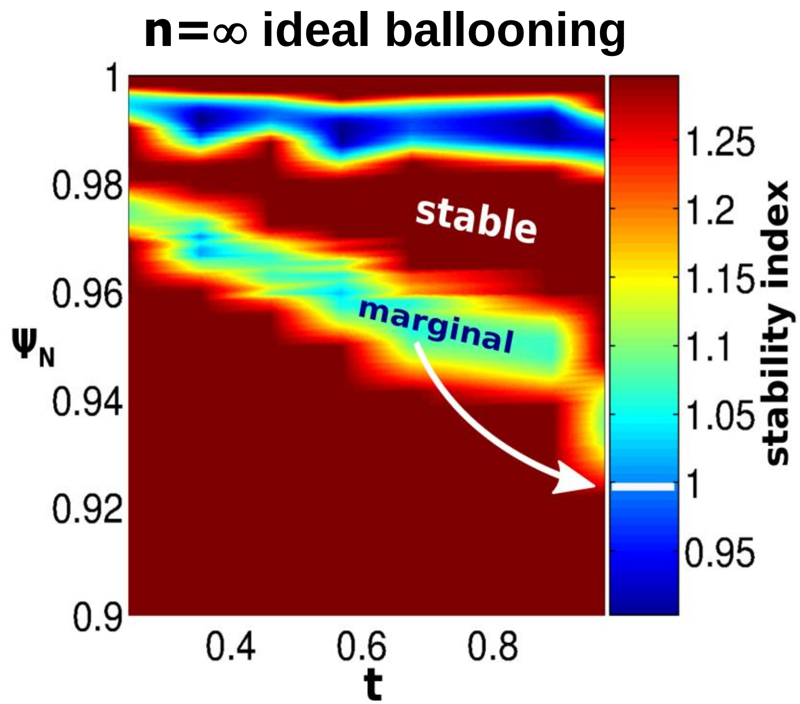
3: Microinstability Evolution at High T_e^{ped}

MTMs dominate plateau

- $\gamma^{MTM}\Uparrow$ through ELM cycle.

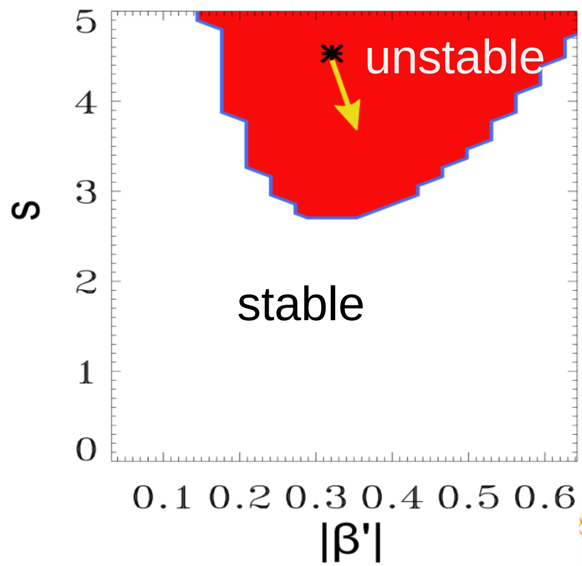
KBMs at marginal stability on knee of P(r)

- **stable** in high T_e^{ped} pedestal



KBMs more stable in pedestal because:

- $J_{bs}\Uparrow \Rightarrow$ magnetic shear $s\Downarrow$
  $\Rightarrow$ approach/access 2nd stability
- high T_e^{ped} has stronger stabilisation as higher J_{bs} at lower collisionality

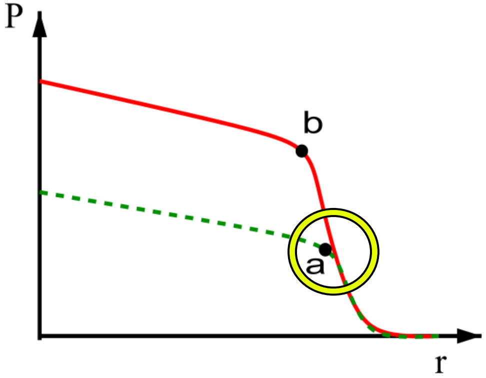


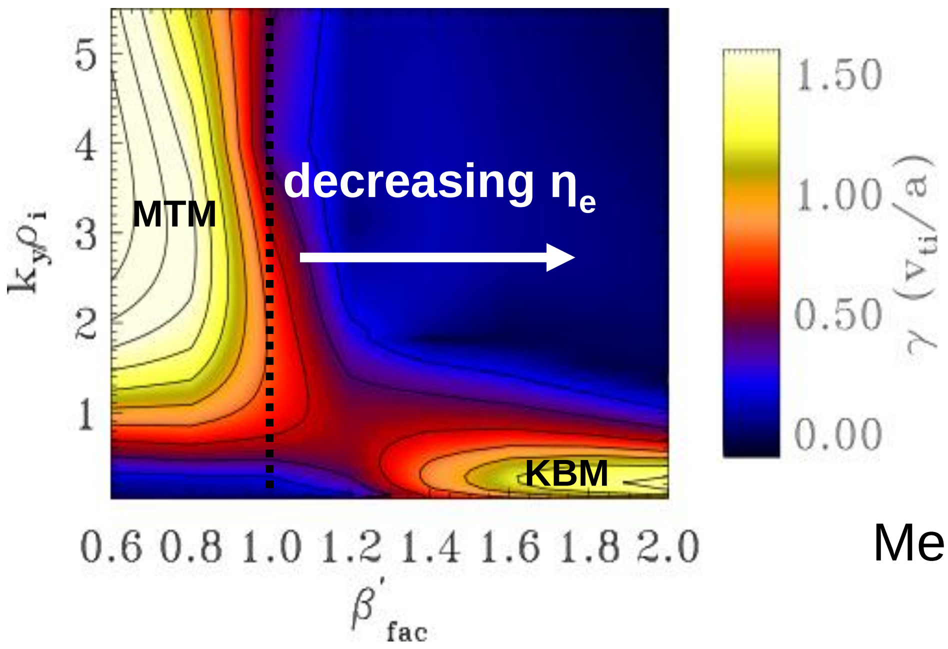
4. Why does Pedestal Expand Inwards?

Artificial scan to mimic pedestal advance on **a**

⇒ <u>scale</u> [β', R/L_{ne}] by β'_{fac} at <u>fixed</u> [n_e, $T_{e,i}$, $R/L_{Te,i}$]

(motivated by measured profile evolution at low T_e^{ped})





MTMs stabilised by

- R/L_{ne}⇧ (disrupts MTM phases)
- β'⇧ (favourable drifts)

until….

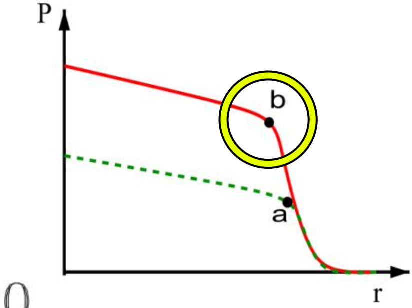
- KBMs unstable at high β'_{fac}

Mechanism may assist pedestal advance

- q_e^{MTM} ⇩, allowing dP_e/dr⇧

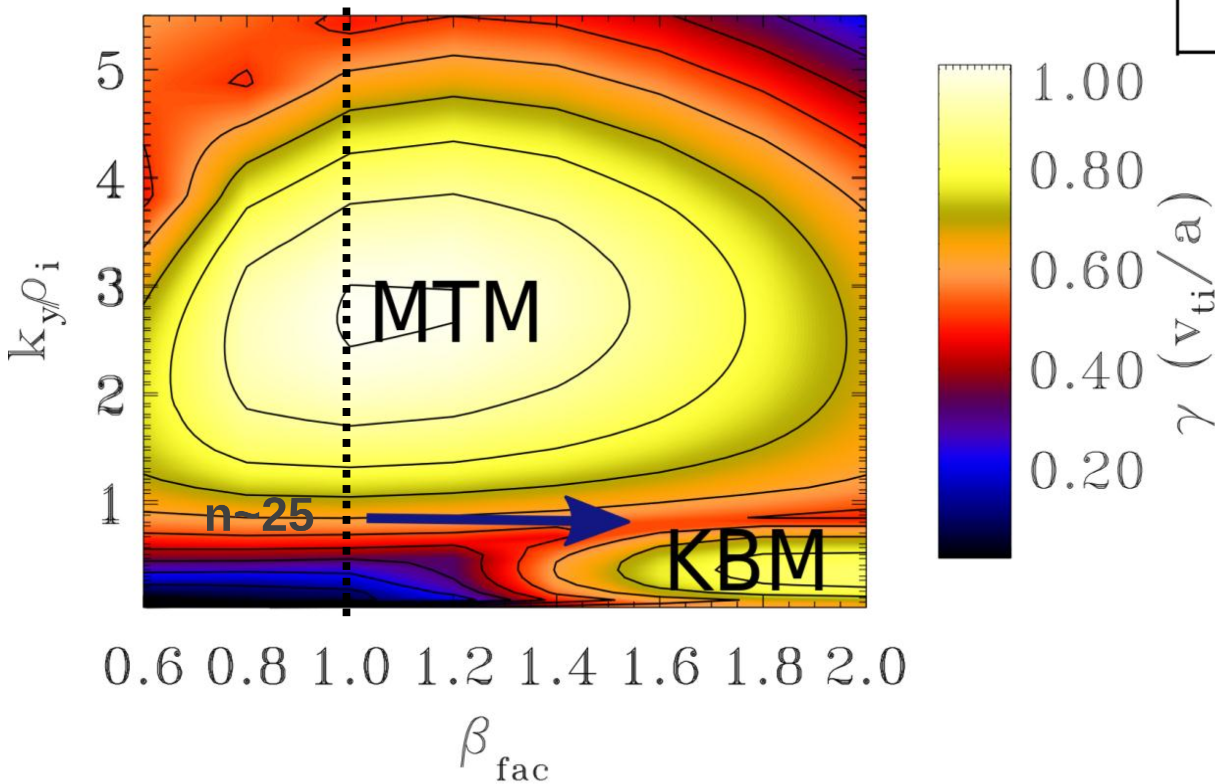
NB similar MTM/KBM transition also in high T_e^{ped}

4. Limits to Inwards Pedestal Expansion?



Scans around **b** seek "equilibria" with interesting μstability

- <u>scale</u> [β, n_e] by β_{fac}, at <u>fixed</u> [dn_e/dr, $T_{e,i}$, $R/L_{Te,i}$, ν_e]



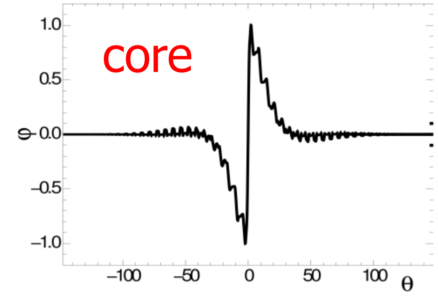
Fully developed pedestal close to threshold where **KBMs + MTMs** are simultaneously strongly unstable over broad k_y range.

- breaching this limit would cause large change in edge transport.

5. Exploring Mechanism for Edge MTMs

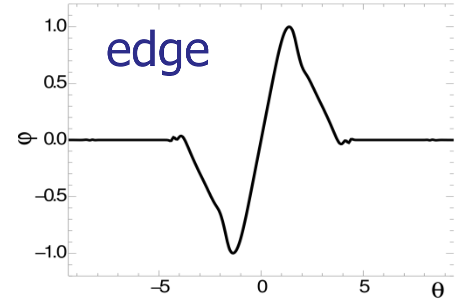
MTMs previously reported in core of STs, conceptual high performance devices, and conventional devices [1-6]

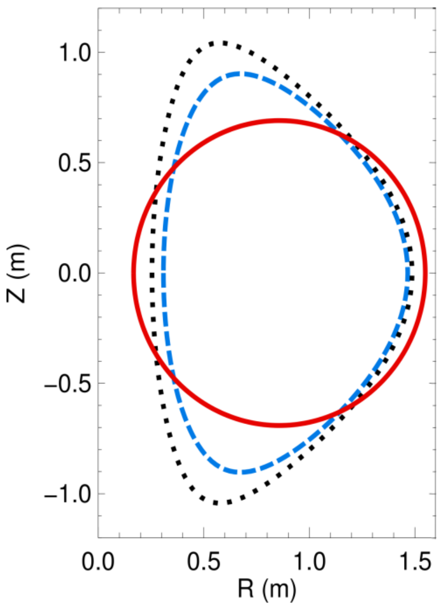
- drive mechanism poorly understood [1]



Investigate edge MTM to improve understanding [7]

- edge MTM Φ efunc. less extended in θ.





Circular s-α model fit to MAST edge

- unstable to similar MTMs
- convenient reference to study edge MTM

[1] Applegate *et al*, PPCF **19**, 1113, (2007

[2] Applegate *et al*, PoP **11**, 5085, (2004)

[3] Wong *et al*, PoP **15**, 056108, (2008)

[4] Kotschenreuther *et al*, NF **40**, 677, (2000

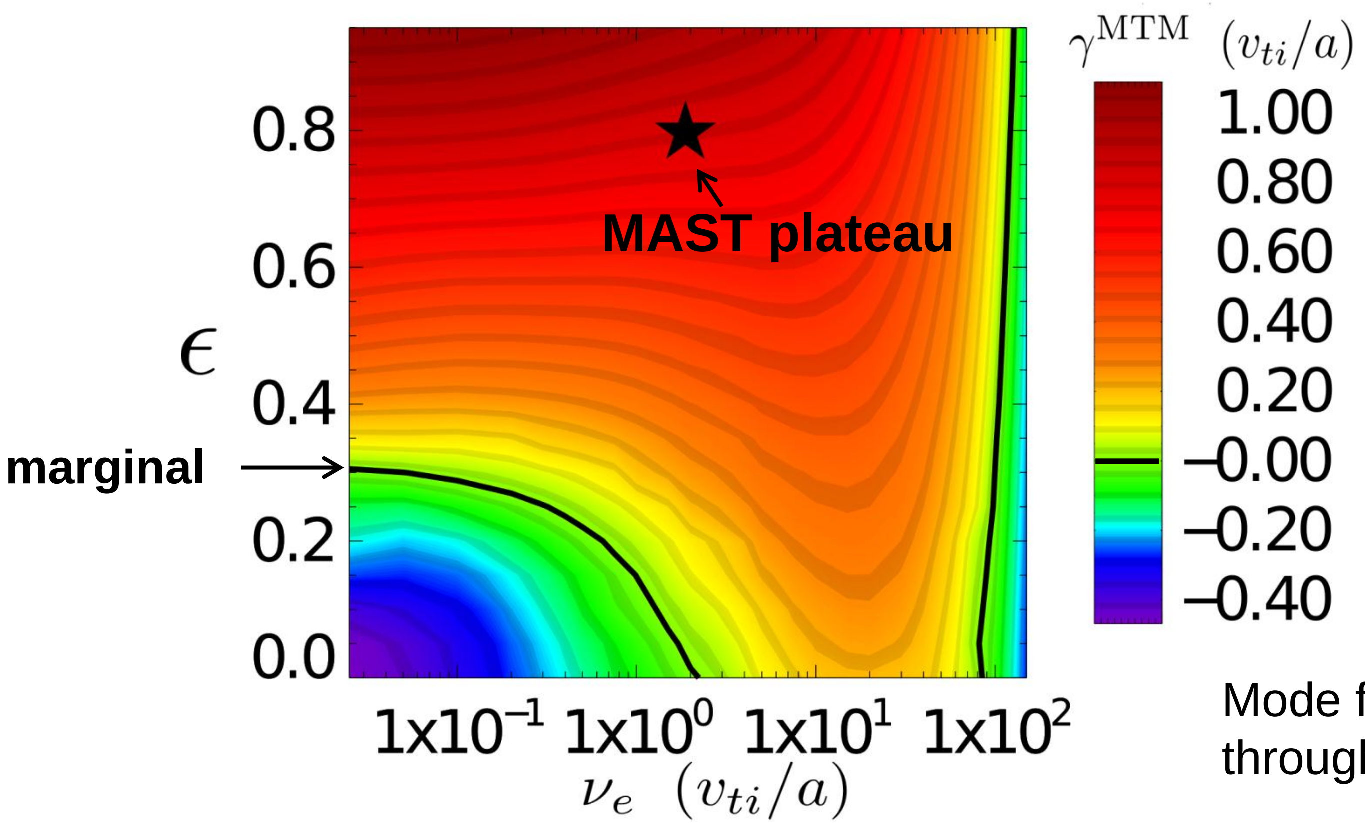
[5] Wilson *et al*, NF **44**, 917, (2004)

[6] Told *et al*, PoP **15**, 102306, (2008)

[7] Dickinson *et al*, submitted to PPCF (2012) http://arxiv.org/abs/1209.3695

5. Influence of Trapping and Collisions

Growth rate at peak of MTM spectrum, γ^{MTM}, versus ϵ, ν_e



Mode frequency $\omega \sim v_{ti}/a$ throughout scan

High ϵ (trapped fraction) is destabilising.

At low ϵ, γ^{MTM} peaks at **finite ν_e**, and MTM **stable** at low ν_e

At high ϵ, γ^{MTM} **peaks** at low ν_e

Collisions not essential to edge MTM drive.

NB leading analytic theories require **finite ν_e** [1,2]

[1] Catto *et al*, Phys Fluids **24**, 243, (1981)

[2] Drake *et al*, Phys Fluids **20**, 1341, (1977)

5. For More on Drive Study

See:

- Dickinson *et al*, submitted to PPCF (2012) http://arxiv.org/abs/1209.3695
- Poster TH5-1, Tomorrow am (Friday)

6. Conclusions

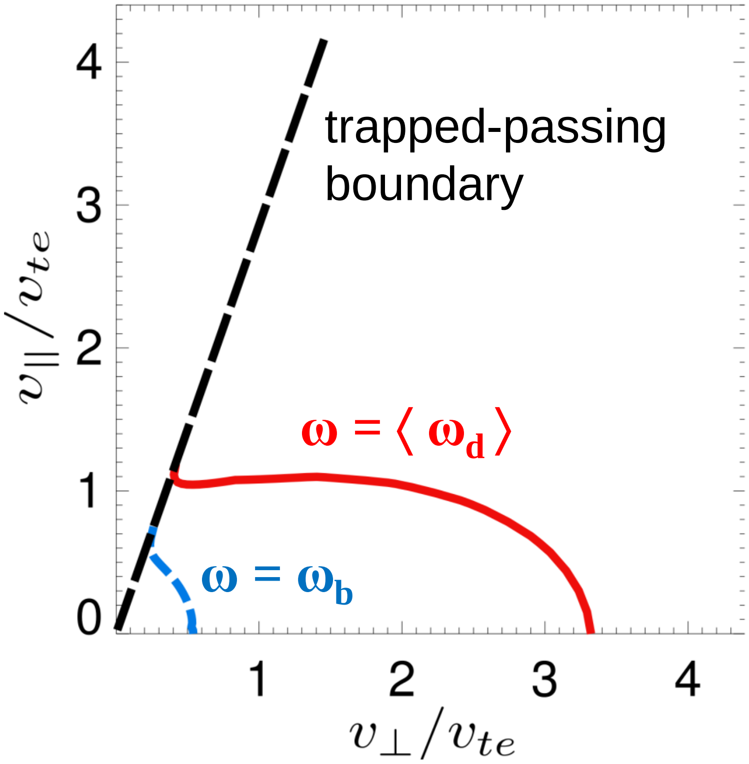
- Plasma profile evolution measured in MAST over ELM cycle:
  - steep dP/dr, dn_e/dr* form rapidly after ELM near separatrix, then advance into core
    *and dT_e/dr at high T_e^{ped}
- Local GK reveals corresponding microstability evolution, $k_y \rho_i \sim O(1)$
  - MTMs dominate in plateau
  - KBMs most unstable near knee of pressure profile
    more stable* in pedestal due to J_{bs}
    *stable at high T_e^{ped}
- MTM/KBM transition at knee
  - MTM stabilised by dn_e/dr⇧ + dP/dr⇧ until… KBM unstable.
  - transition may assist inwards advance of pedestal
  - knee of fully developed pedestal close to threshold where MTMs+KBMs are strongly unstable over broad k_y range
- Edge MTMs studied in simplified circular s-α model equilibrium
  - large ϵ (or trapped fraction) is destabilising
  - at large ϵ MTMs do not need finite ν_e

Extra Slides

5. Comparing Frequencies*

Mode frequency, ω, compared with:

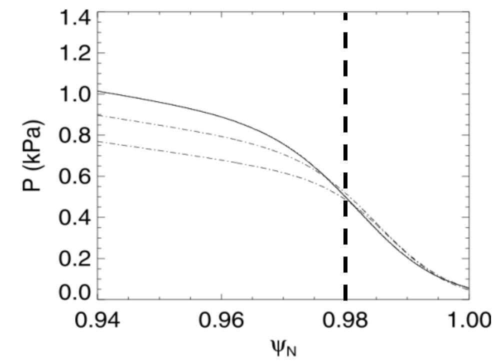
- trapped e bounce frequency, ω_b
- trapped e precession frequency, $\langle \omega_d \rangle$



- $\omega \sim \langle \omega_d \rangle$ for thermal trapped electron
  $\Rightarrow$ drift resonance?
- $\omega \sim O(\omega_b)$
  $\Rightarrow$ bounce averaging unsuitable for trapped particle response

Dominant Modes in Pedestal: KBMs

Consider dominant mode at t=0.5, Ψ_n=0.98, $k_y\rho_i$=0.218

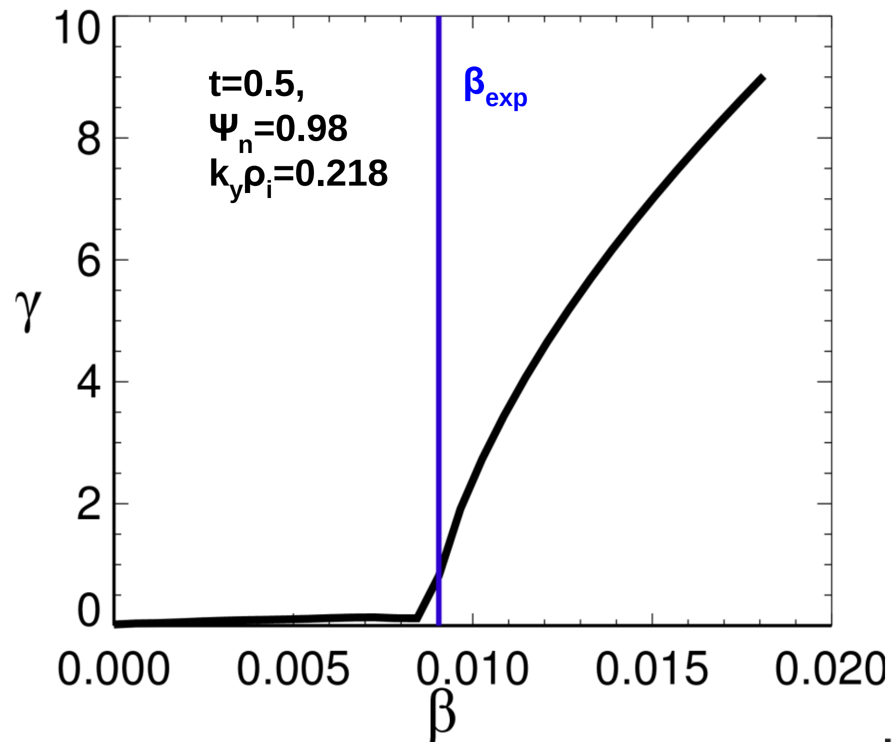


β scan shows classic KBM signature

- $\beta_{exp} > \beta_{crit}$
- δ**B** essential
- (electrostatic mode at low β)

KBM driven by any source of dP/dr:

- R/L_n, R/L_{Te}, R/L_{ti}
- $\Rightarrow$ transport in all channels



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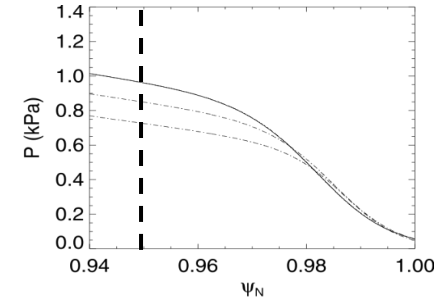
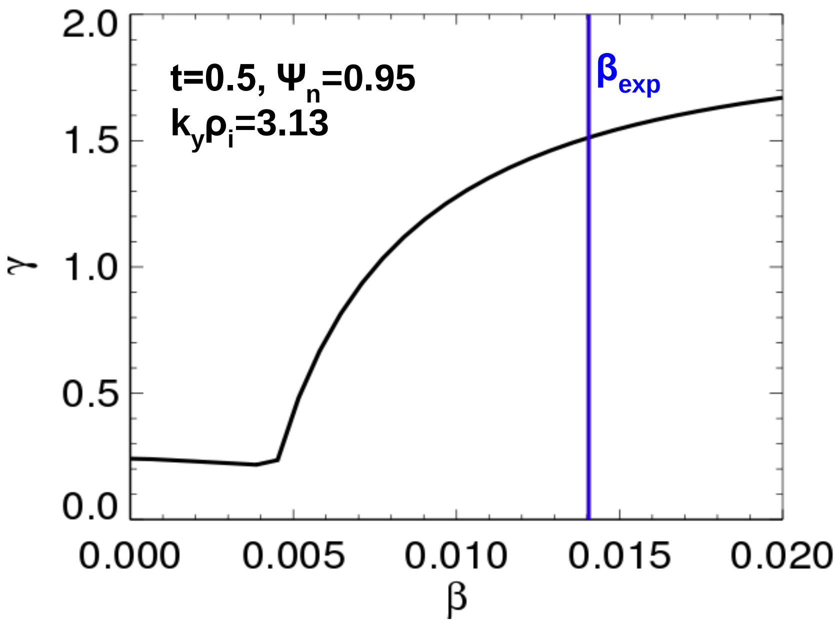
Dominant Modes in Plateau: MTMs

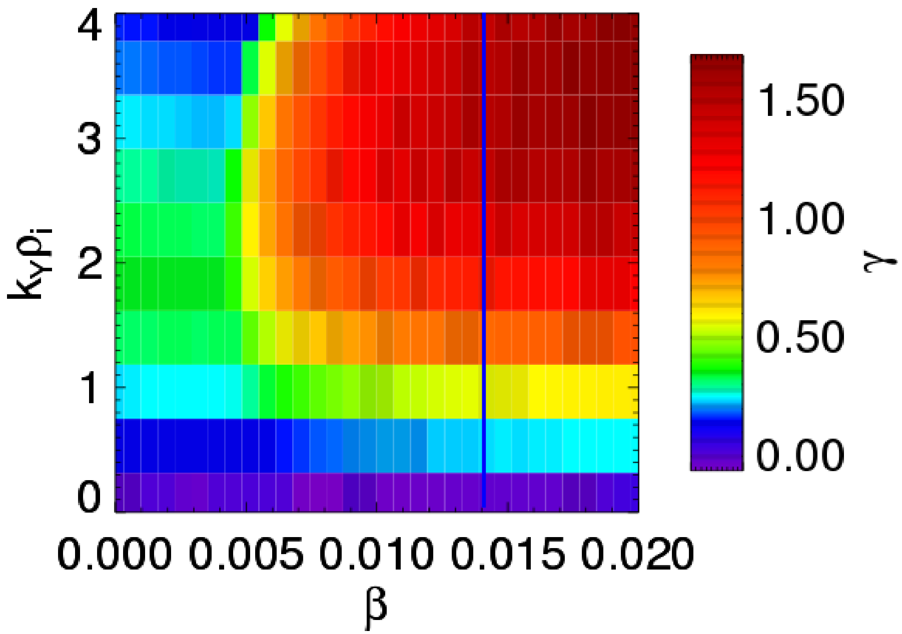
Consider dominant mode at t=0.5, Ψ_n=0.95, $k_y\rho_i$~3





β scan reveals

- EM mode, β_{exp} >> β_{crit}
- (electrostatic mode at low β)



MTMs driven by R/L_{Te}

- mainly electron heat transport

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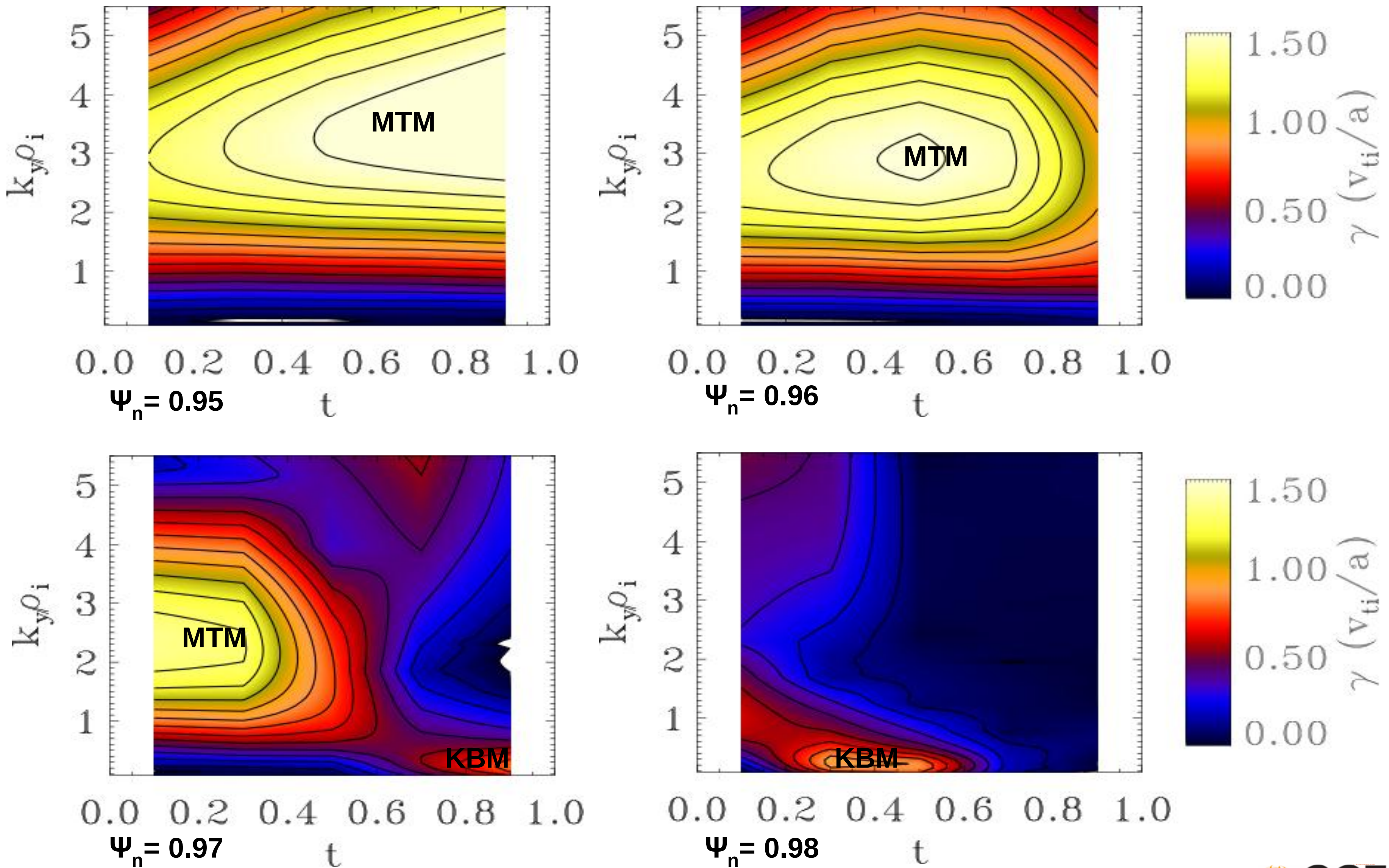
Evolution of γ Spectrum on Surfaces



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