NSTX-U is sponsored by the
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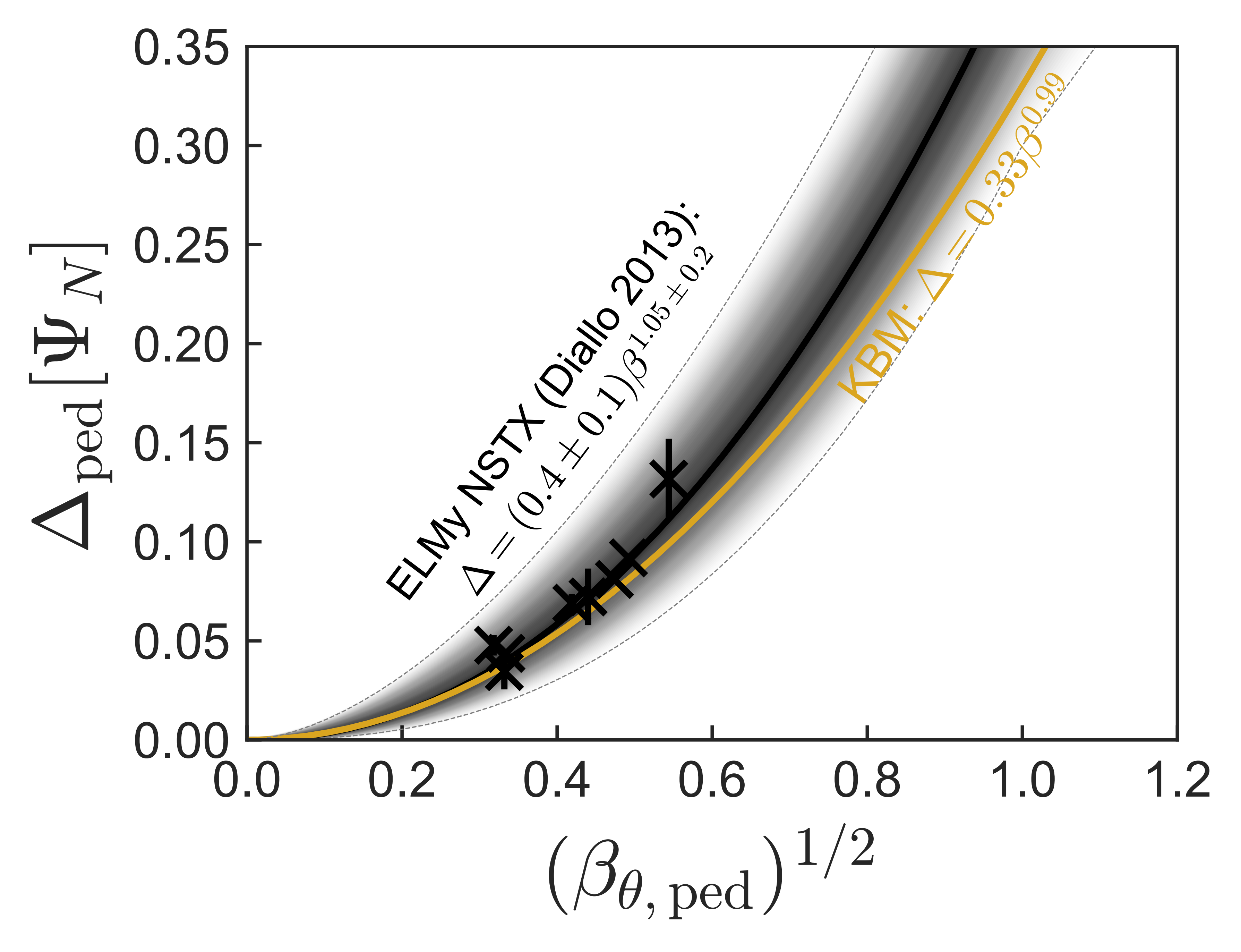
Fusion Energy Sciences

Kinetic Ballooning Mode Constraints in NSTX Pedestals

J. F. Parisi, W. Guttenfelder, A. O. Nelson, A. Kleiner, C. Clauser

Oct 31 2022



Outline

Part I: Stability

Part II: Transport

Part I: Stability

Hypothesis: Kinetic Ballooning Mode (KBM) thresholds predict pedestal height and width ∇p constraint for NSTX

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- KBM stability threshold **lower** than ideal MHD mode.

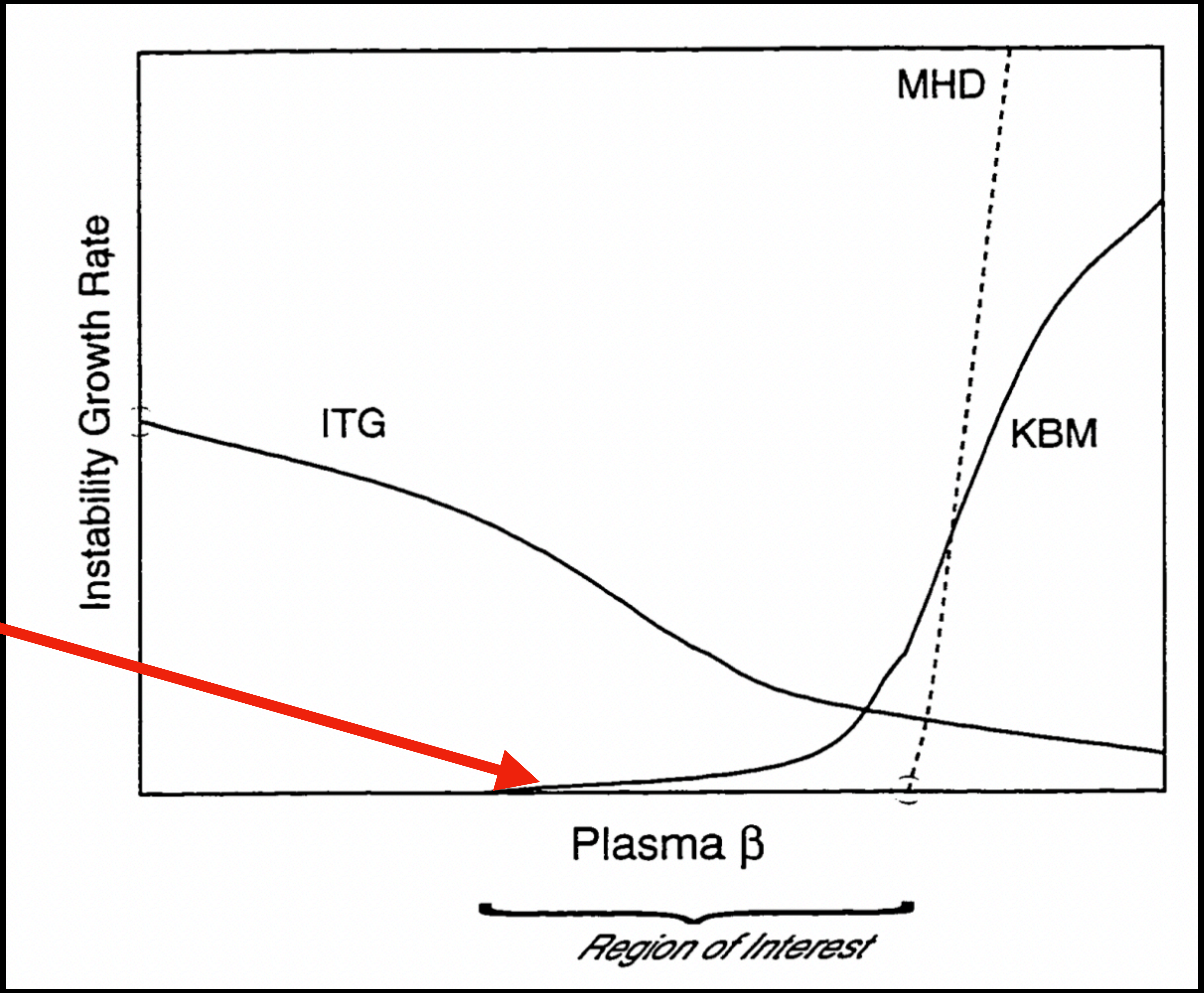

Fig 1: Schematic instability growth rate versus β. ***Adapted from Fig 1.2*** **[Snyder Thesis, 1999]**

Hypothesis: KBM thresholds predict pedestal height and width ∇p constraint for NSTX

- KBM = ideal ∇p-driven ballooning + kinetic physics.
- KBM stability threshold **lower** than ideal MHD mode.
- KBM signatures:

$\chi_i/\chi_e \sim 1$ (ion/electron heat diffusivity ratio)

$D_e/\chi_e \sim 1$ (particle, heat diffusivity ratio)

Growth rate γ sensitive to ∇T_i and ∇T_e

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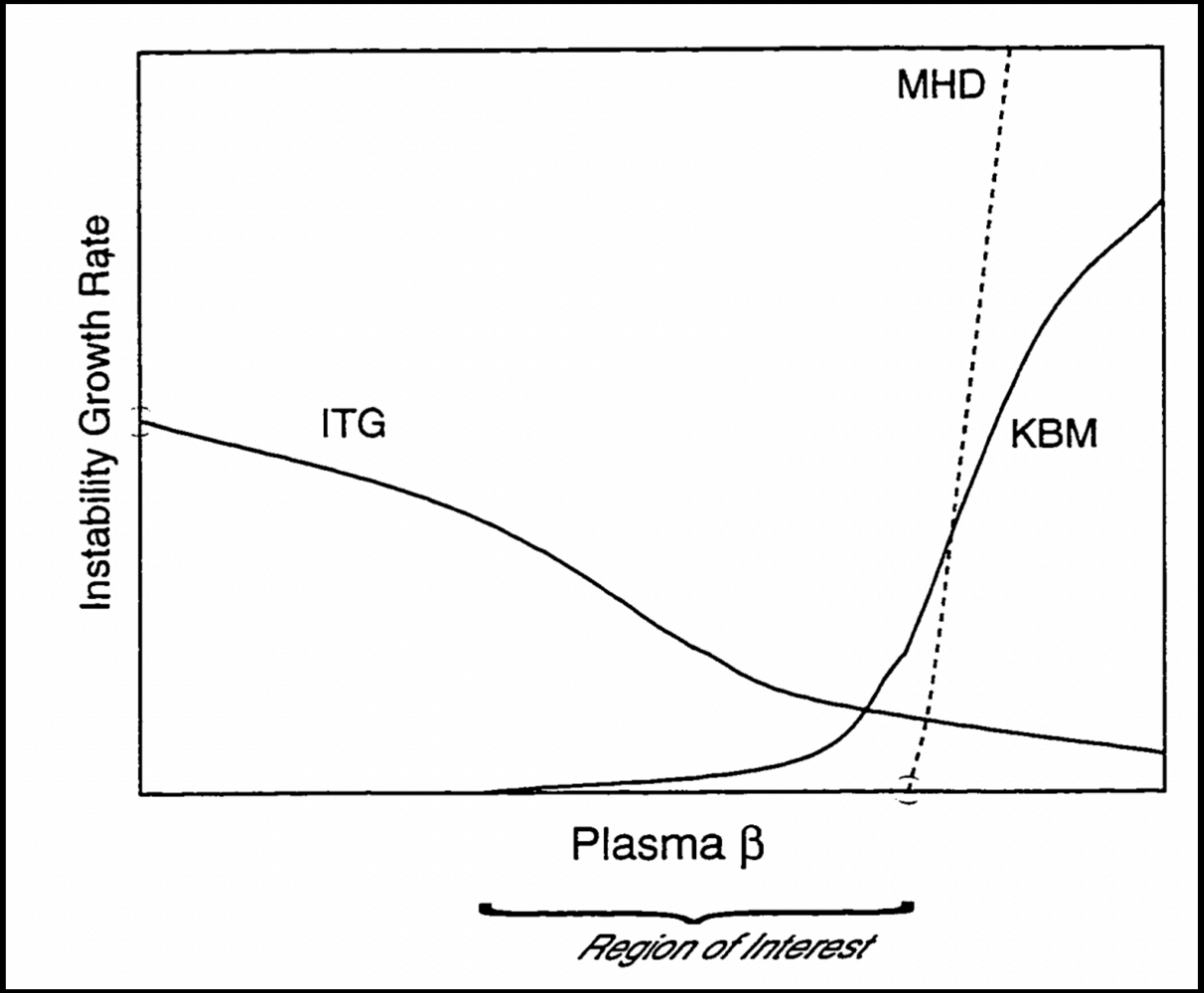
- Basis for EPED model:
  β_{pedestal} builds up in ELM cycle, KBM transport stiff —> KBM sets maximum ∇p.



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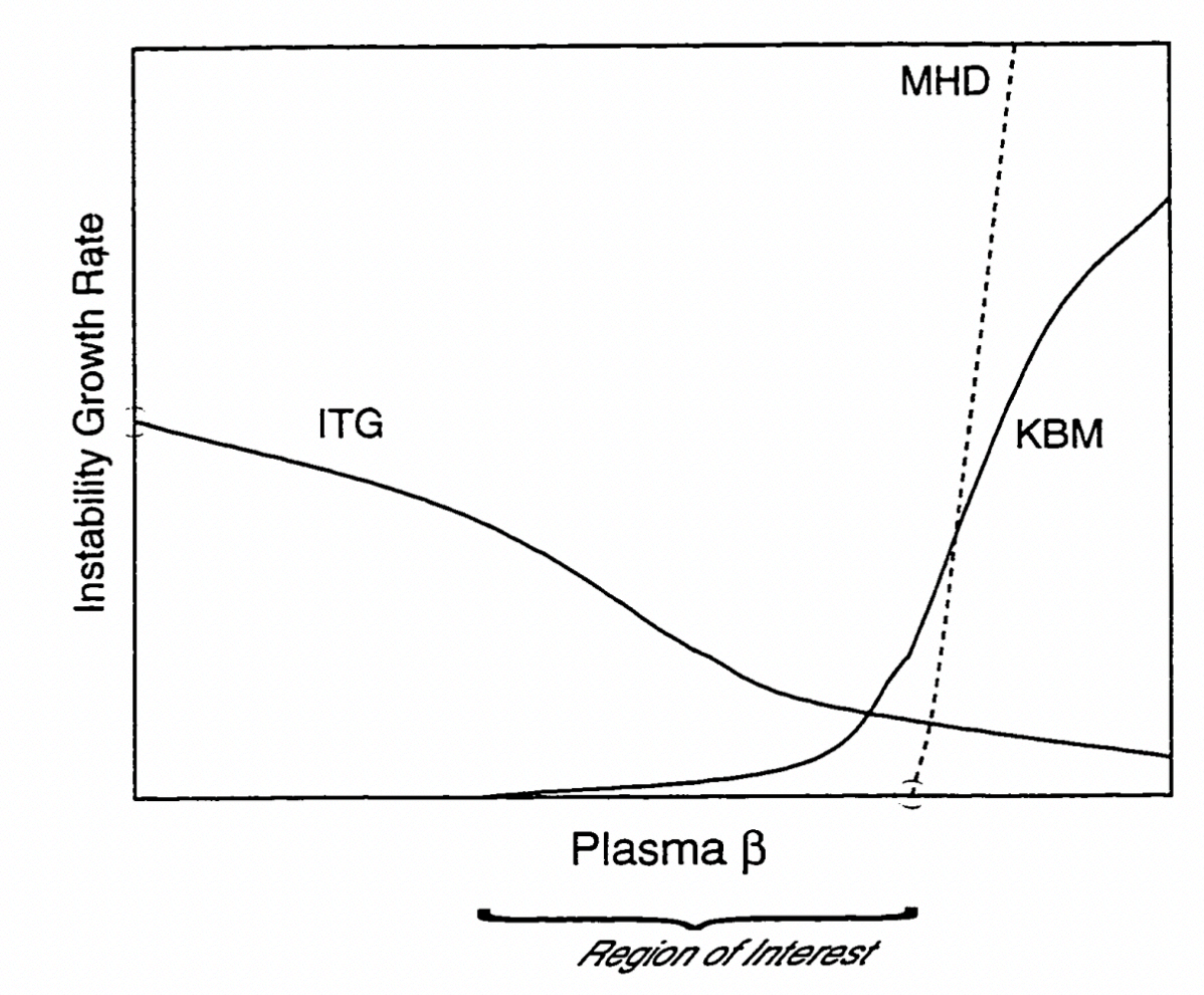
- KBM stability threshold **lower** than ideal MHD mode.
- Basis for EPED model: β_{pedestal} builds up in ELM cycle, KBM transport stiff —> KBM sets maximum ∇p.
- We find important differences b/w KBM and ideal stability in NSTX.



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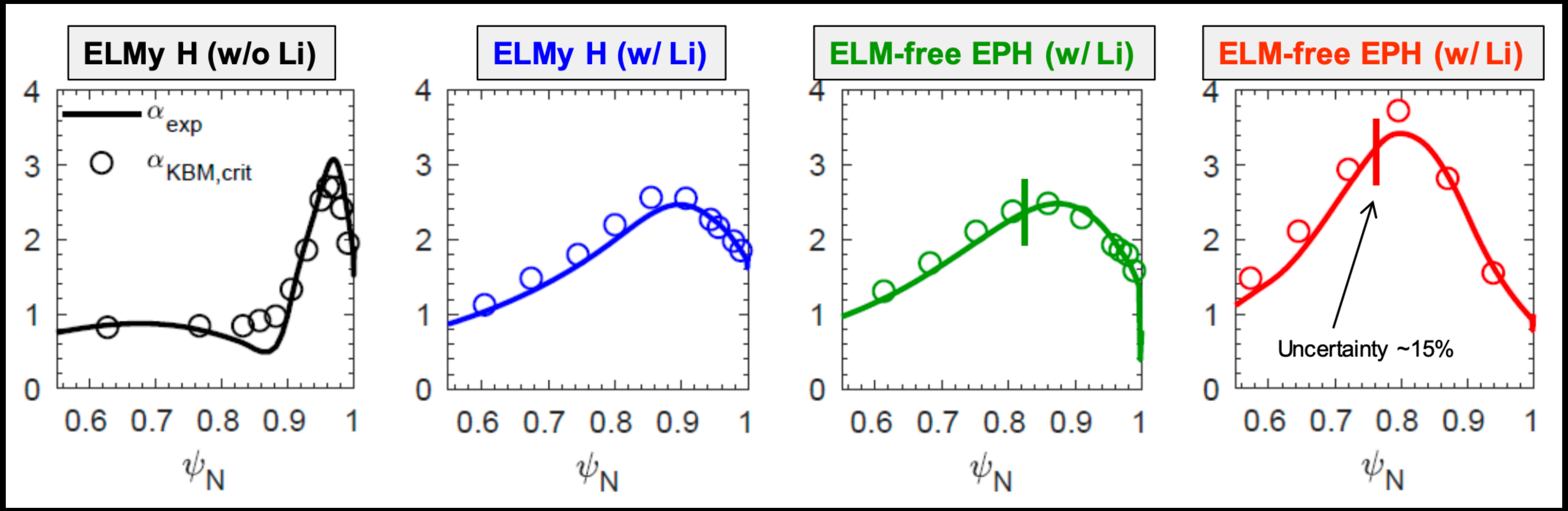

Fig 1: NSTX α profiles and critical KBM α values. **Adapted from W. Guttenfelder APS 2022.**

- Recent work [Guttenfelder, 2022] shows NSTX experimental profiles within 10% of KBM critical gradient $\alpha_{\mathrm{KBM,crit}}$.

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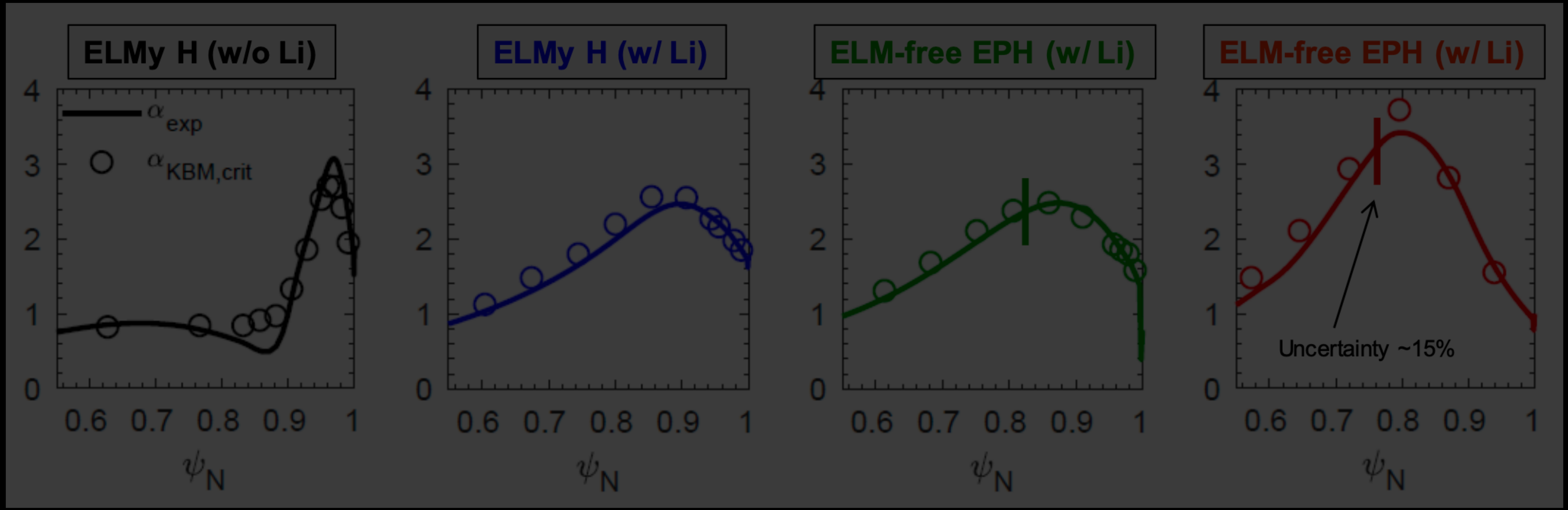

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- Recent work [Guttenfelder, 2022] shows NSTX experimental profiles within 10% of KBM critical gradient $\alpha_{\mathrm{KBM,crit}}$.
- Related important topic: non-ideal peeling ballooning modes. See A. Kleiner [NF 2021, 2022] (resistive effects important).

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Why:

EPED ∇p prediction successful in many devices, not sufficient for all NSTX discharges.*

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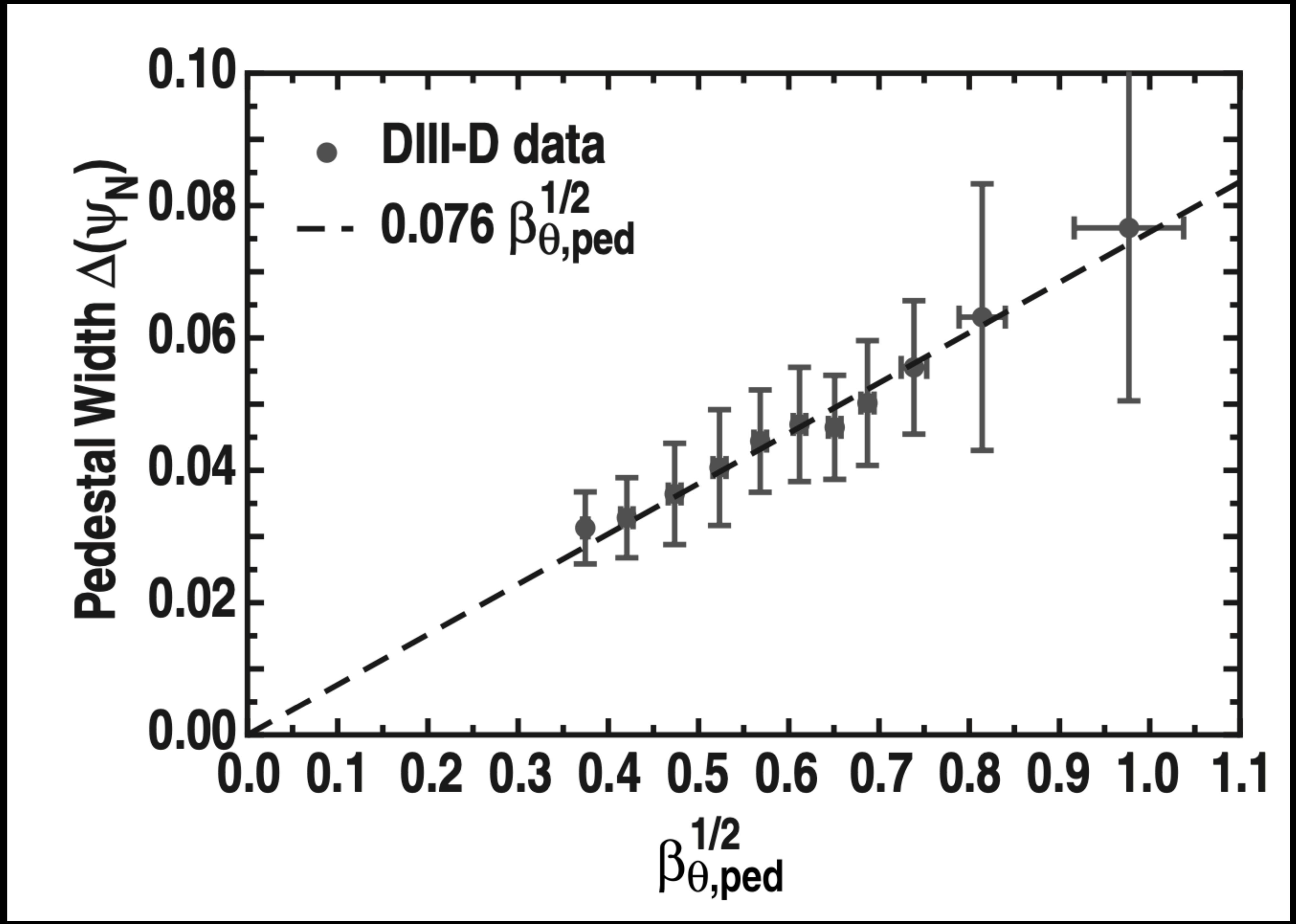

Fig 1: Pedestal width versus $\sqrt{\beta_{\theta,\mathrm{ped}}}$ for DIIID discharges. ***Adapted from Fig 2*** **[Snyder, NF, 2009]**

$$\beta_{\theta,\mathrm{ped}} = 2\mu_0 p_{\mathrm{ped}} / B_\theta^2$$

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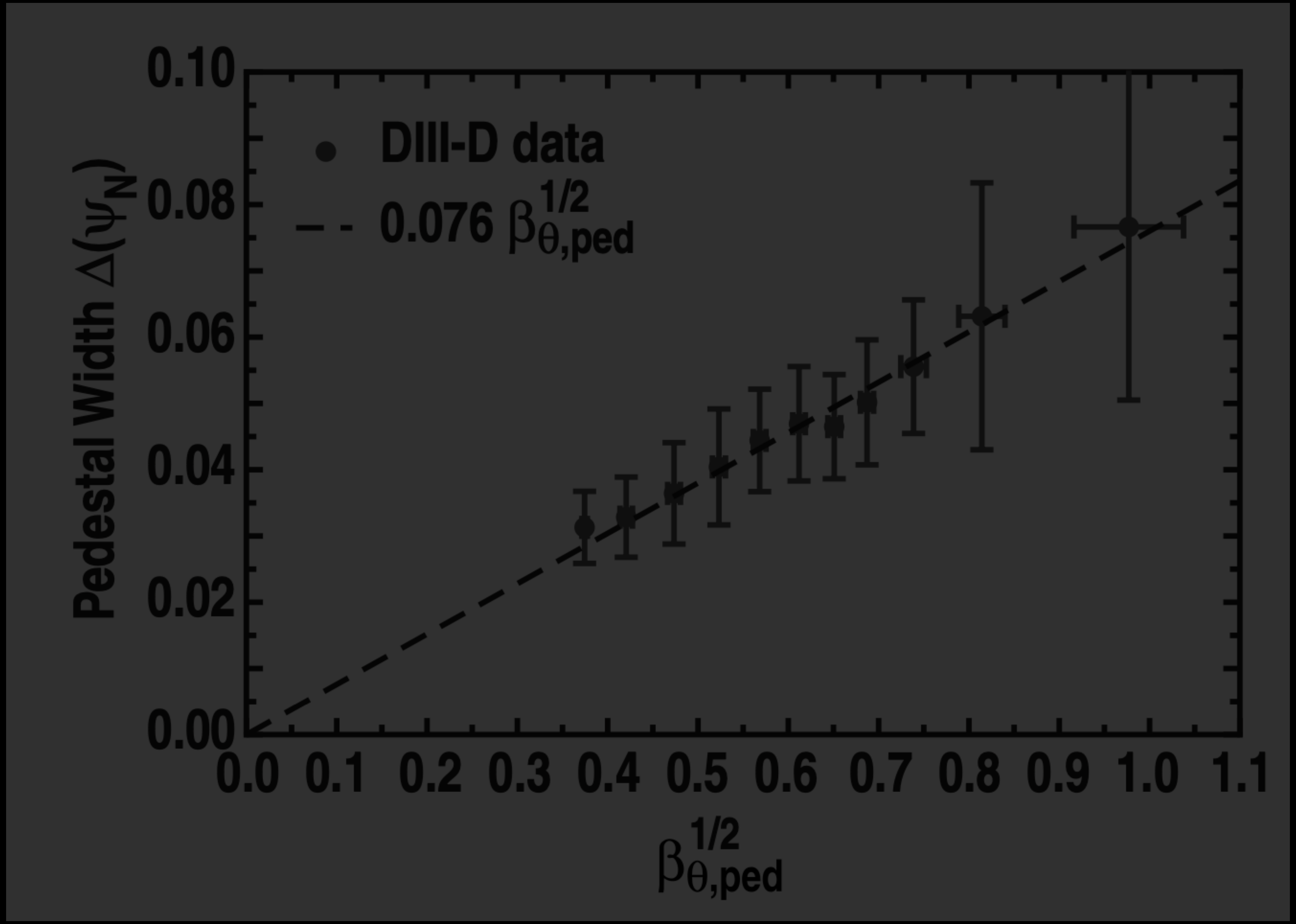

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EPED Ballooning Critical Pedestal (BCP) constraint different for low-A=R/a.

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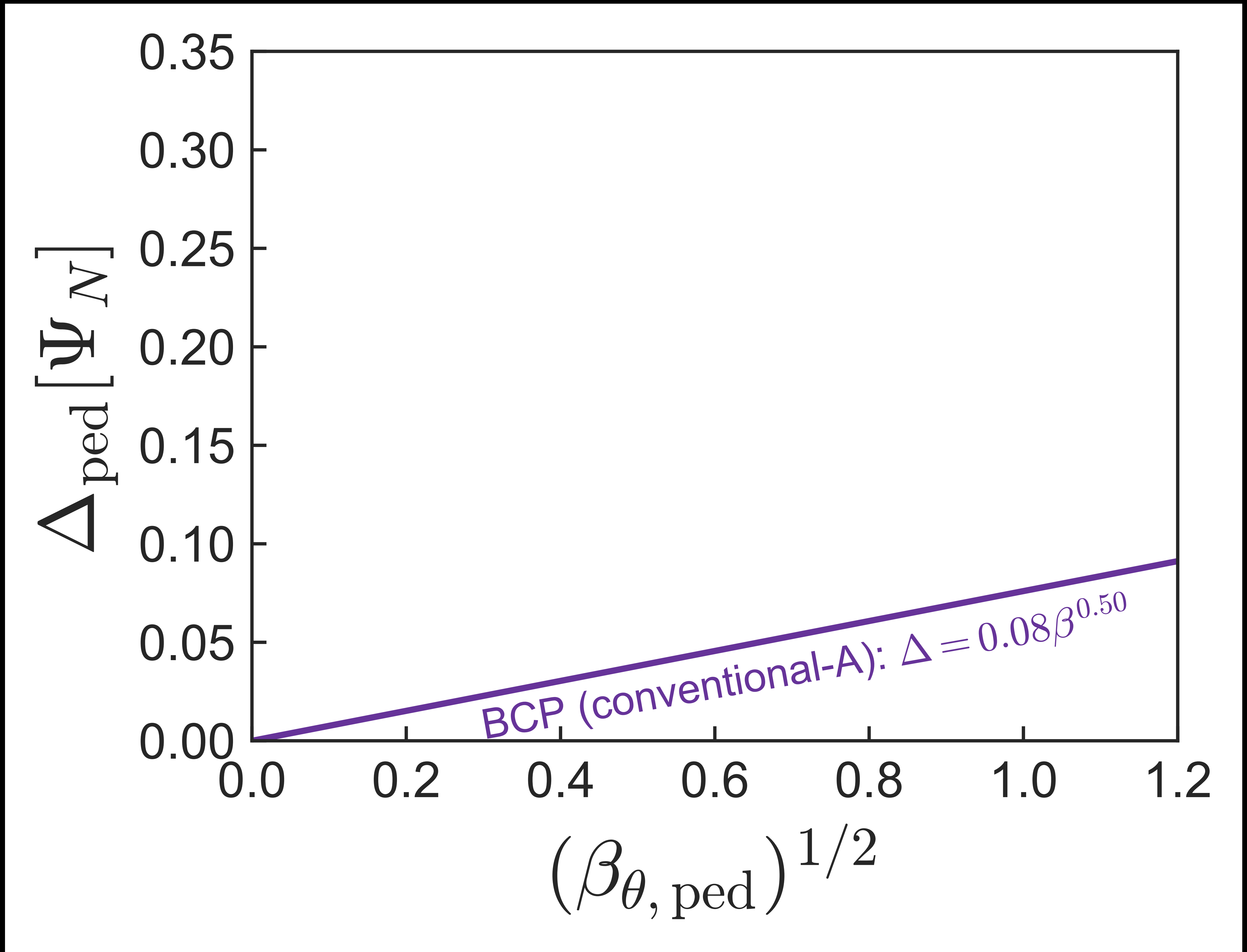
BCP (Conventional-A): $\Delta \sim \beta_{\theta,\mathrm{ped}}^{1/2}$



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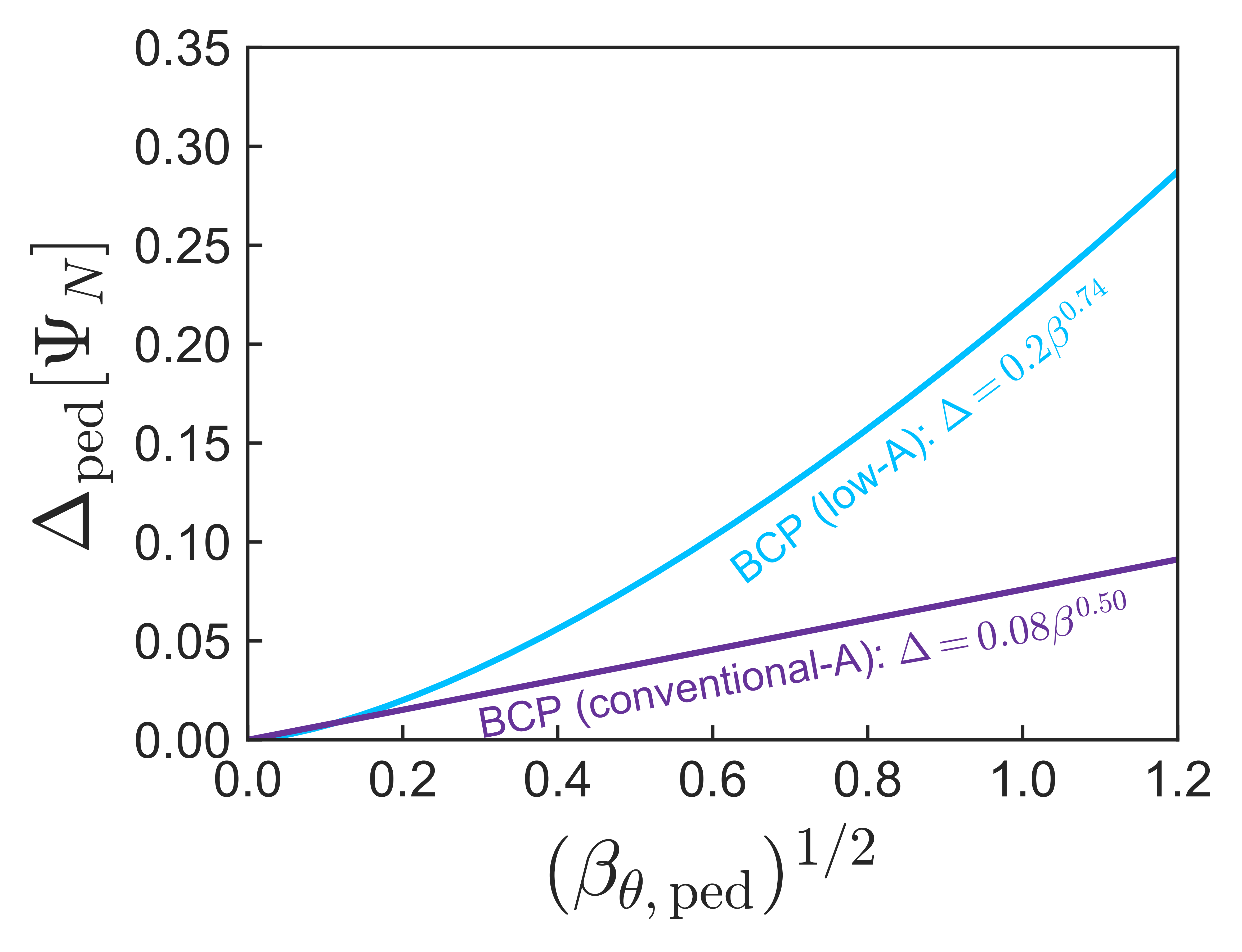
BCP (Low-A): $\Delta \sim \beta_{\theta,\text{ped}}^{0.74}$



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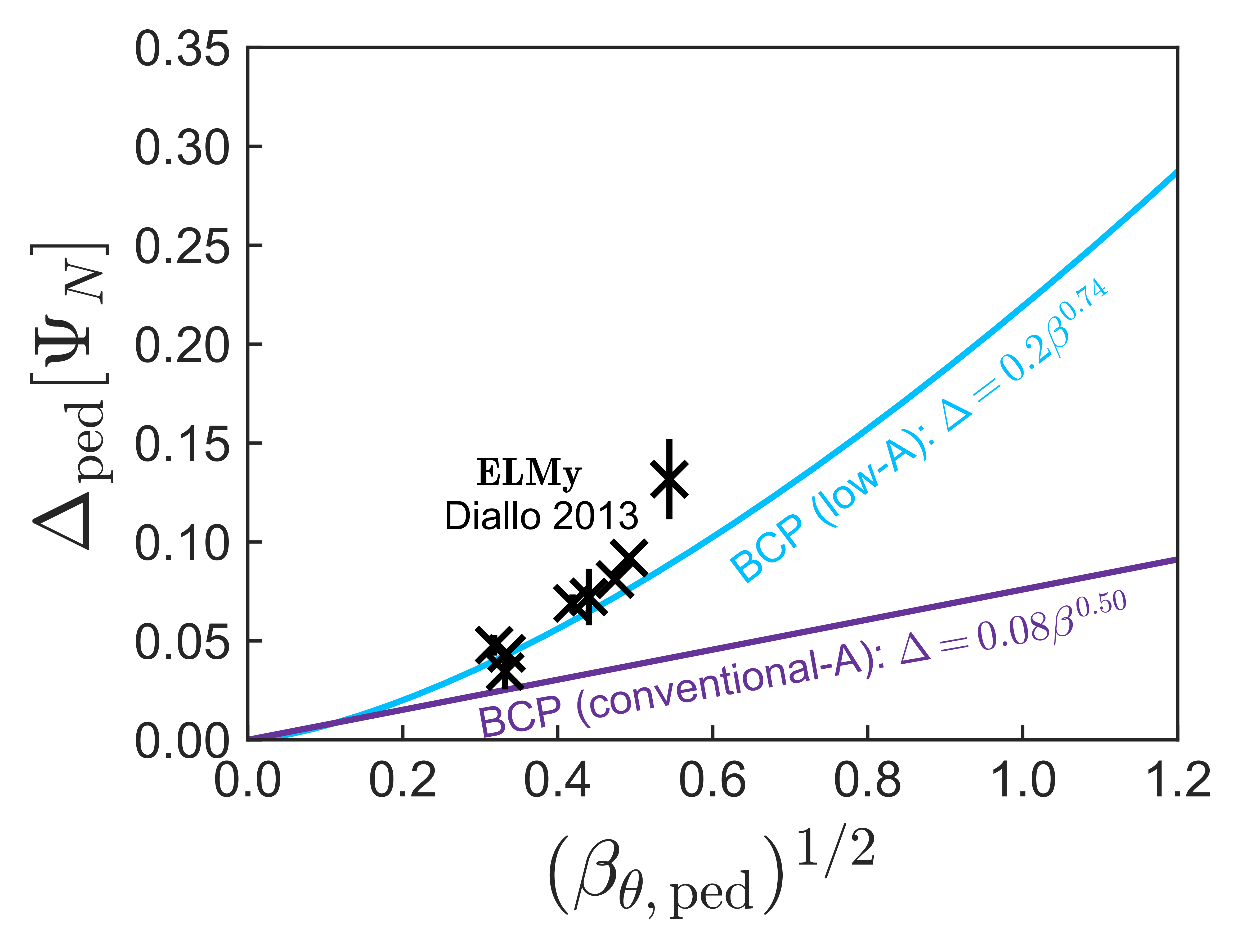
ELMy NSTX



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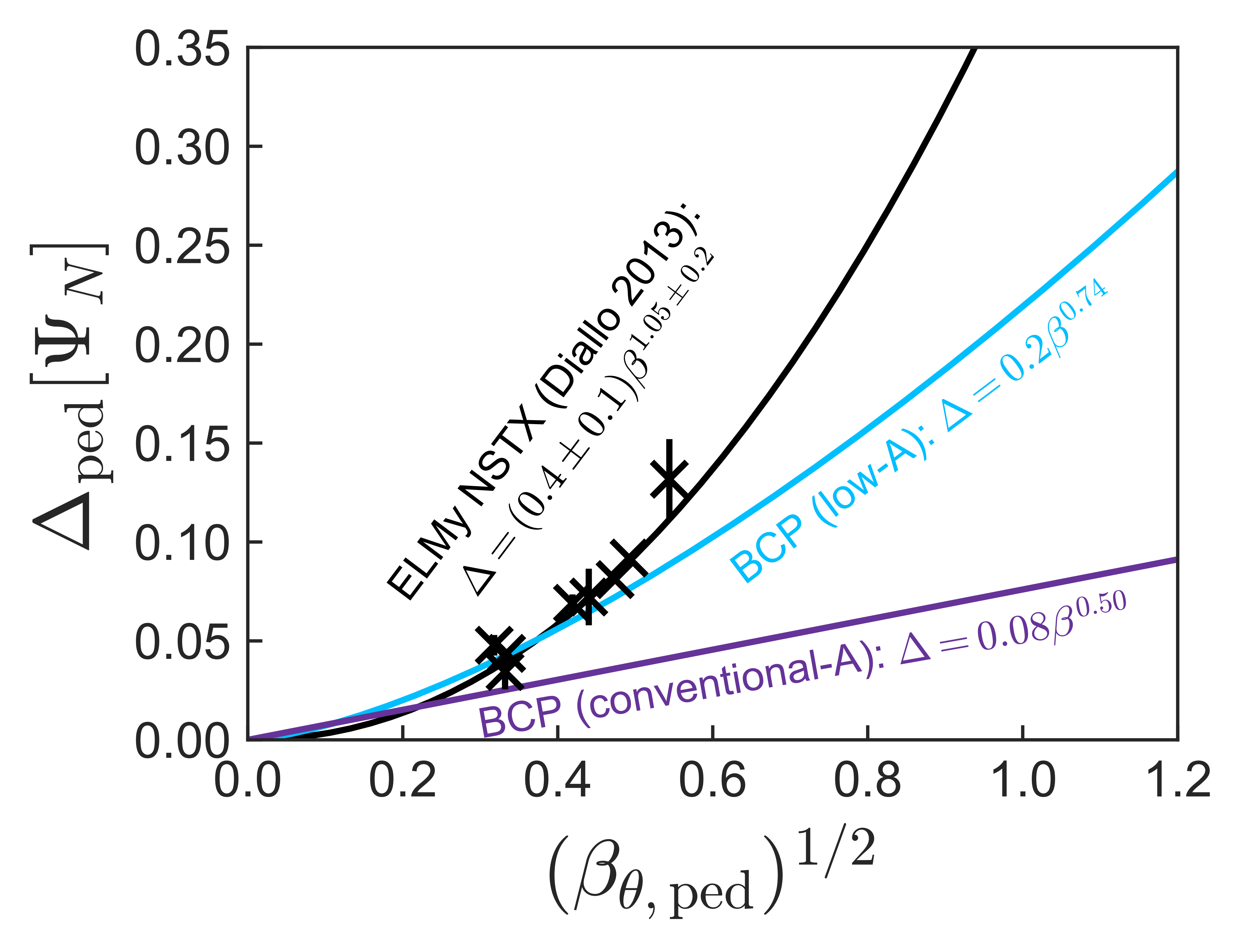
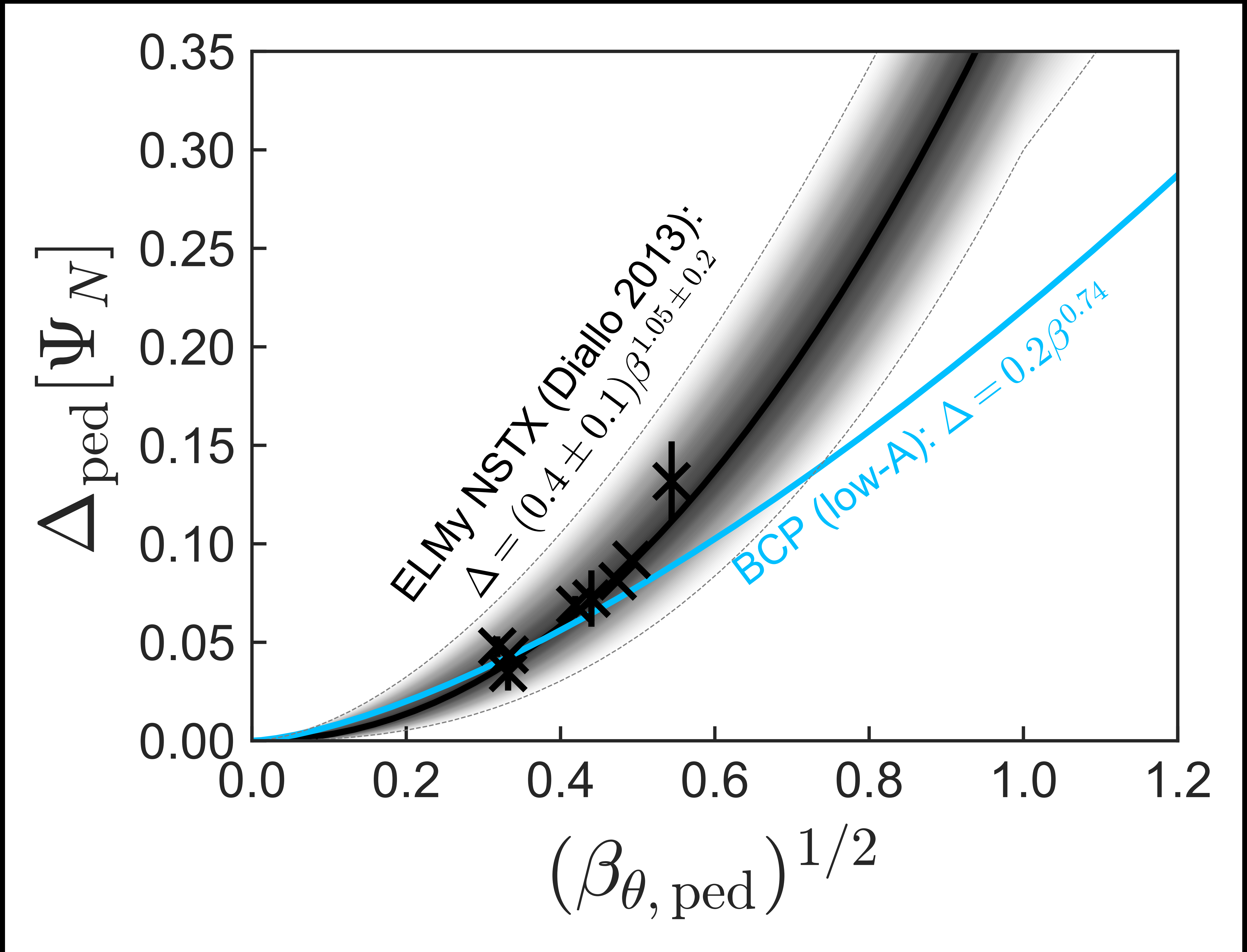
ELMy NSTX: $\Delta \sim \beta_{\theta,\mathrm{ped}}^{1.05}$

$$\beta_{\theta,\mathrm{ped}} = 2\mu_0 p_{\mathrm{ped}}/B_\theta^2$$



EPED Ballooning Critical Pedestal (BCP) constraint different for low A=R/a.

BCP for low-A partially recovers ELMy NSTX scaling.



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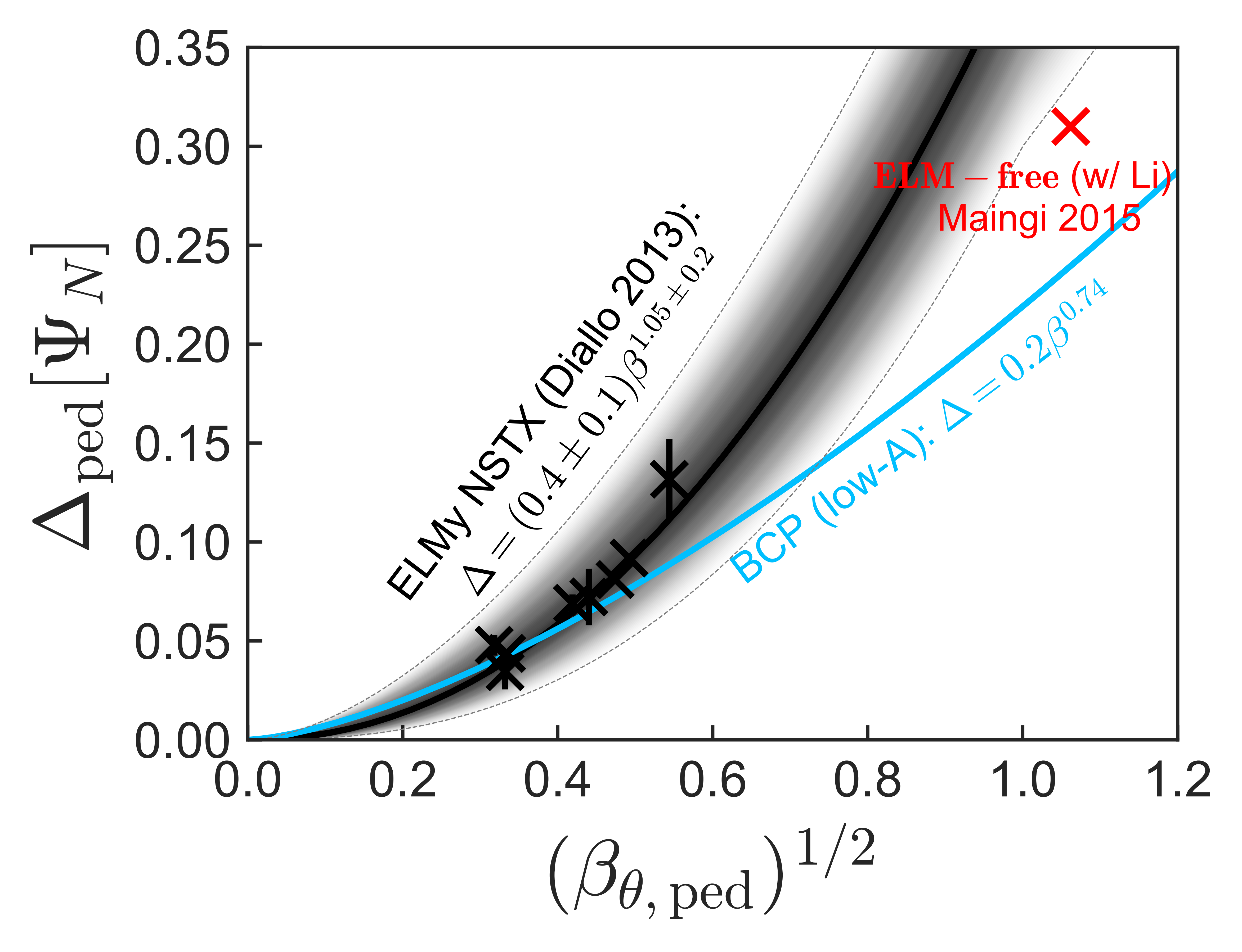
ELM-free NSTX discharges deviate from scalings [Maingi 2015, JNM].



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Important for NSTX-U and future ST reactors.

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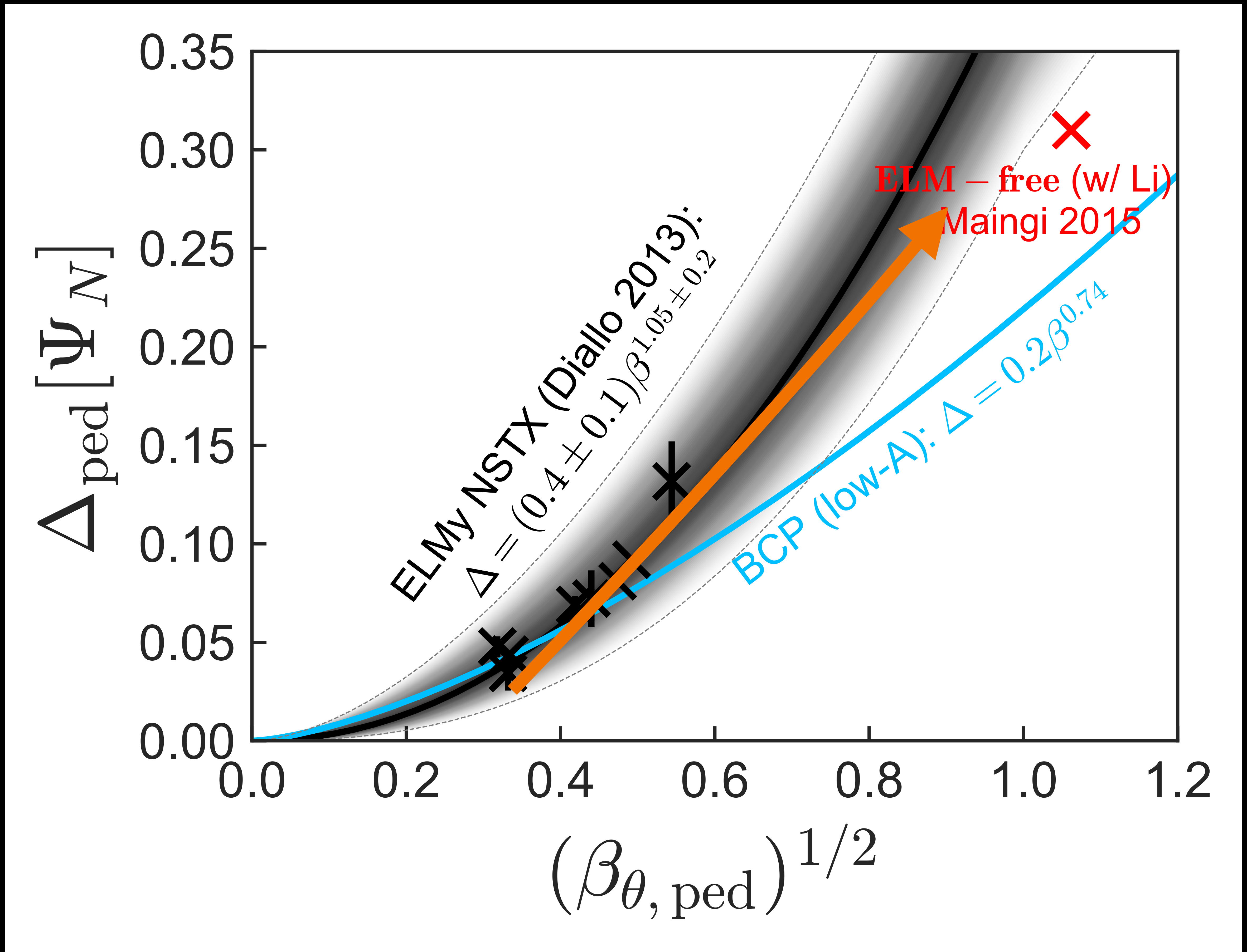

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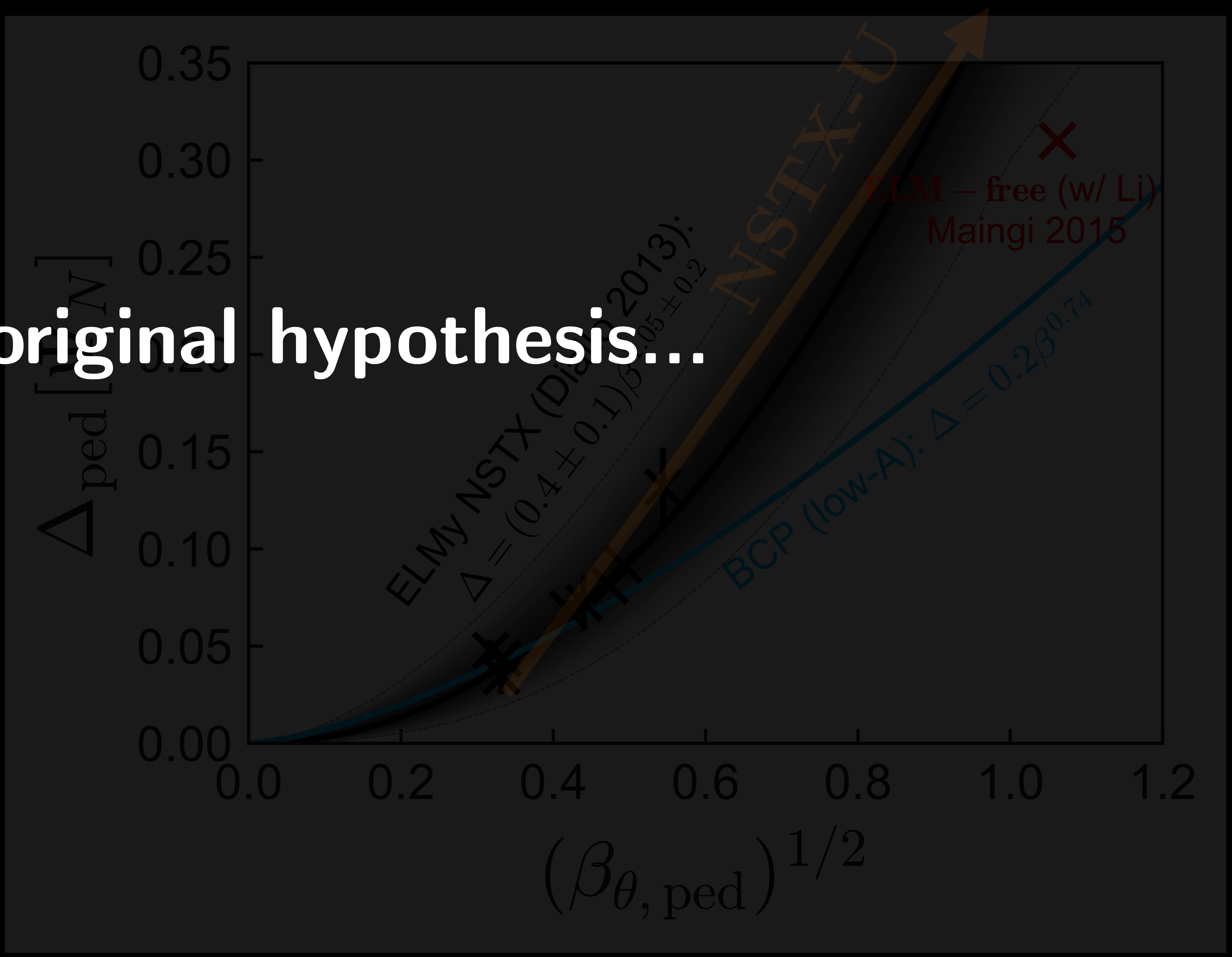
Future NSTX-U pedestals at higher pressure, current.



$$\beta_{\theta,\rm ped} = 2\mu_0 p_{\rm ped}/B_\theta^2$$

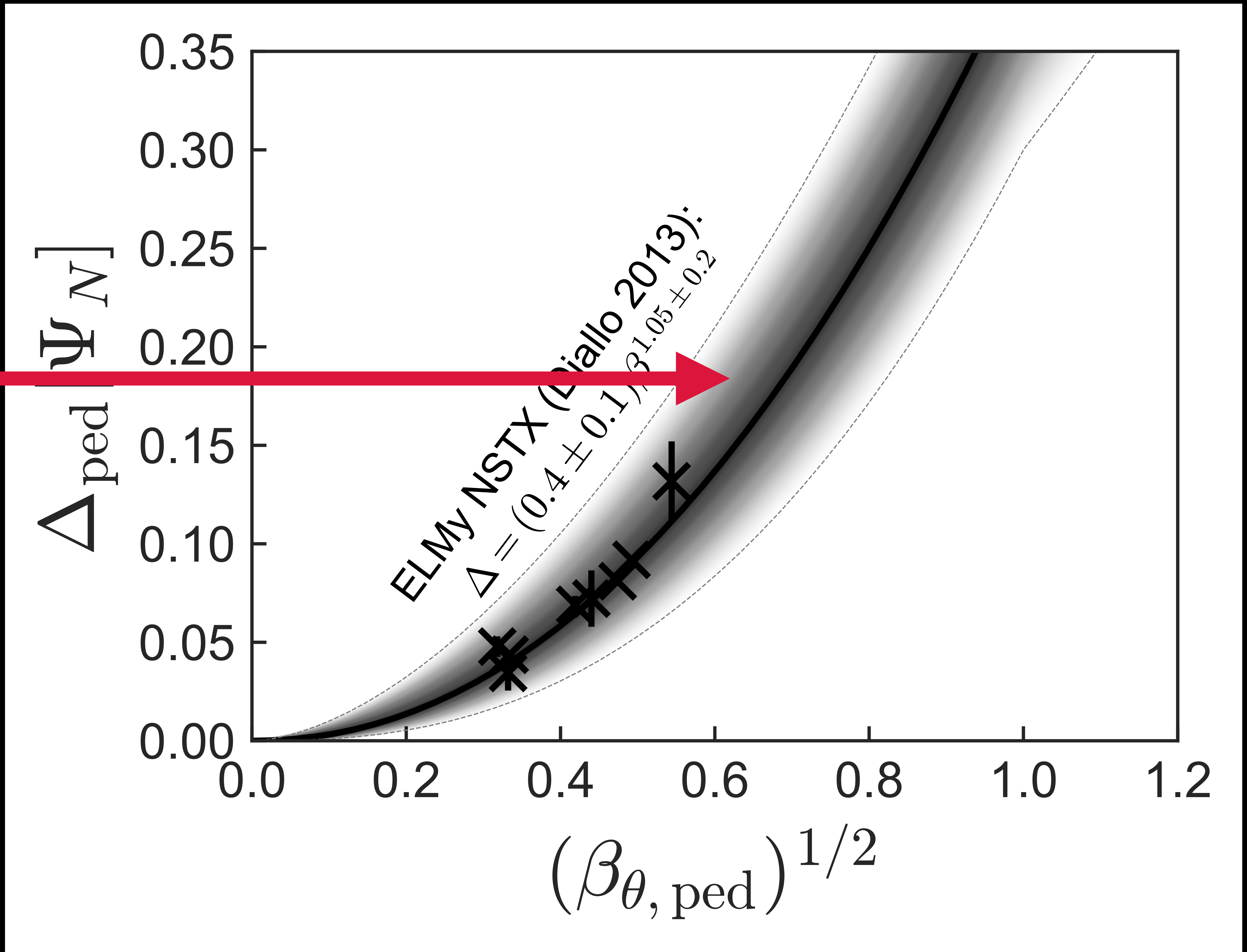
Going back to original hypothesis...

Hypothesis: KBM thresholds predict pedestal height and width ∇p constraint for NSTX

Measure of success:

KBM reproduces height width scaling found for NSTX experiments:

$$\Delta_{\text{ped}} = (0.4 \pm 0.1)(\beta_{\theta,\text{ped}})^{1.05\pm0.2}$$



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Why:

EPED ∇p prediction successful in many devices, not sufficient for all NSTX discharges.*

Important because pedestal height p_{ped} and width Δ_{ped} useful for $nT\tau_E$, fusion gain Q.

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$T_{e,\text{ped}}/T_{e,\text{ped}}^{(\text{EPED})}$	1.0	0.67	0.5
Modelled Q	9.0	5.1	3.0

Table 1: **Adapted from [Hughes 2020, JPP]**, Energy gain Q for three different $T_{e,\text{ped}}/T_{e,\text{ped}}^{\text{EPED}}$ values for SPARC.

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SPARC Q predicted to decrease 3x with 50% pedestal degradation

—>

large reactor design uncertainty

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What:

Use linear gyrokinetics to scan in self-consistent equilibria with varying p_{ped}, Δ_{ped} to determine stability boundaries. EPED-inspired, adding non-ideal physics.

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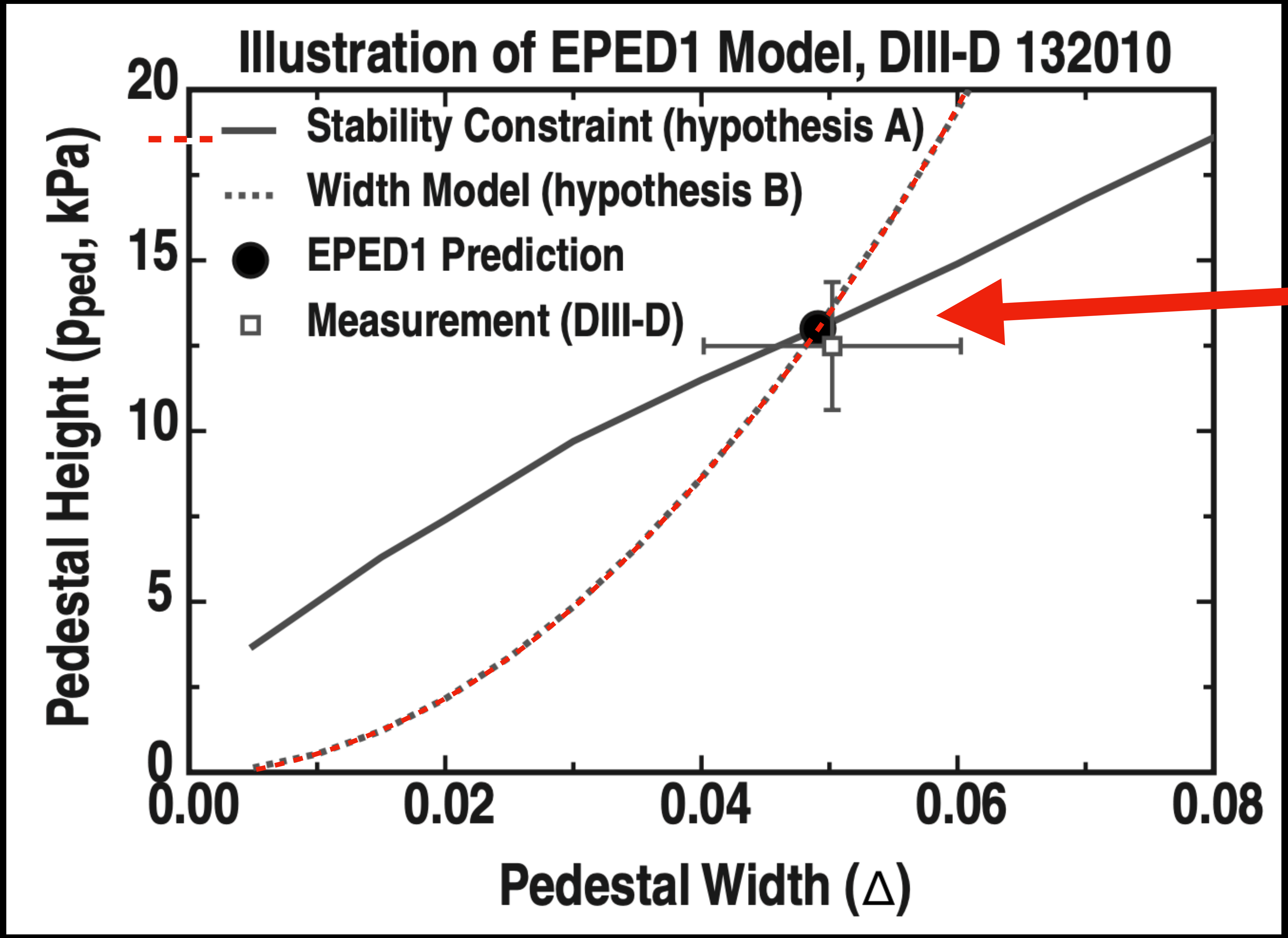
Fig 1: Pedestal height versus width for a DIIID discharge. ***Adapted from Fig 5* [Snyder, NF, 2009]**



EPED evaluates ideal ballooning critical pedestal (BCP) constraint for model equilibria on a height, width grid.

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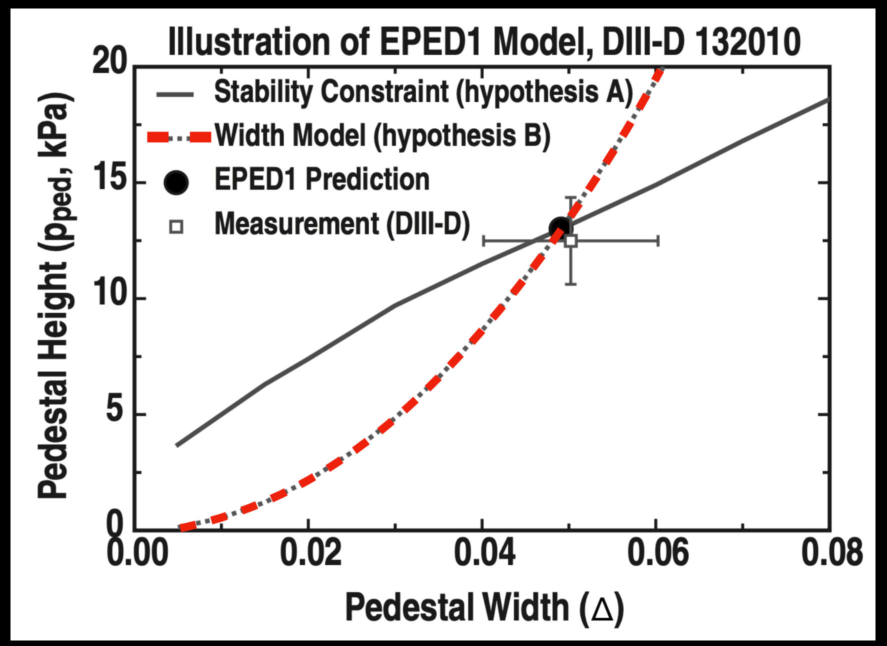

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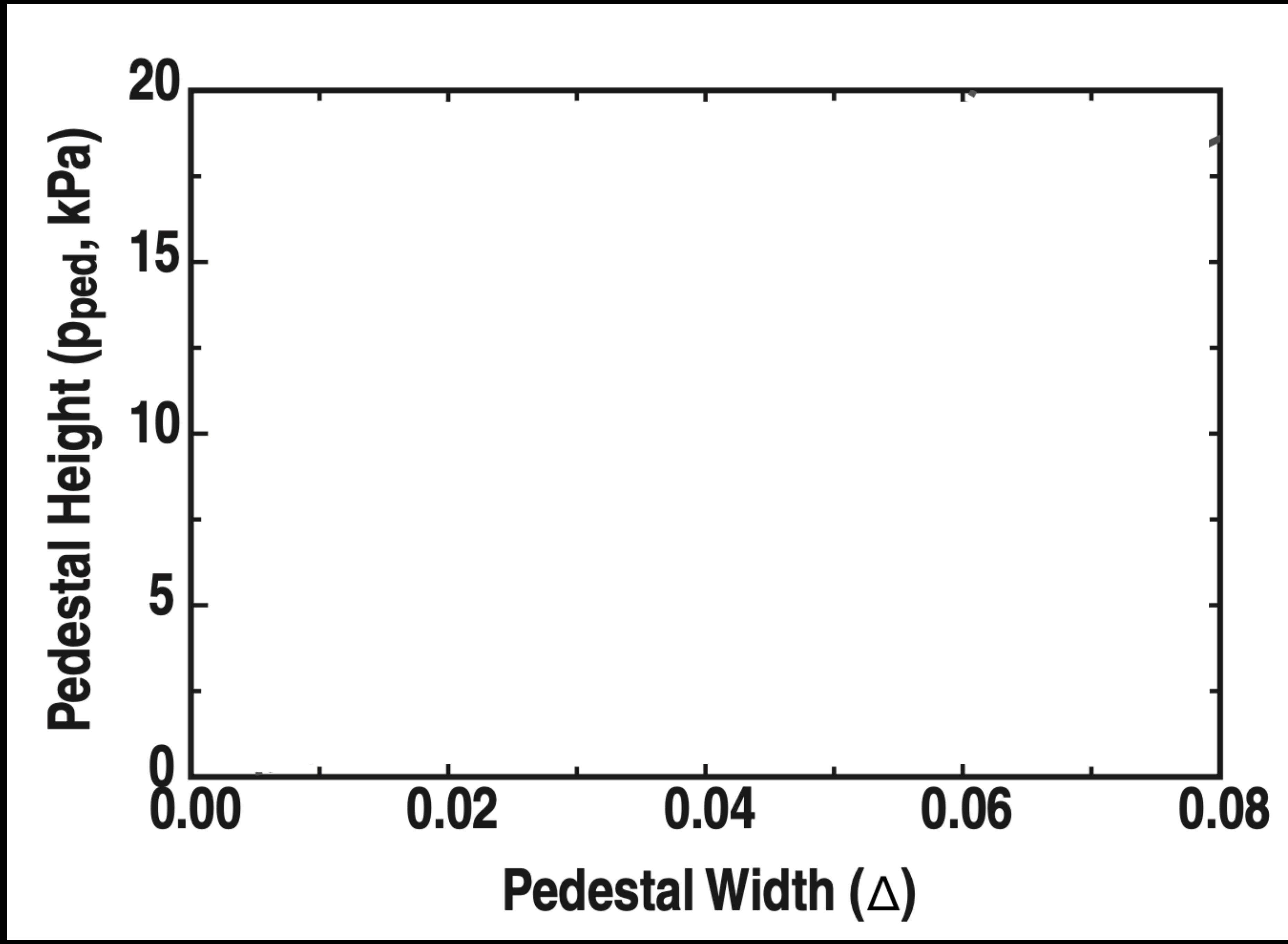
Our goal:

Take EPED-like height-width grid, run gyrokinetics.



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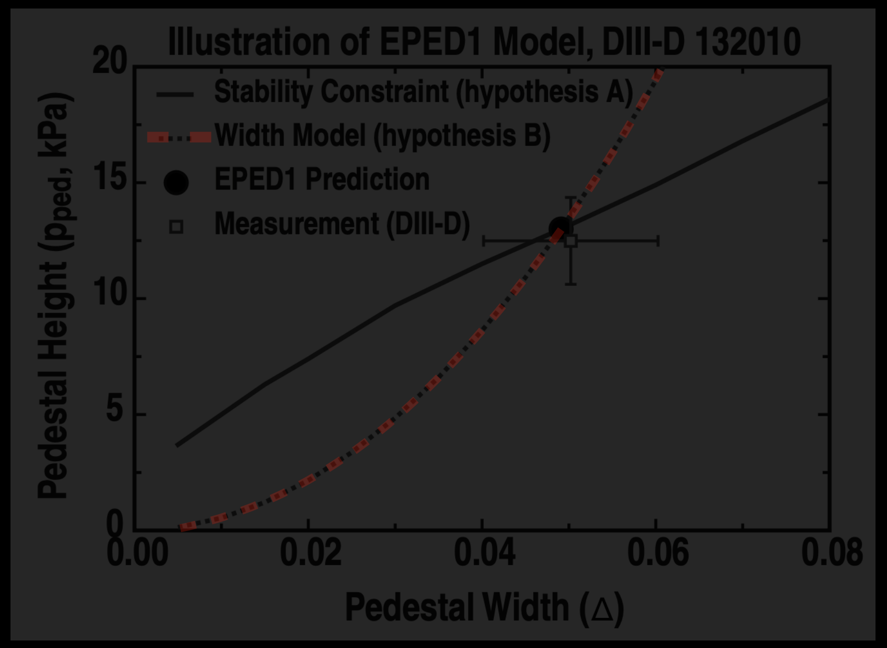
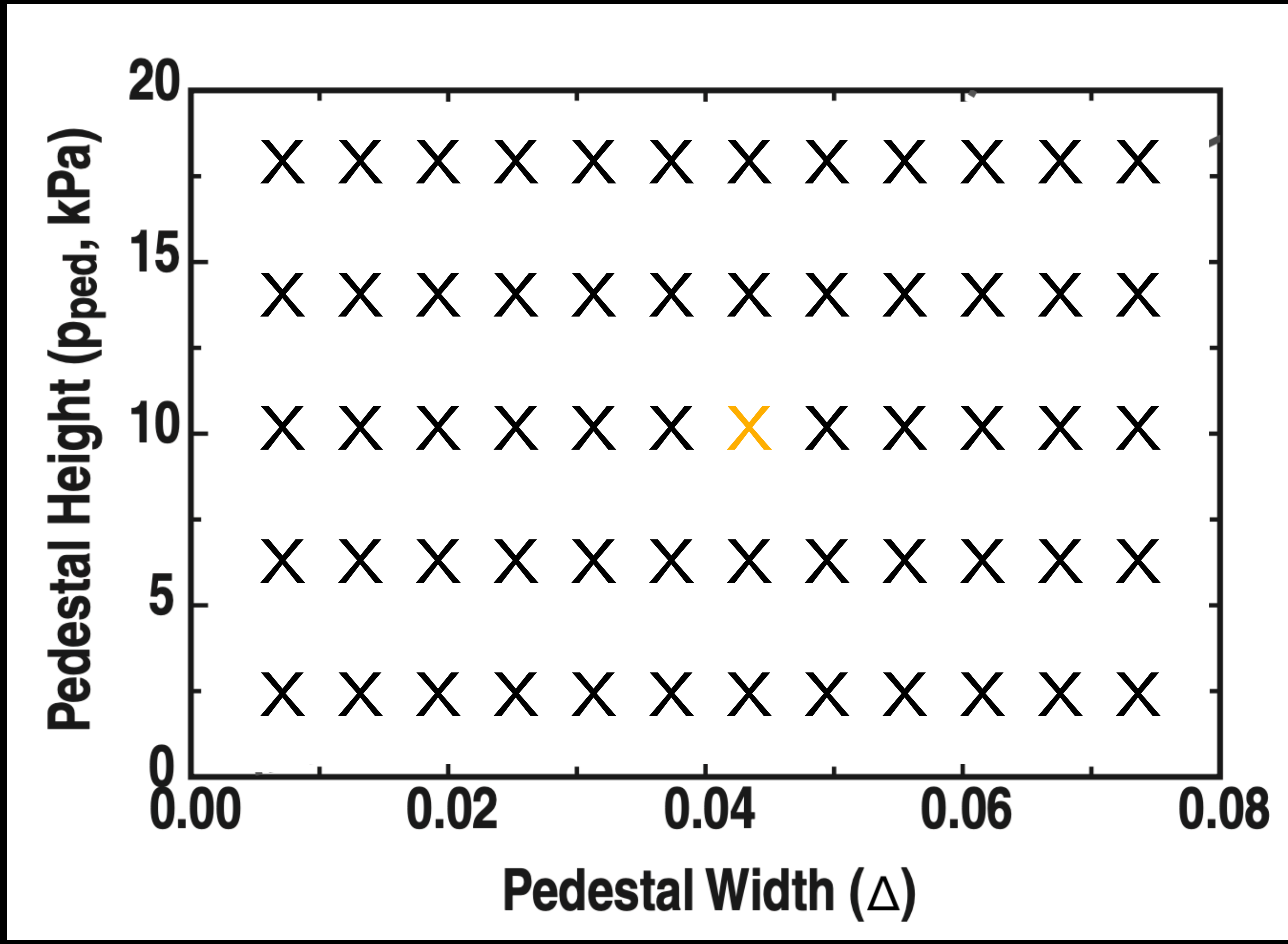


Fig 1: Pedestal height versus width for a DIIID discharge. *Adapted from Fig 5* [Snyder, NF, 2009]

Starting from experiment, we vary equilibria self-consistently in height, width space.



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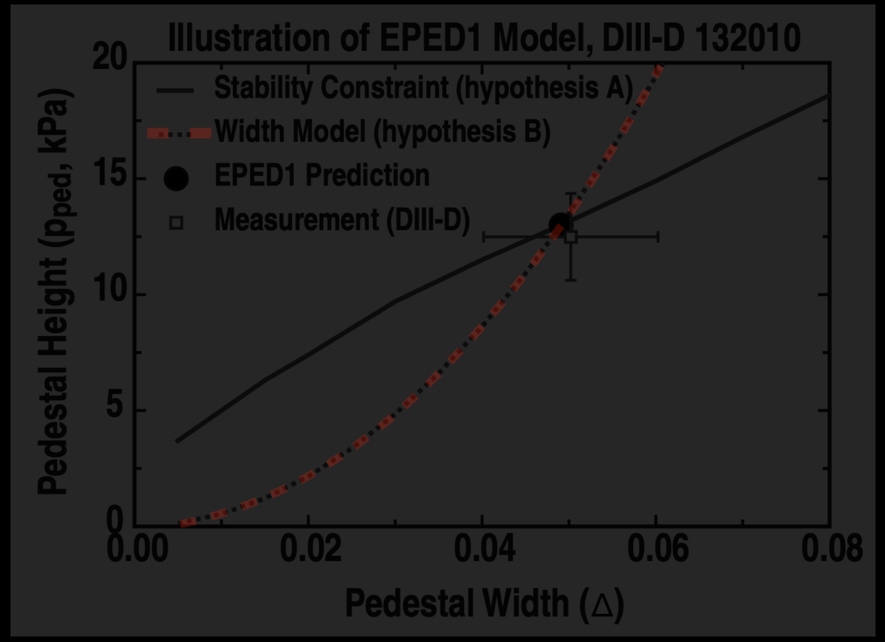
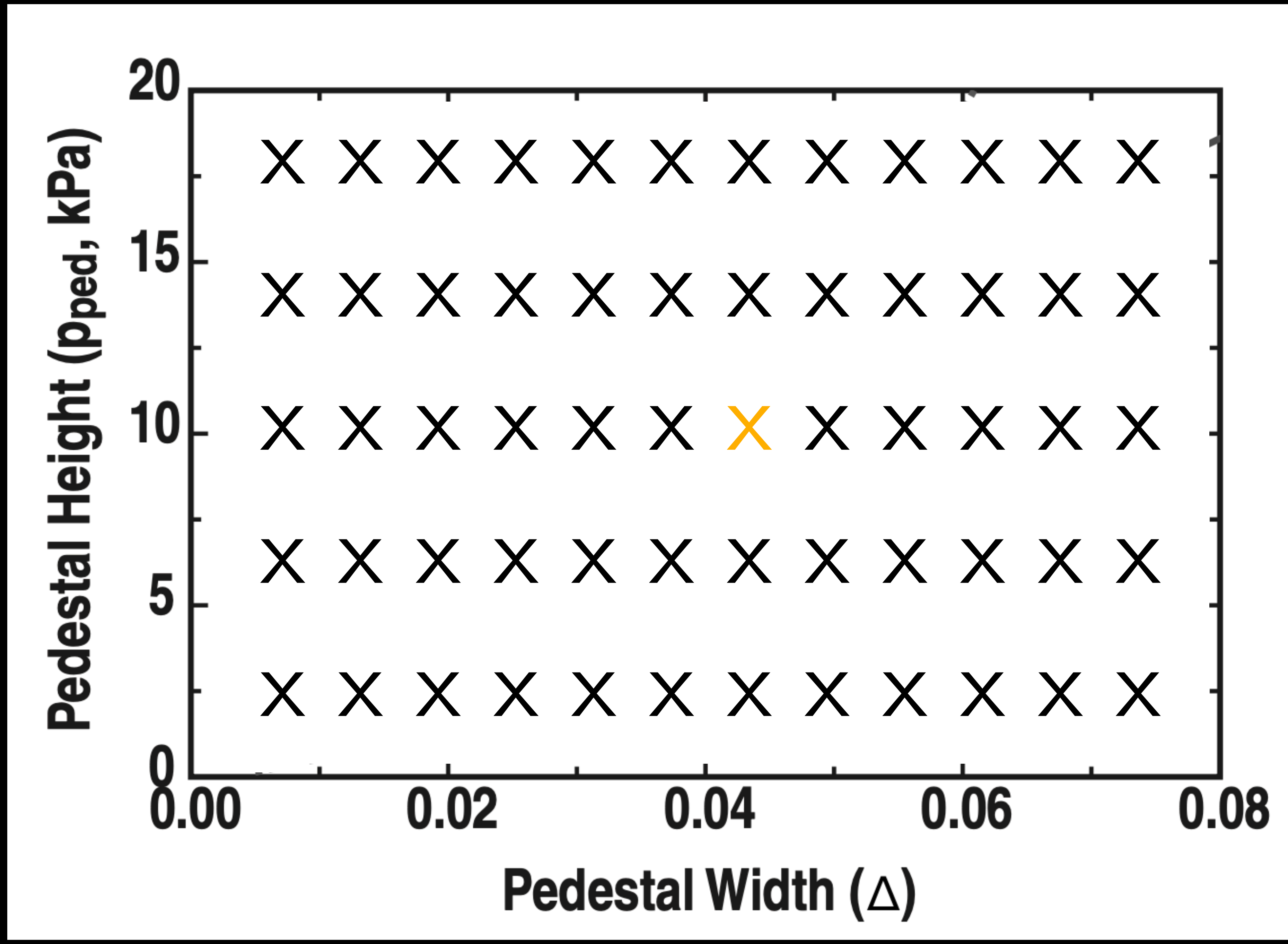


Fig 1: Pedestal height versus width for a DIIID discharge. *Adapted from Fig 6* [Snyder, NF, 2009]

Starting from experiment, we vary equilibria self-consistently in height, width space.

Run linear gyrokinetic simulations for each equilibrium



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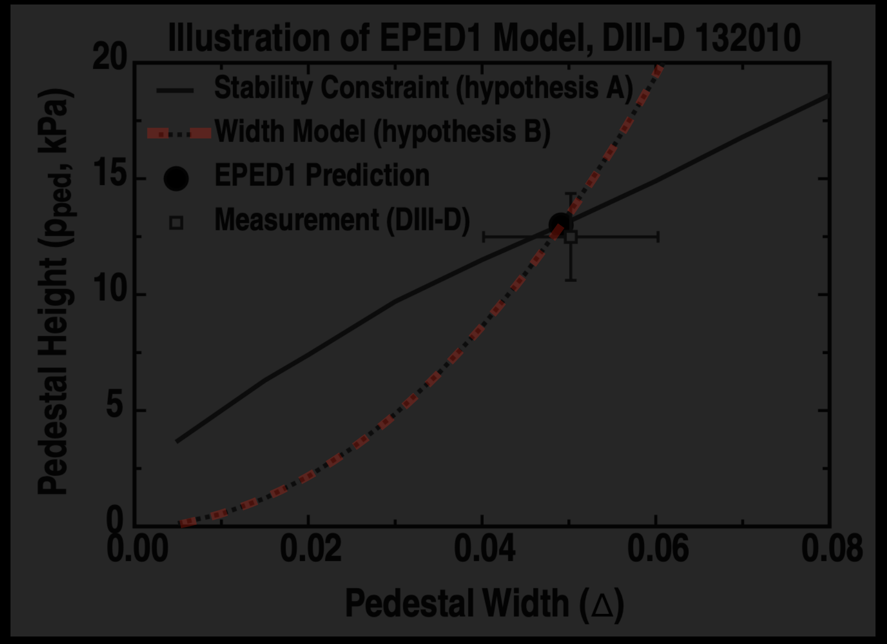

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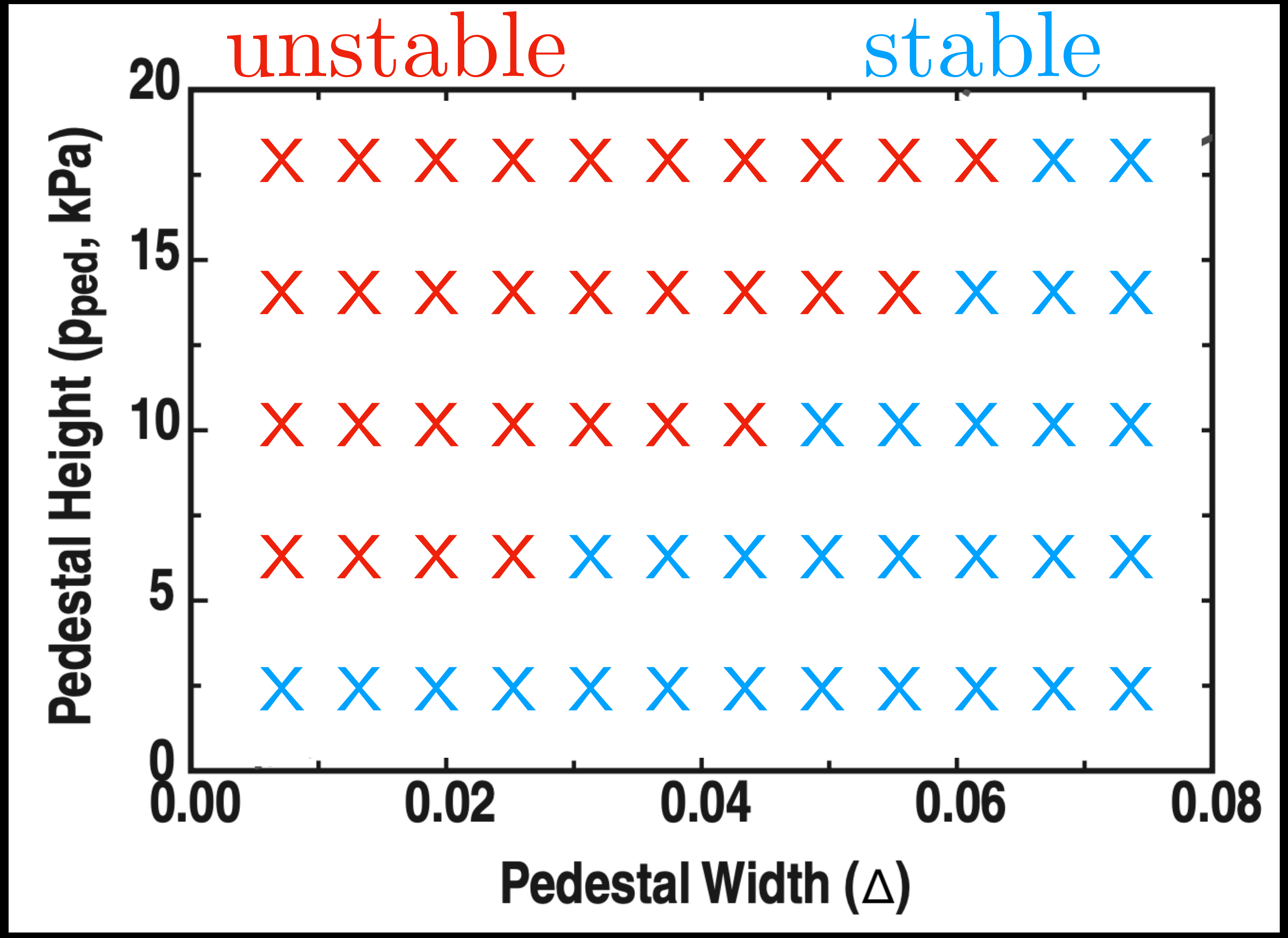

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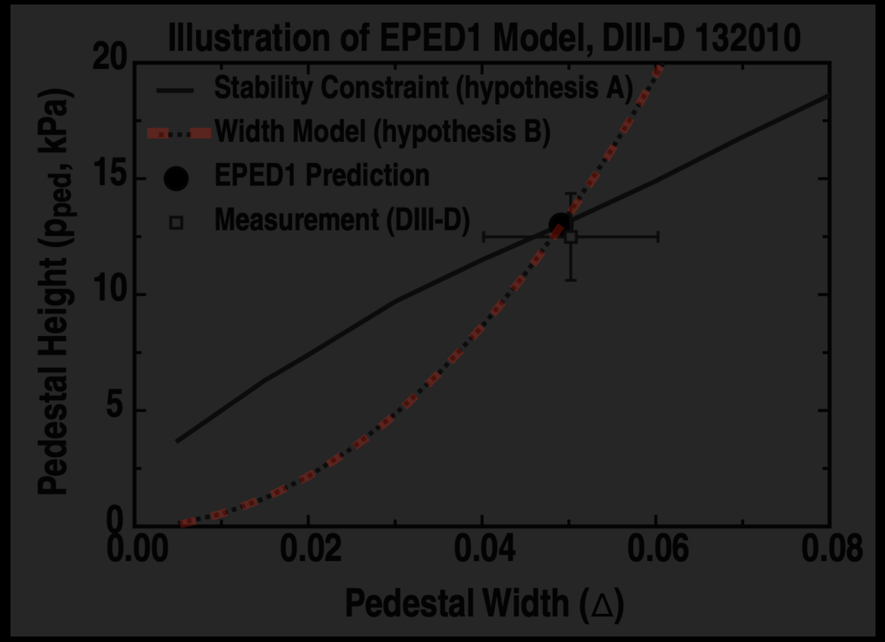

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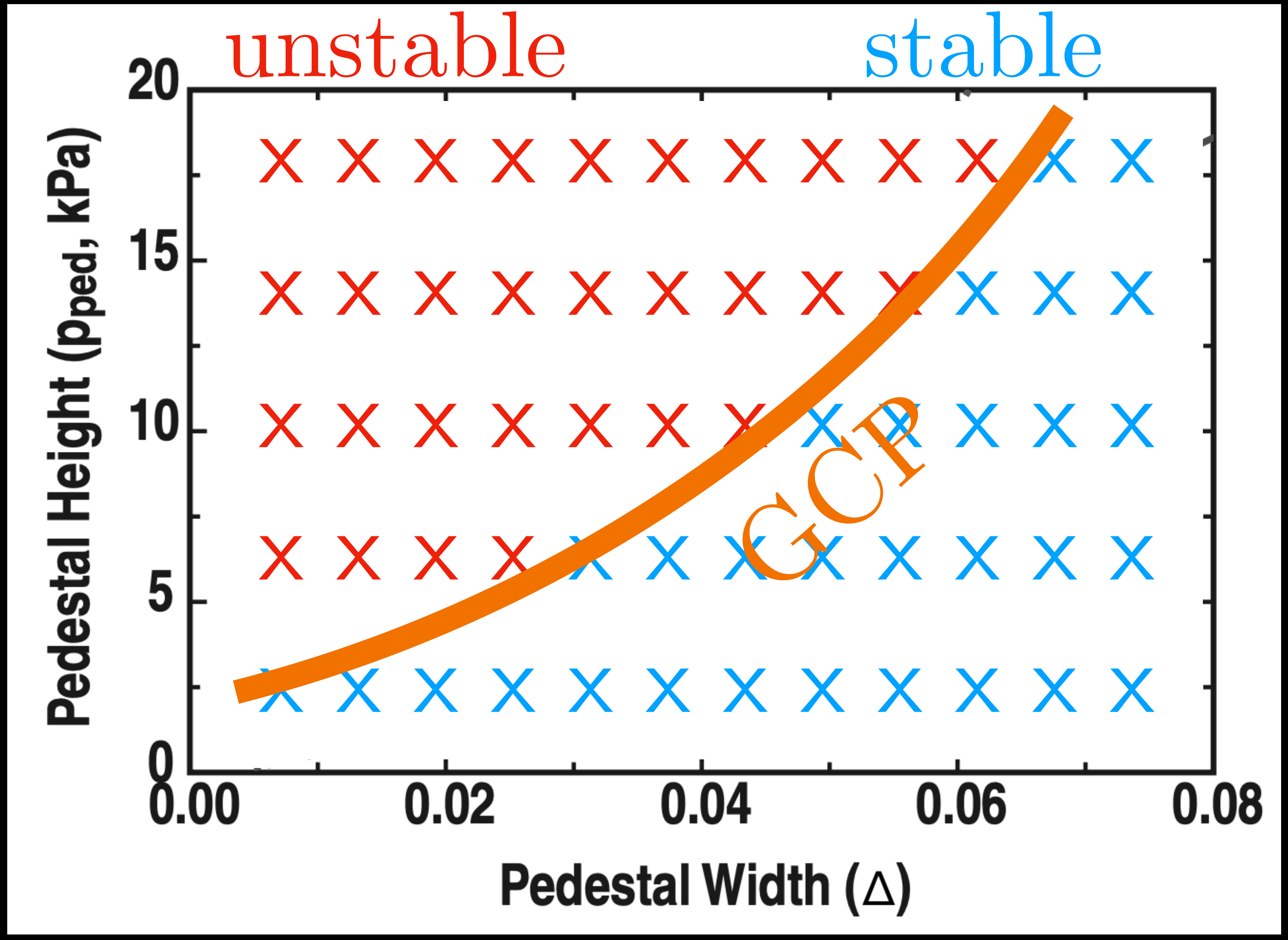
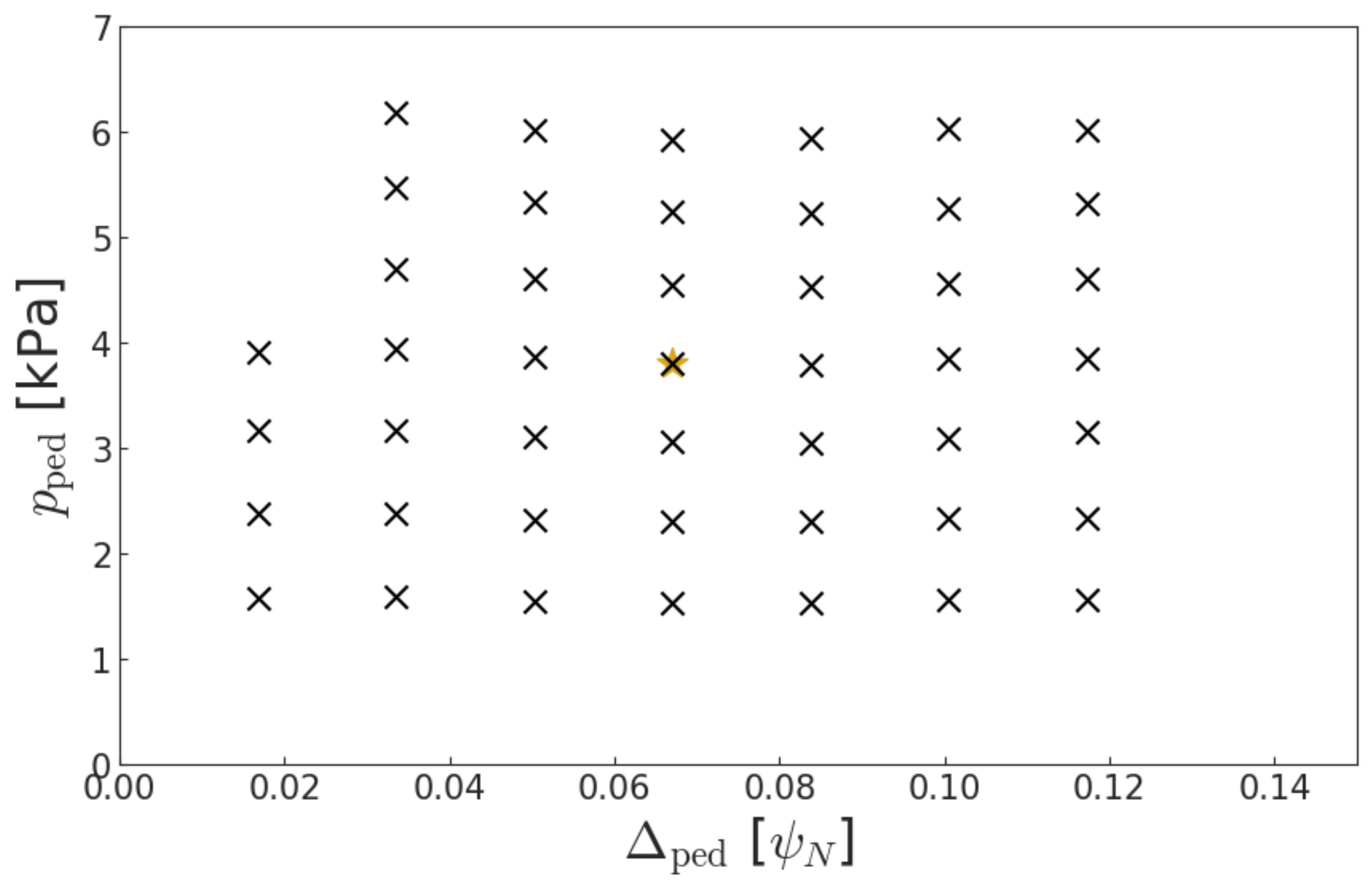
Starting from experiment, we vary equilibria self-consistently in height, width space.

Run linear gyrokinetic simulations for each equilibrium, determine gyrokinetic critical pedestal (GCP) stability constraint.



Finding the Gyrokinetic Critical Pedestal (GCP)

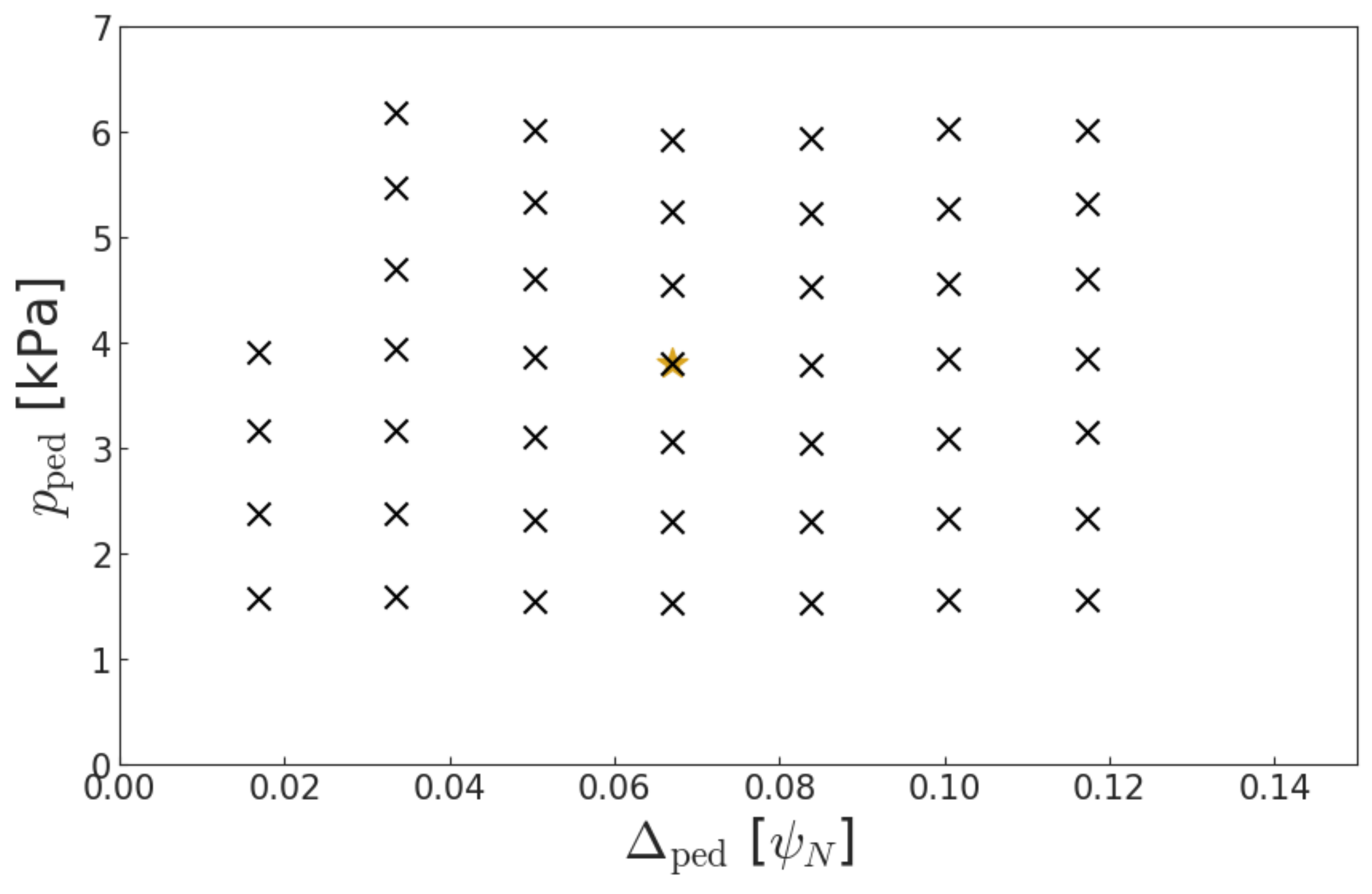
Construct $p_{\mathrm{ped}}, \Delta_{\mathrm{ped}}$ grid



Finding the Gyrokinetic Critical Pedestal (GCP)

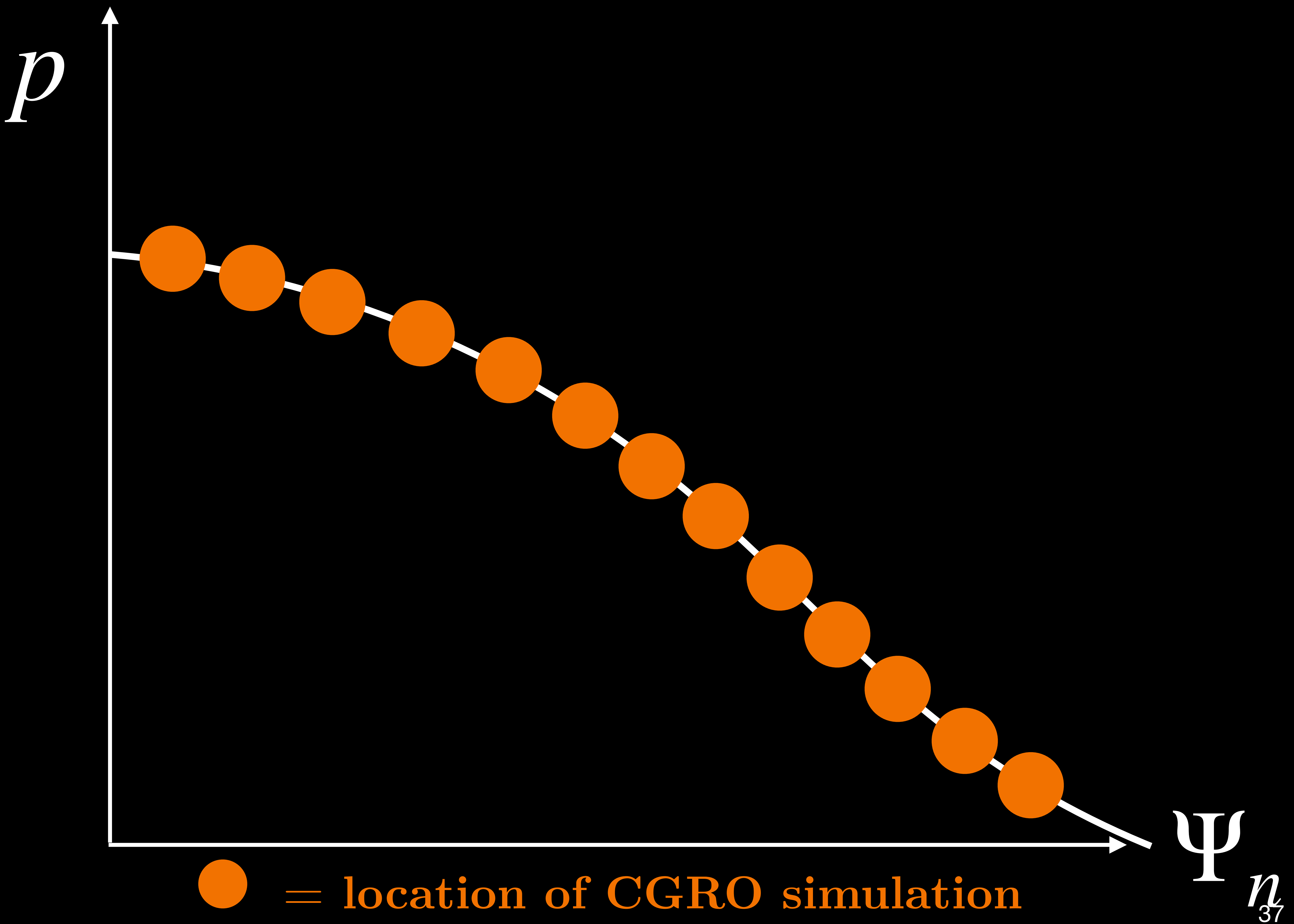
Construct $p_{\mathrm{ped}}, \Delta_{\mathrm{ped}}$ grid

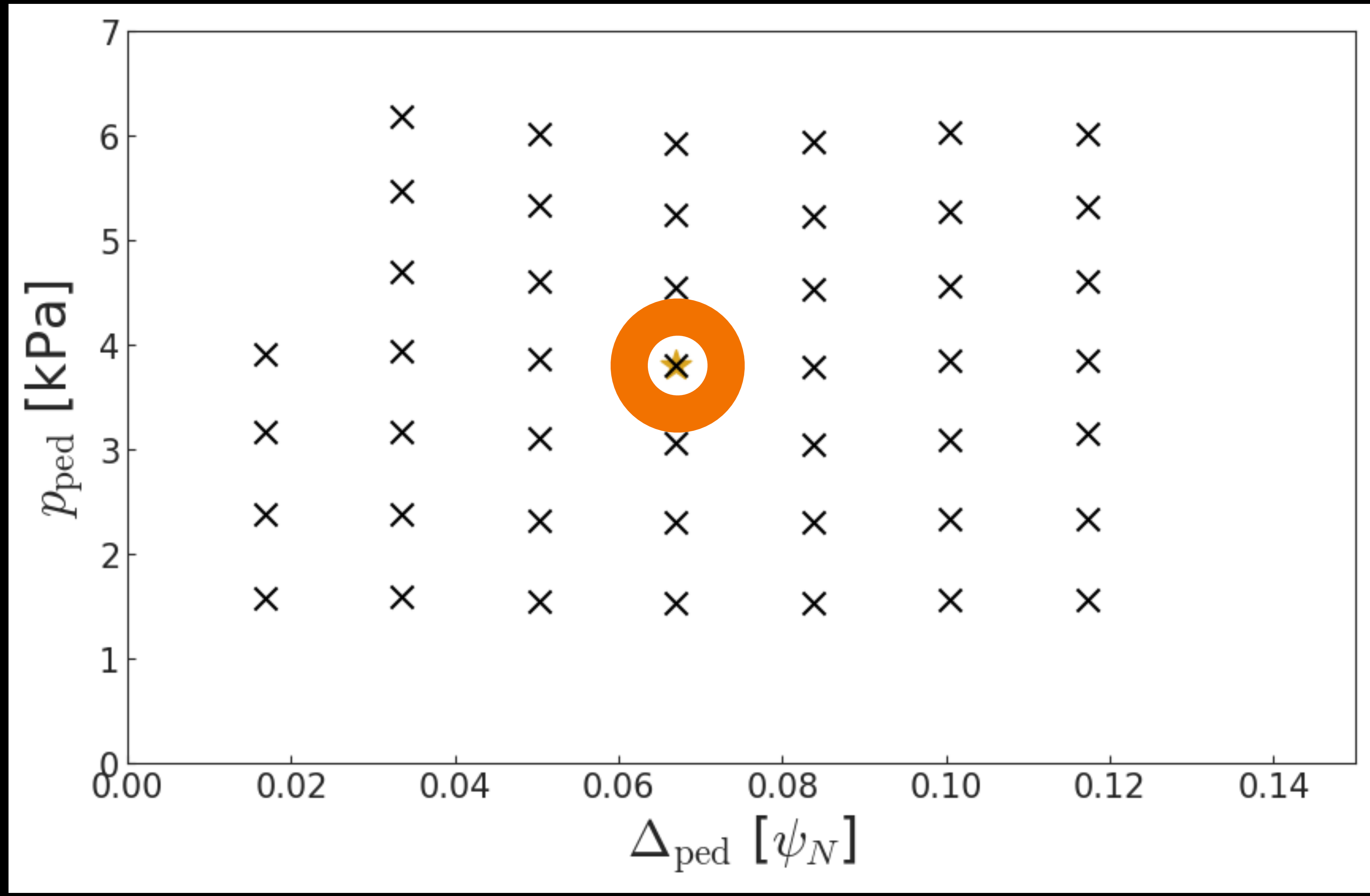
Self-consistent NSTX equilibria across a range of pedestal widths and heights.



Finding the Gyrokinetic Critical Pedestal (GCP)

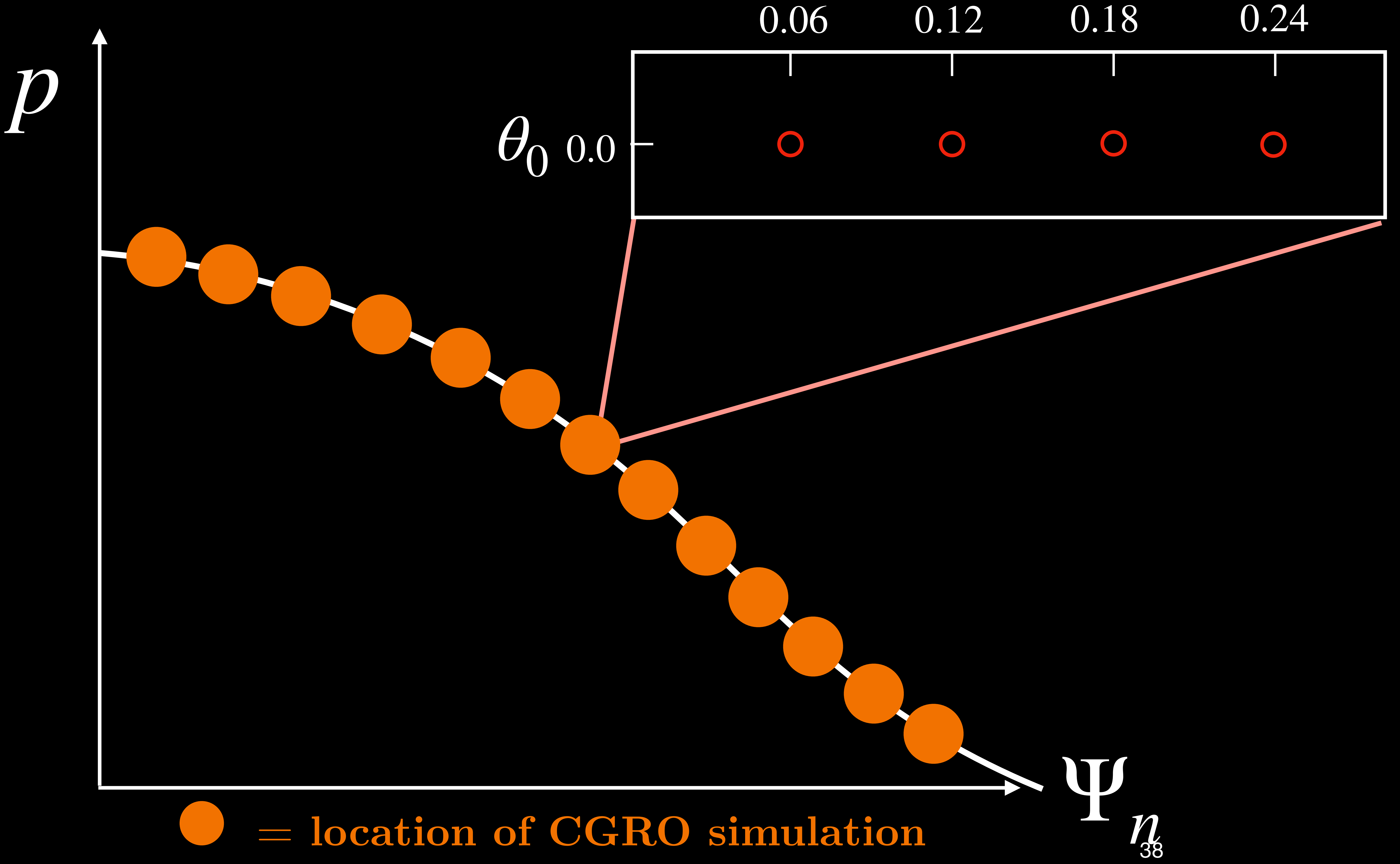
Set up radial grid across full pedestal

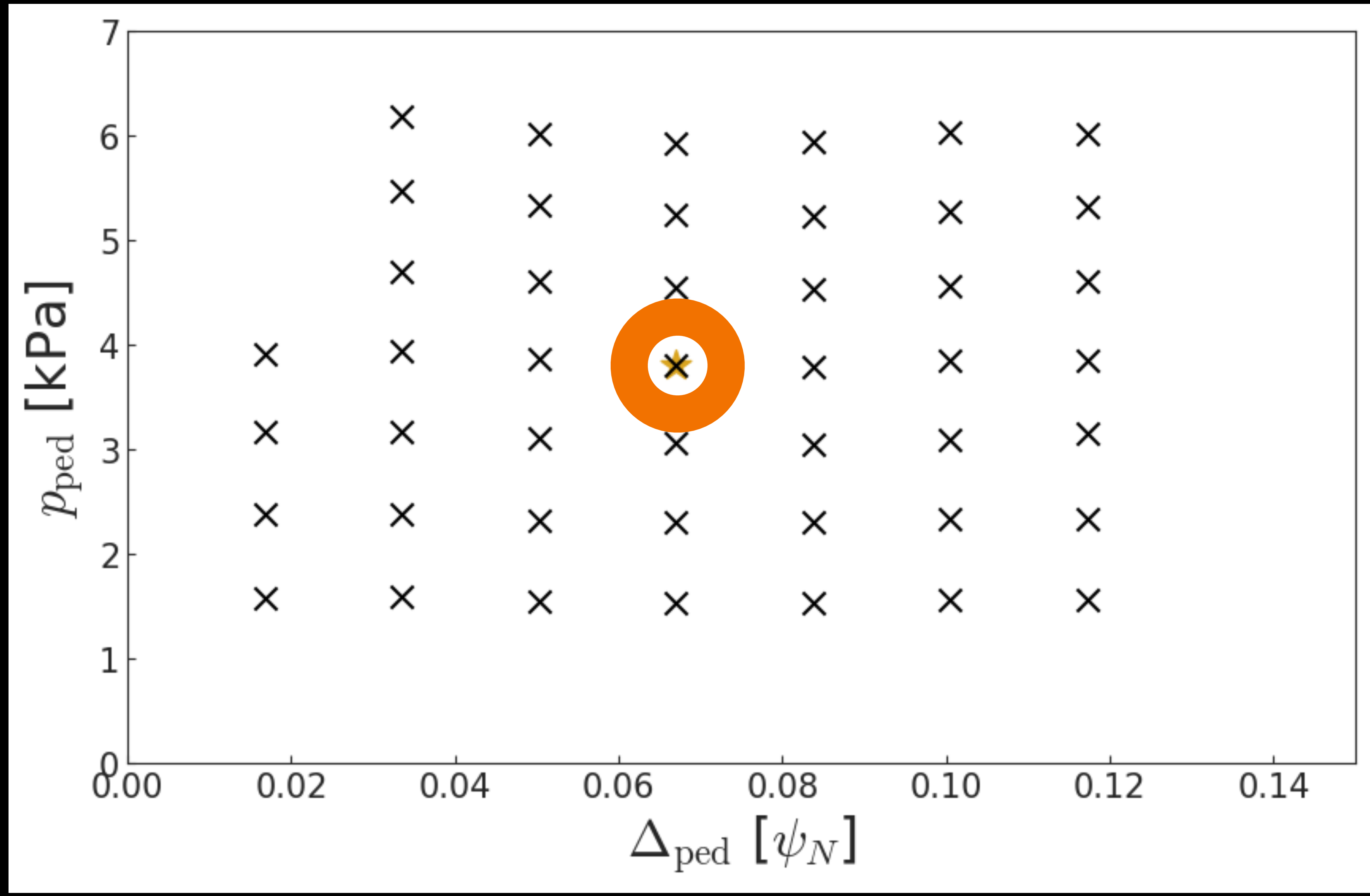




Finding the Gyrokinetic Critical Pedestal (GCP)

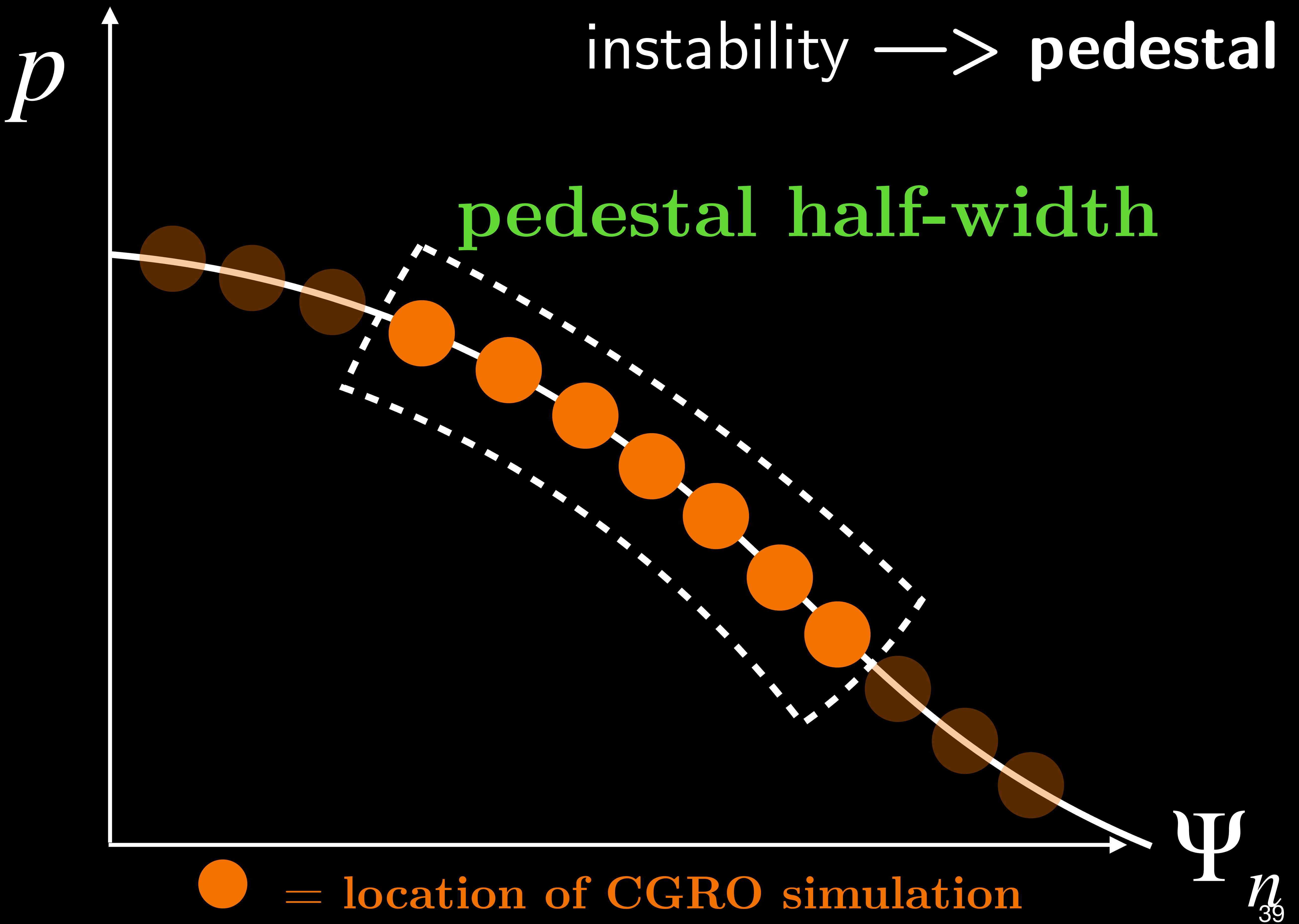
Set up radial grid across full pedestal, binormal wavenumbers $k_y \rho_i$, radial wavenumber $\theta_0 = k_x / k_y \hat{s}$.

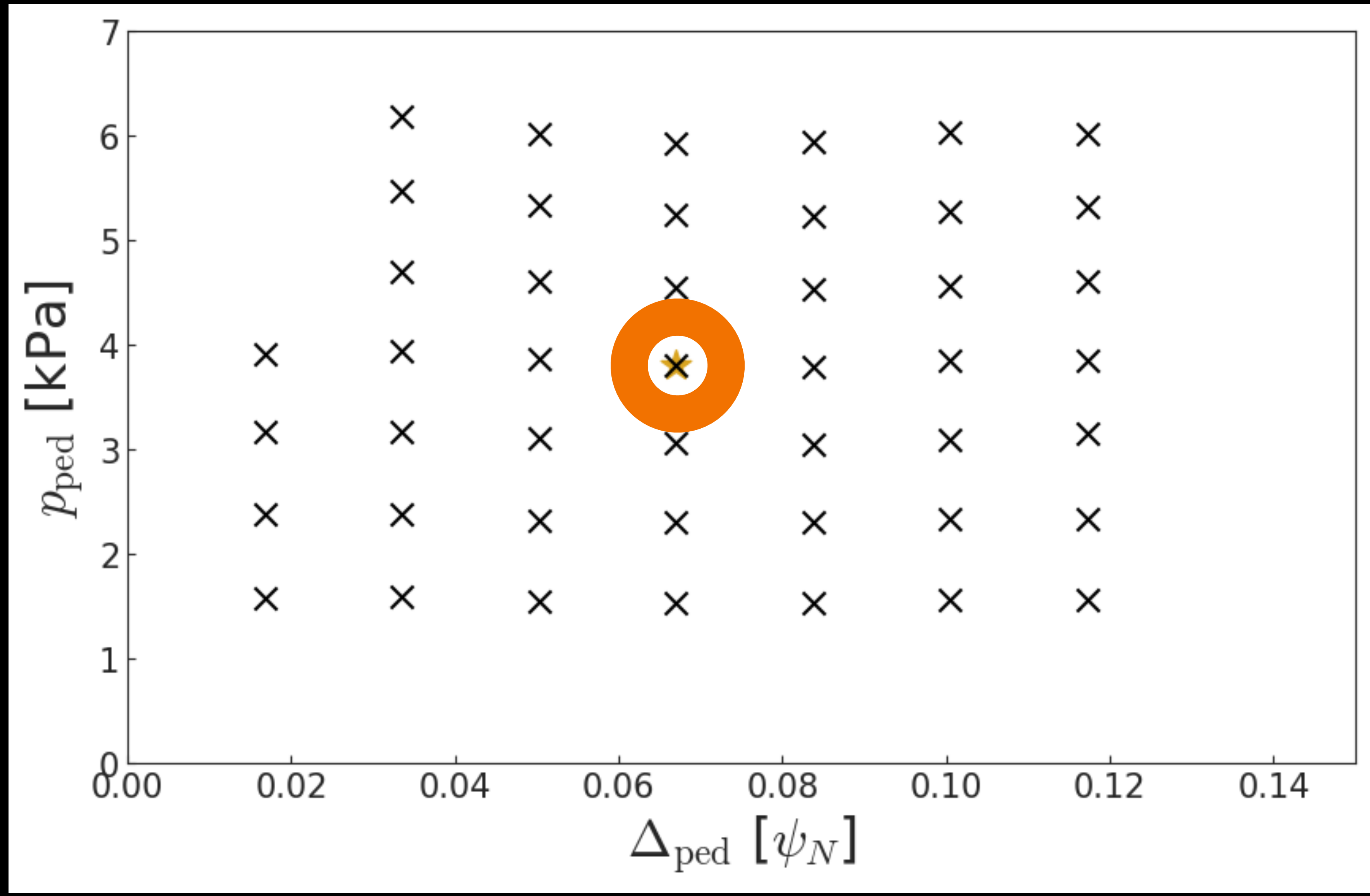




Finding the Gyrokinetic Critical Pedestal (GCP)

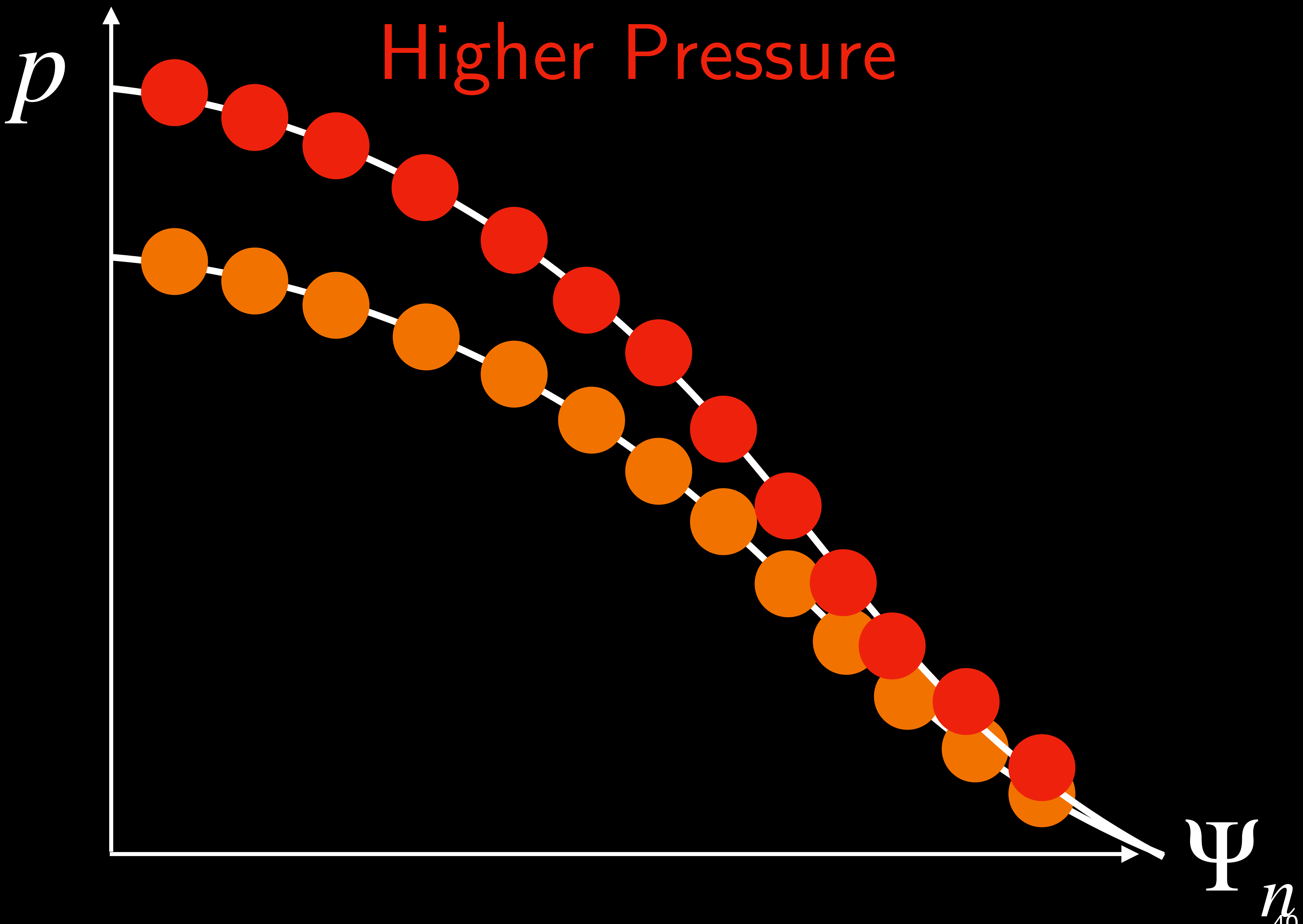
If all modes across half-width are unstable to same instability —> **pedestal GCP unstable**

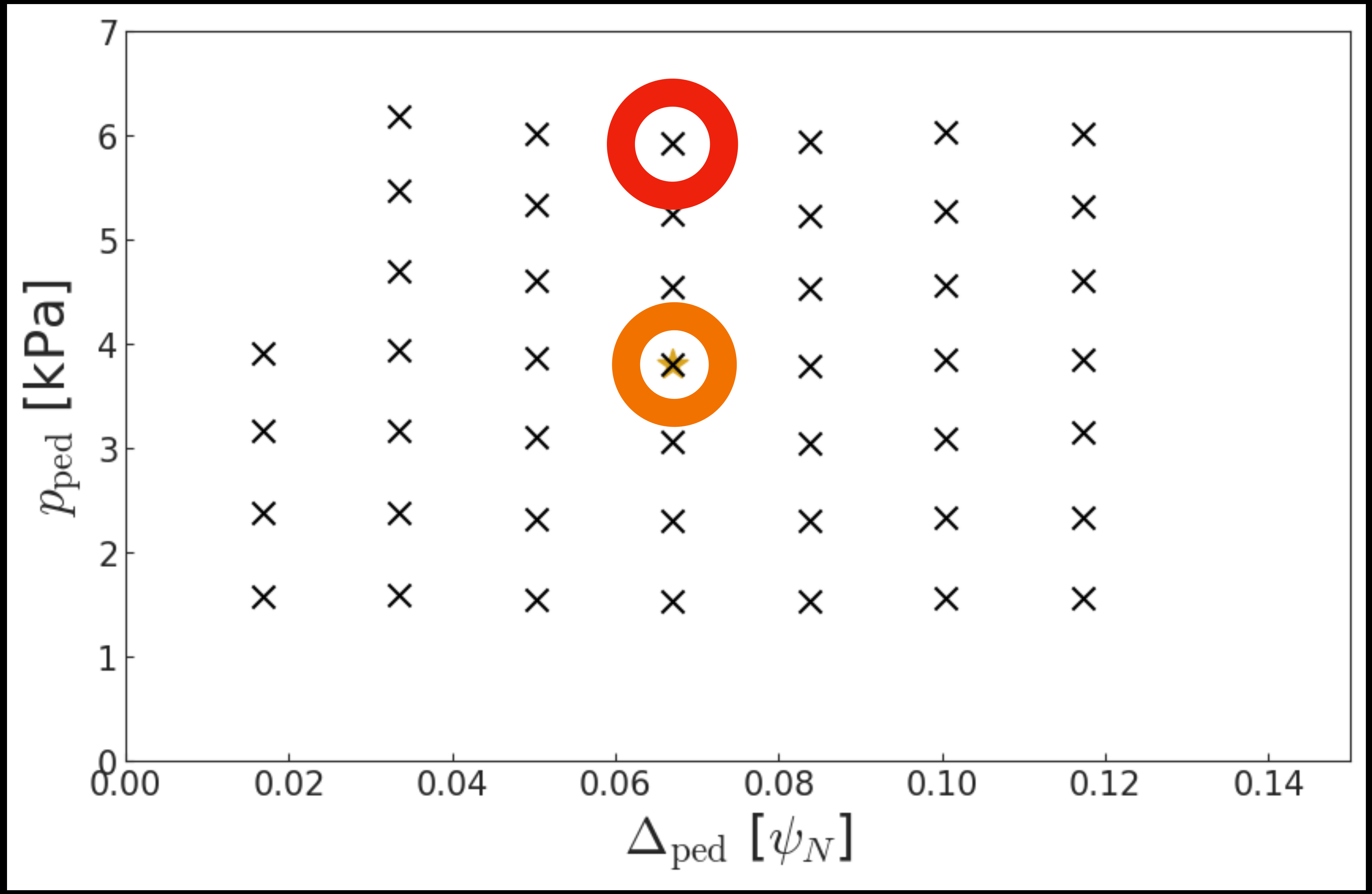




Finding the Gyrokinetic Critical Pedestal (GCP)

Pedestal Height Scan





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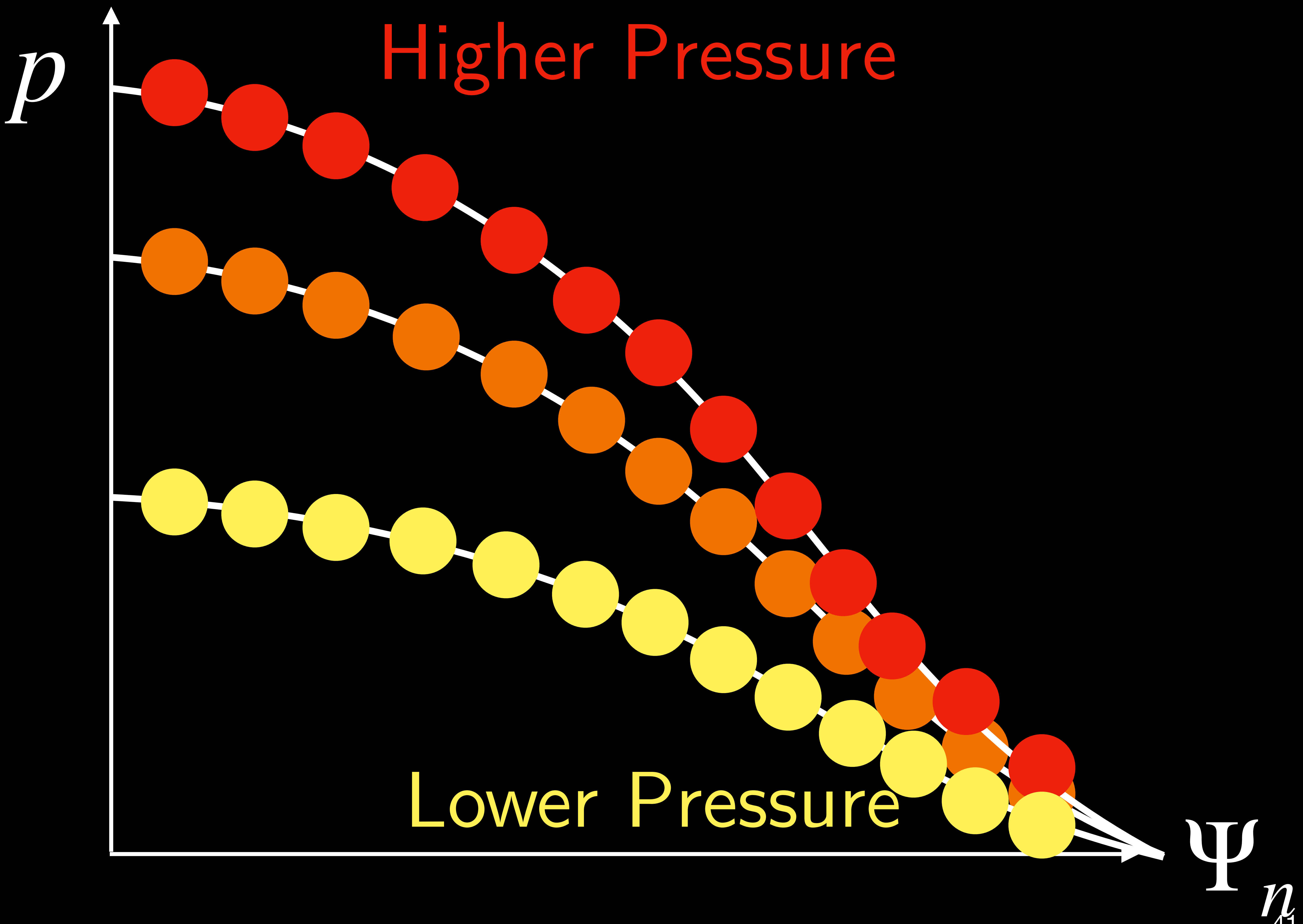
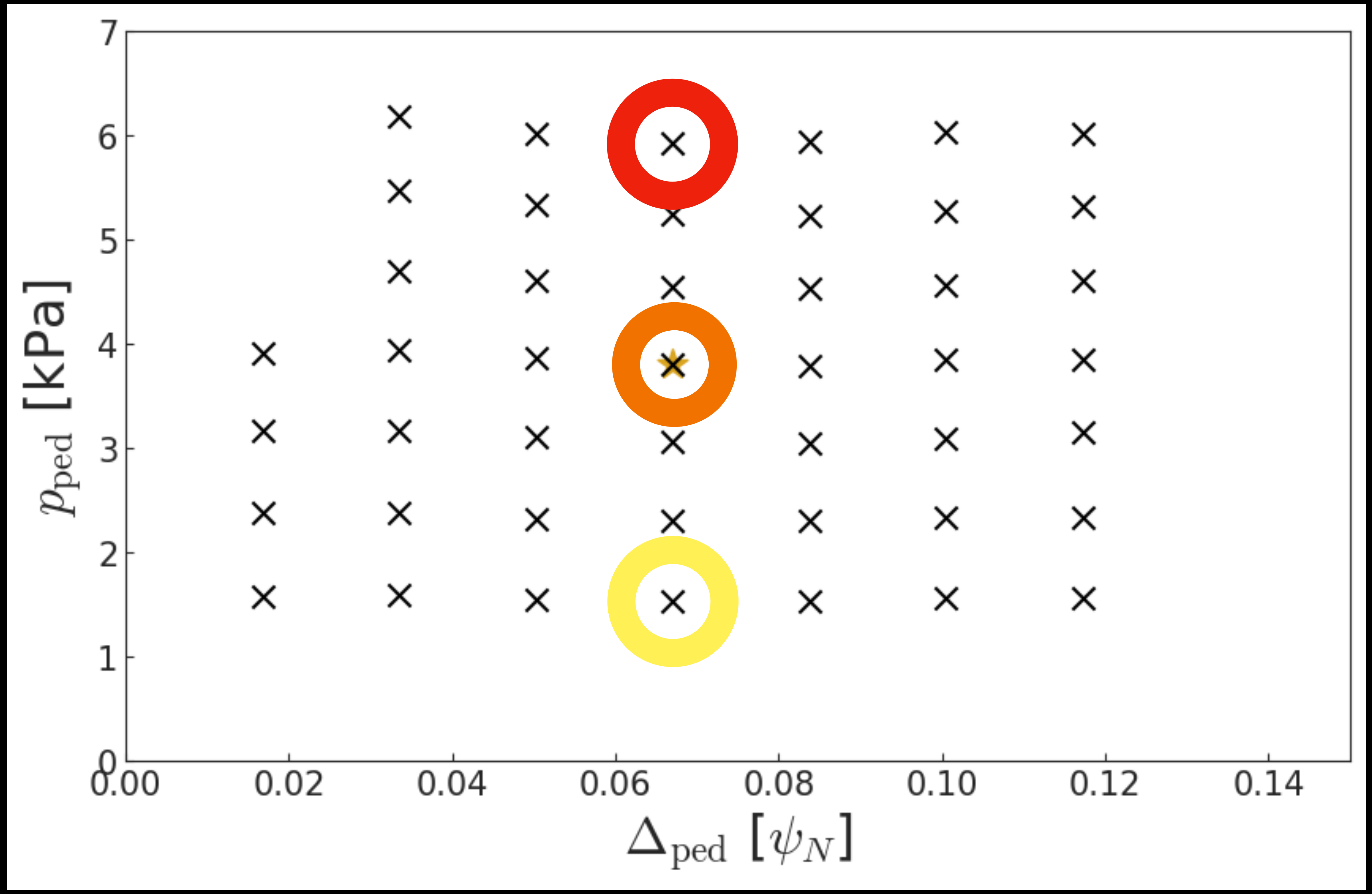
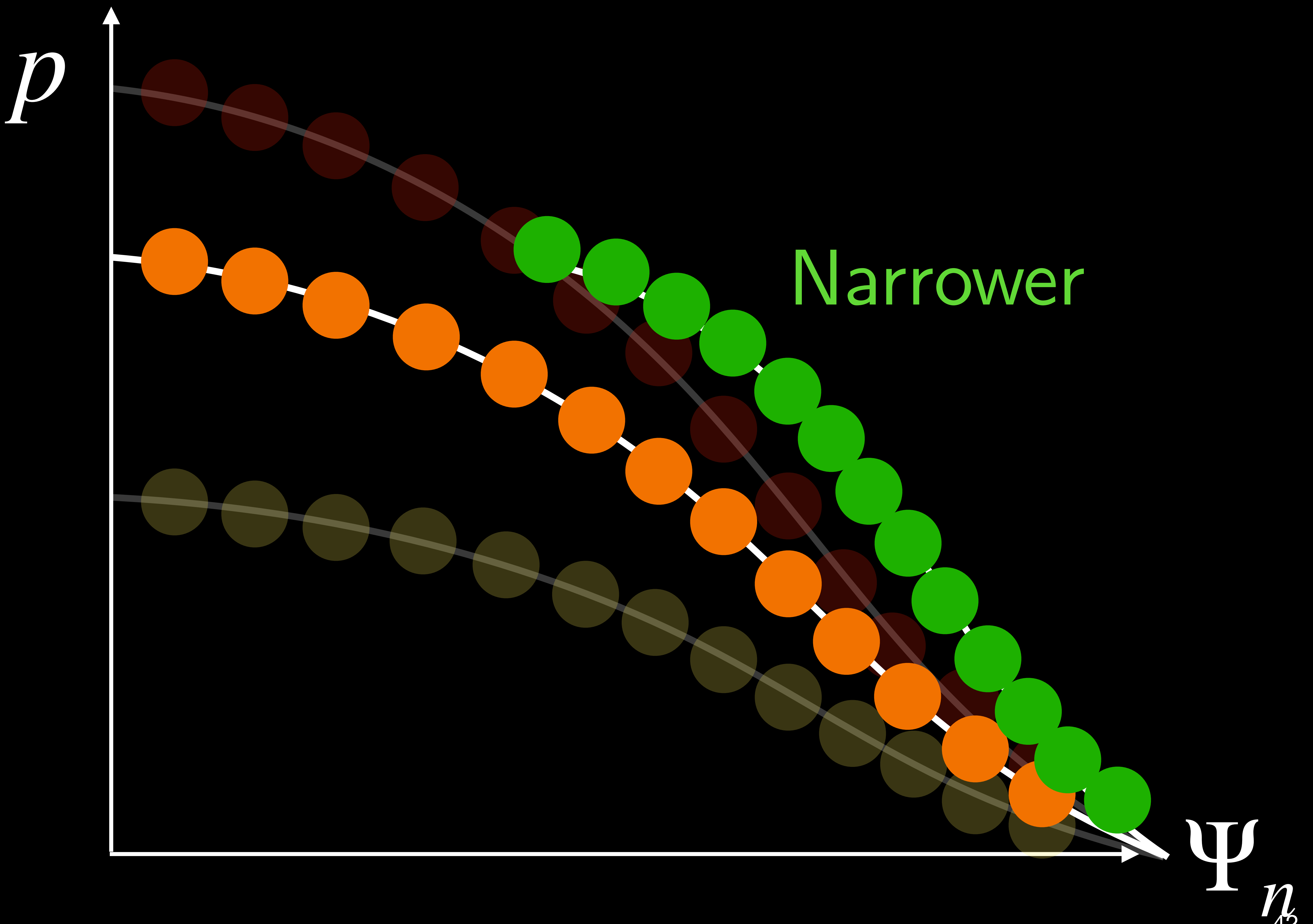
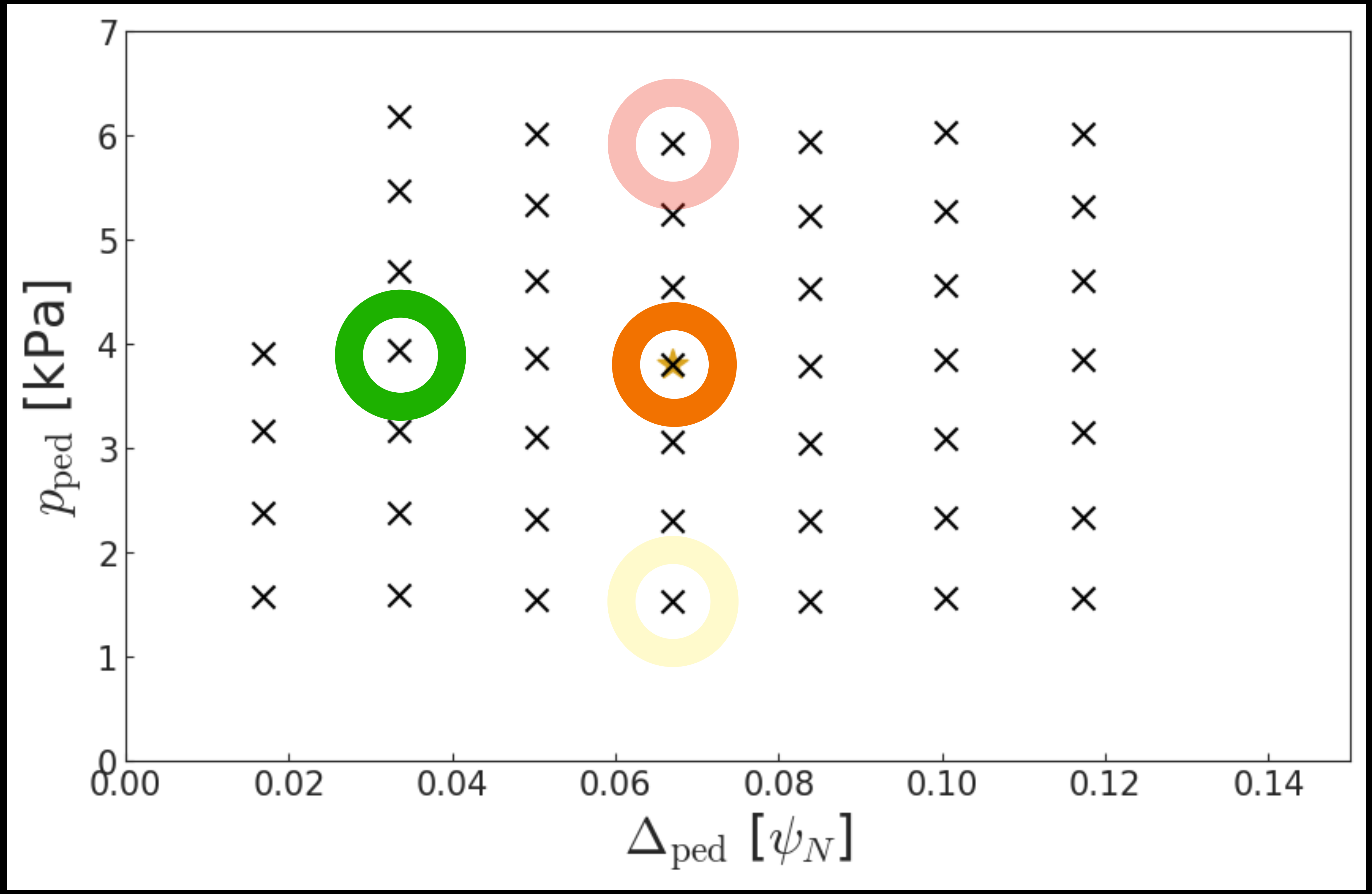




Finding the Gyrokinetic Critical Pedestal (GCP)

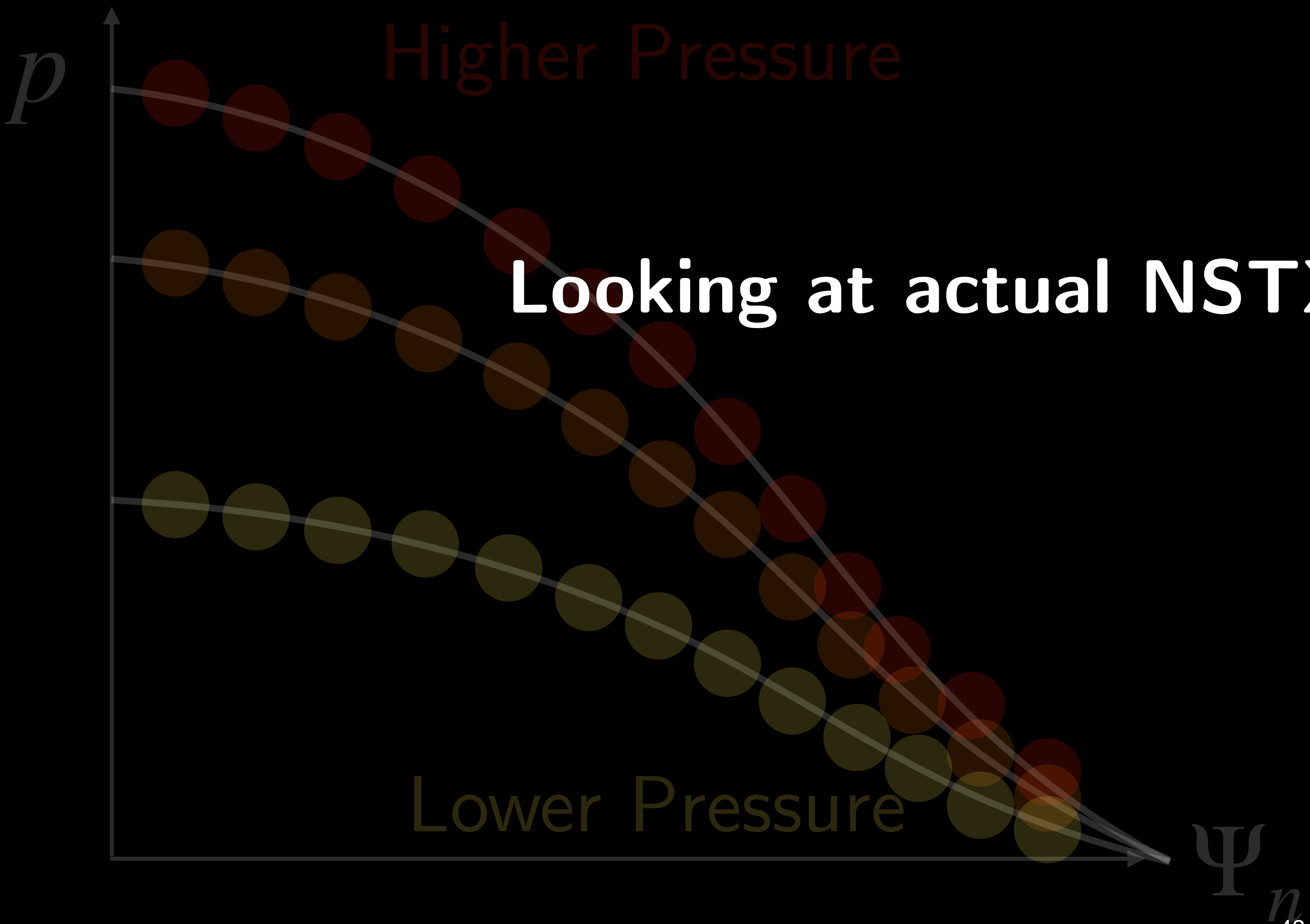
Pedestal Width Scan

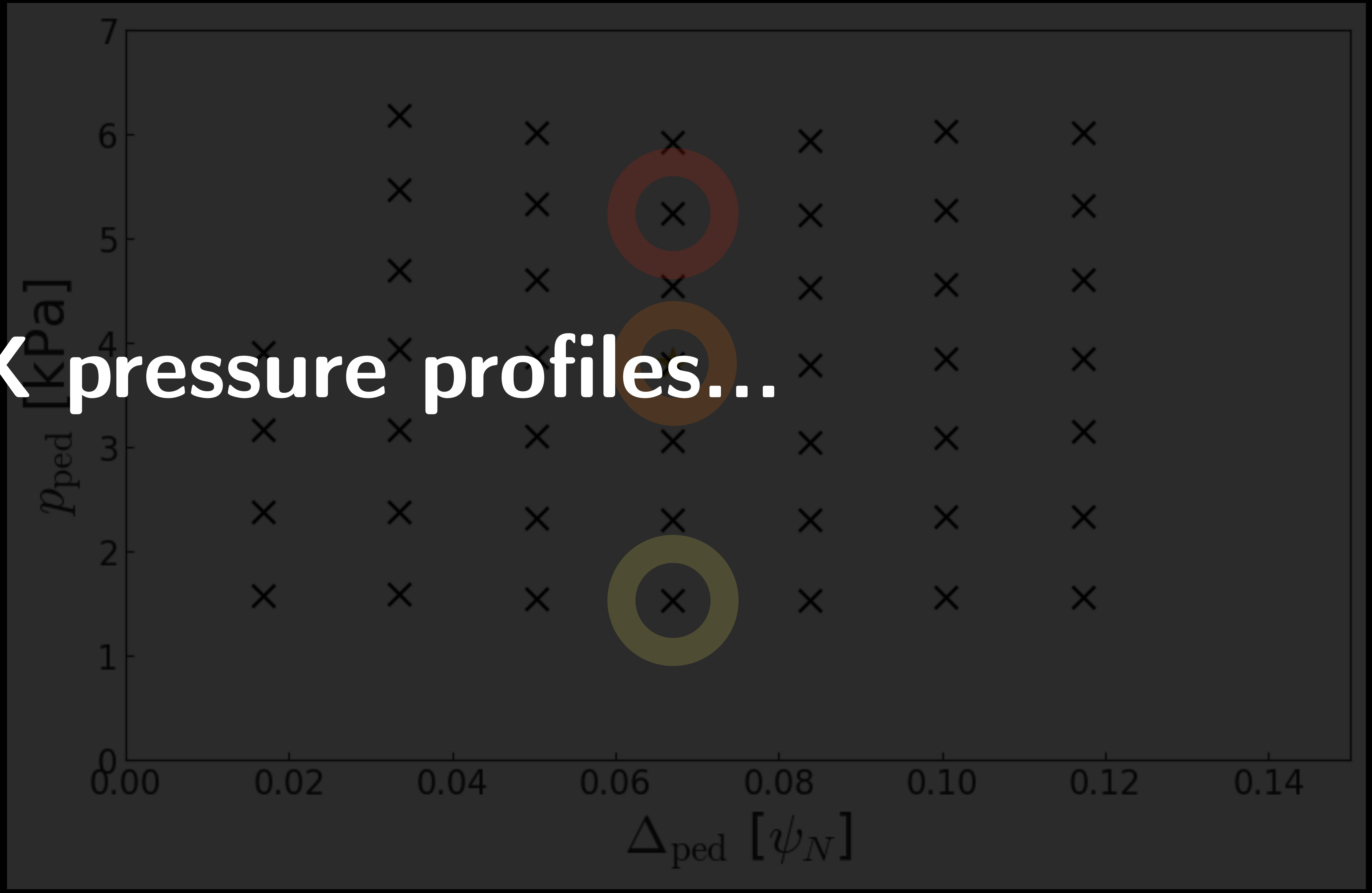




Finding the Gyrokinetic Critical Pedestal (GCP)

Pedestal Height Scan



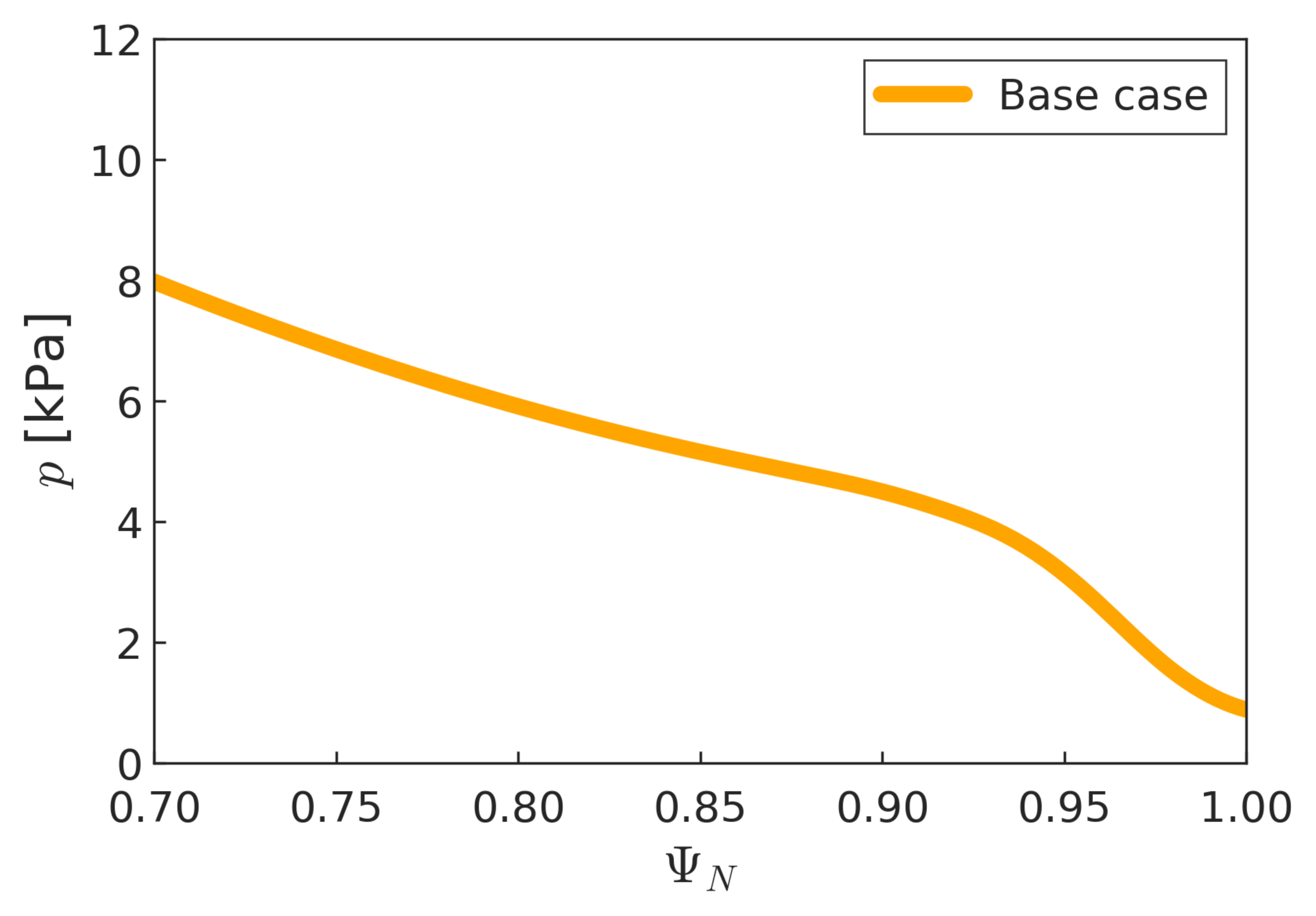


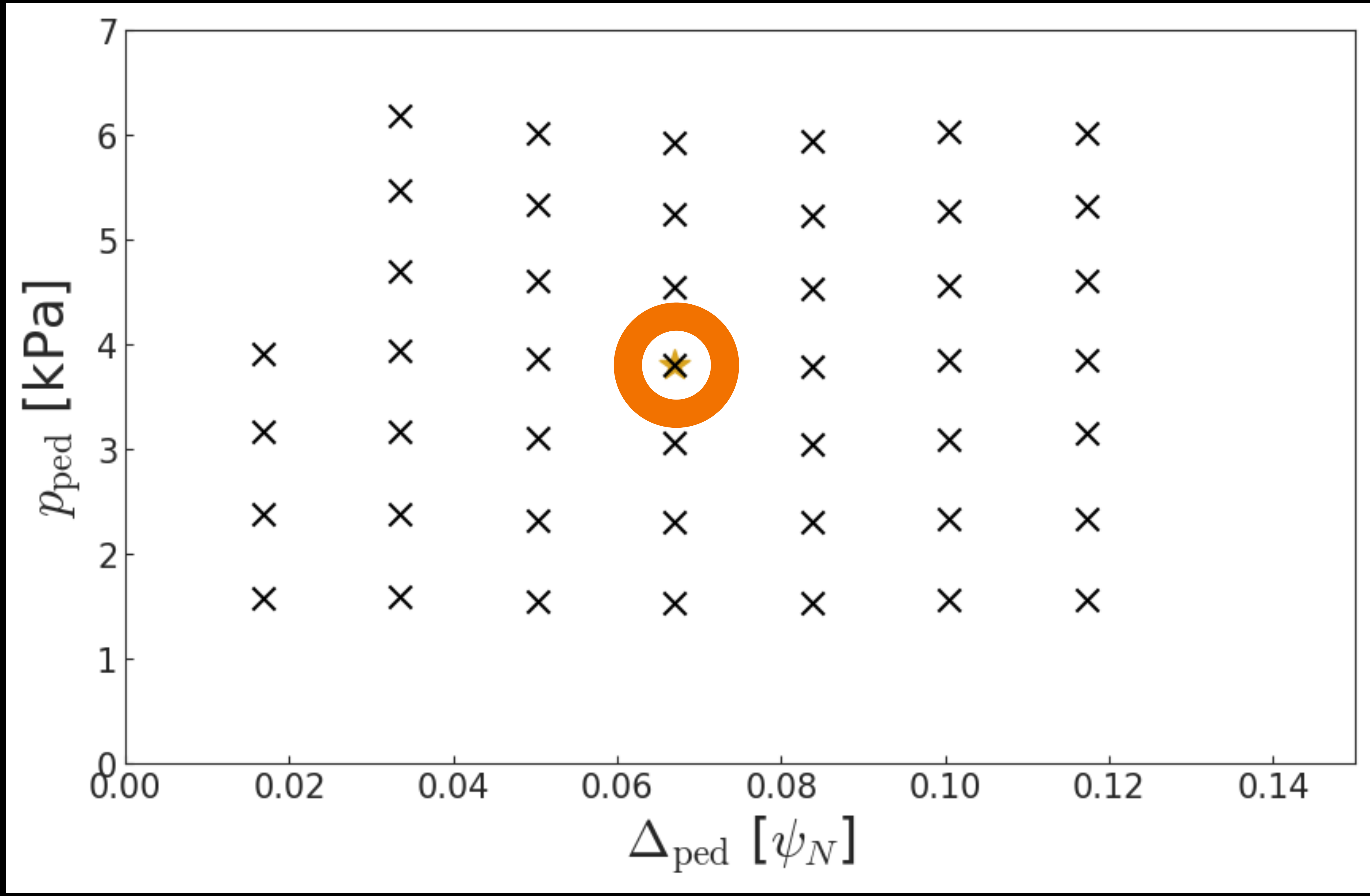
Looking at actual NSTX pressure profiles...

Finding the Gyrokinetic Critical Pedestal (GCP)

Pedestal Height Scan

Base case NSTX 132543 pressure profile

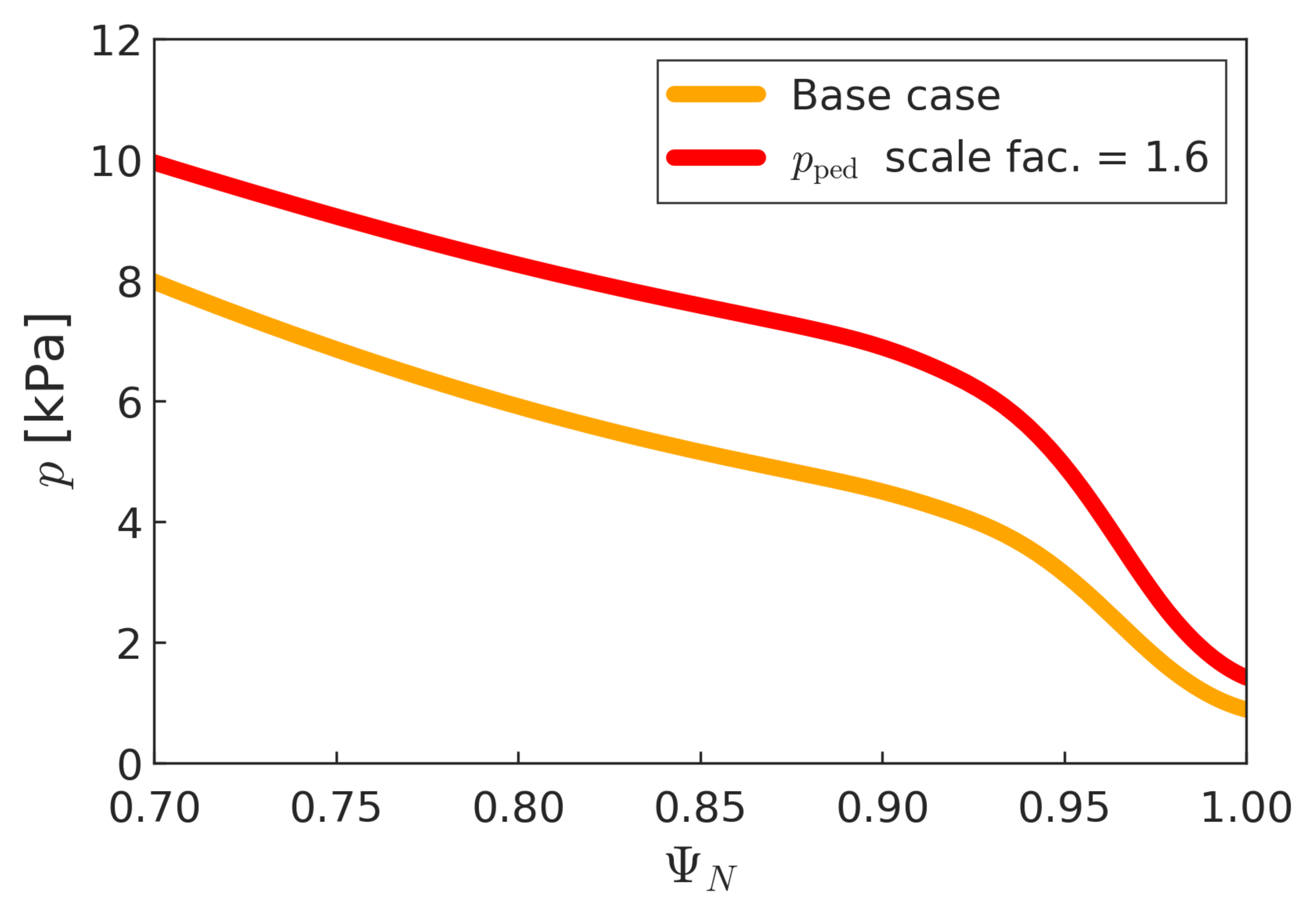


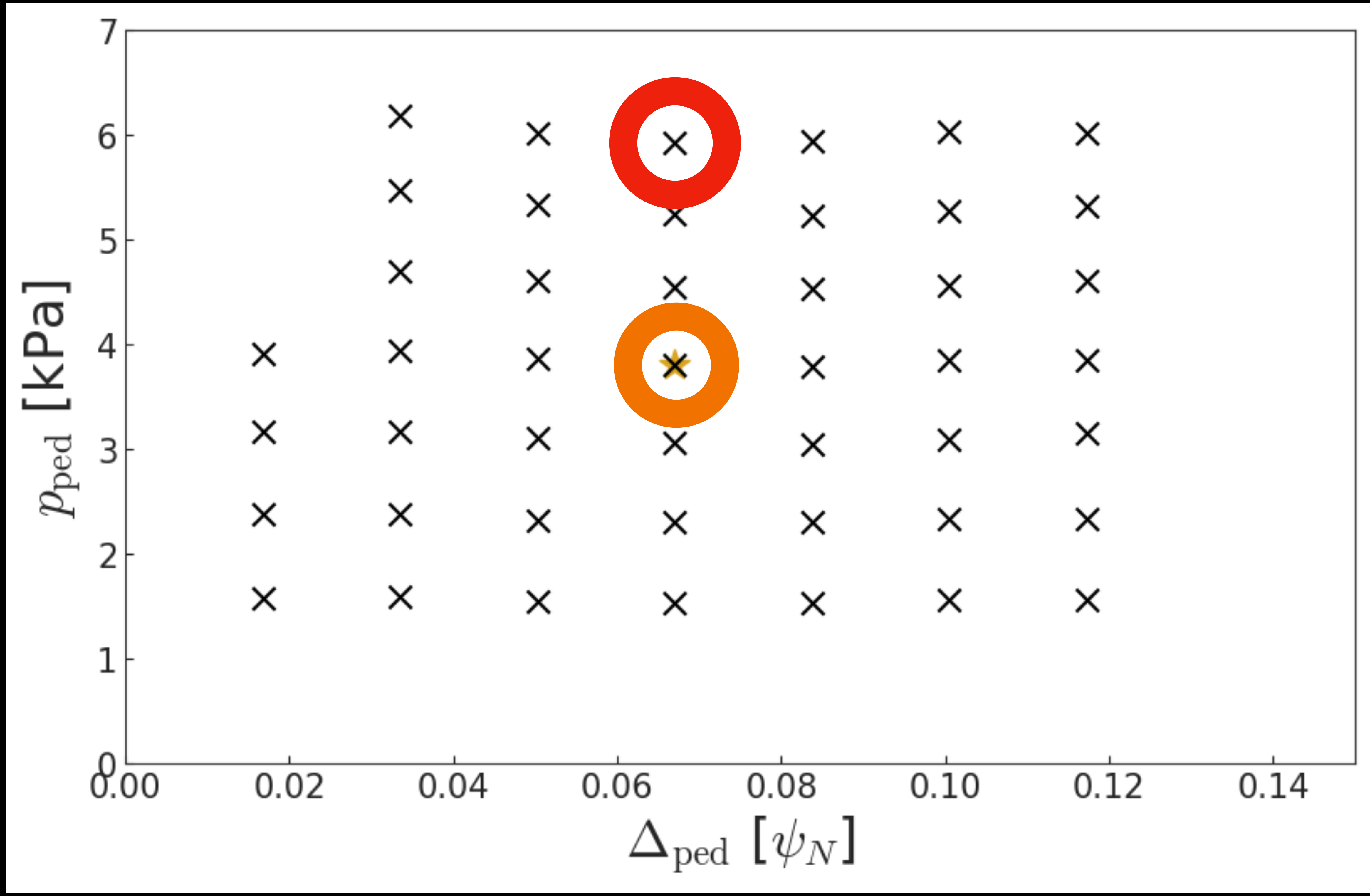


Finding the Gyrokinetic Critical Pedestal (GCP)

Pedestal Height Scan

$1.6 \times p_{\text{ped}}$ rescaling

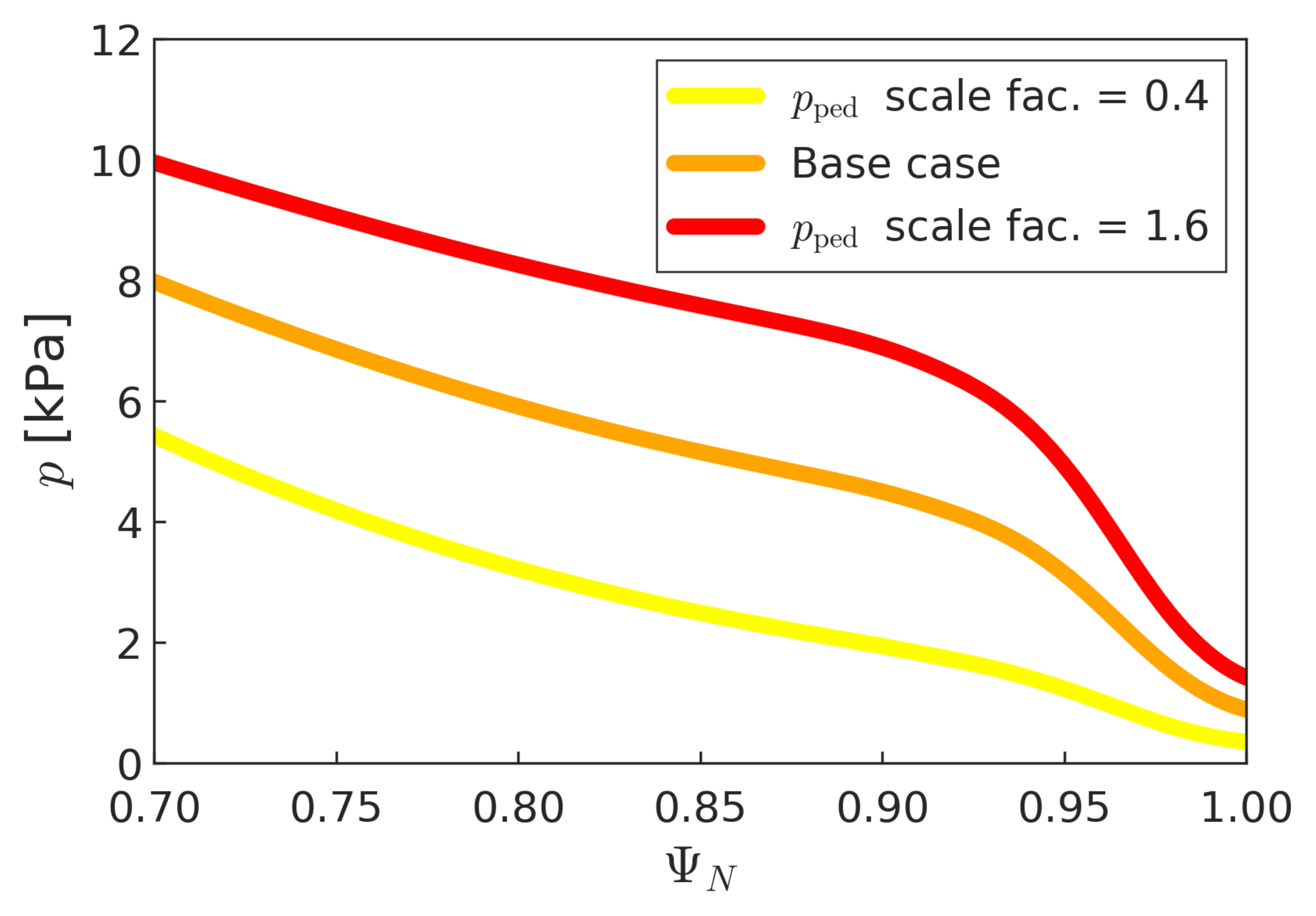


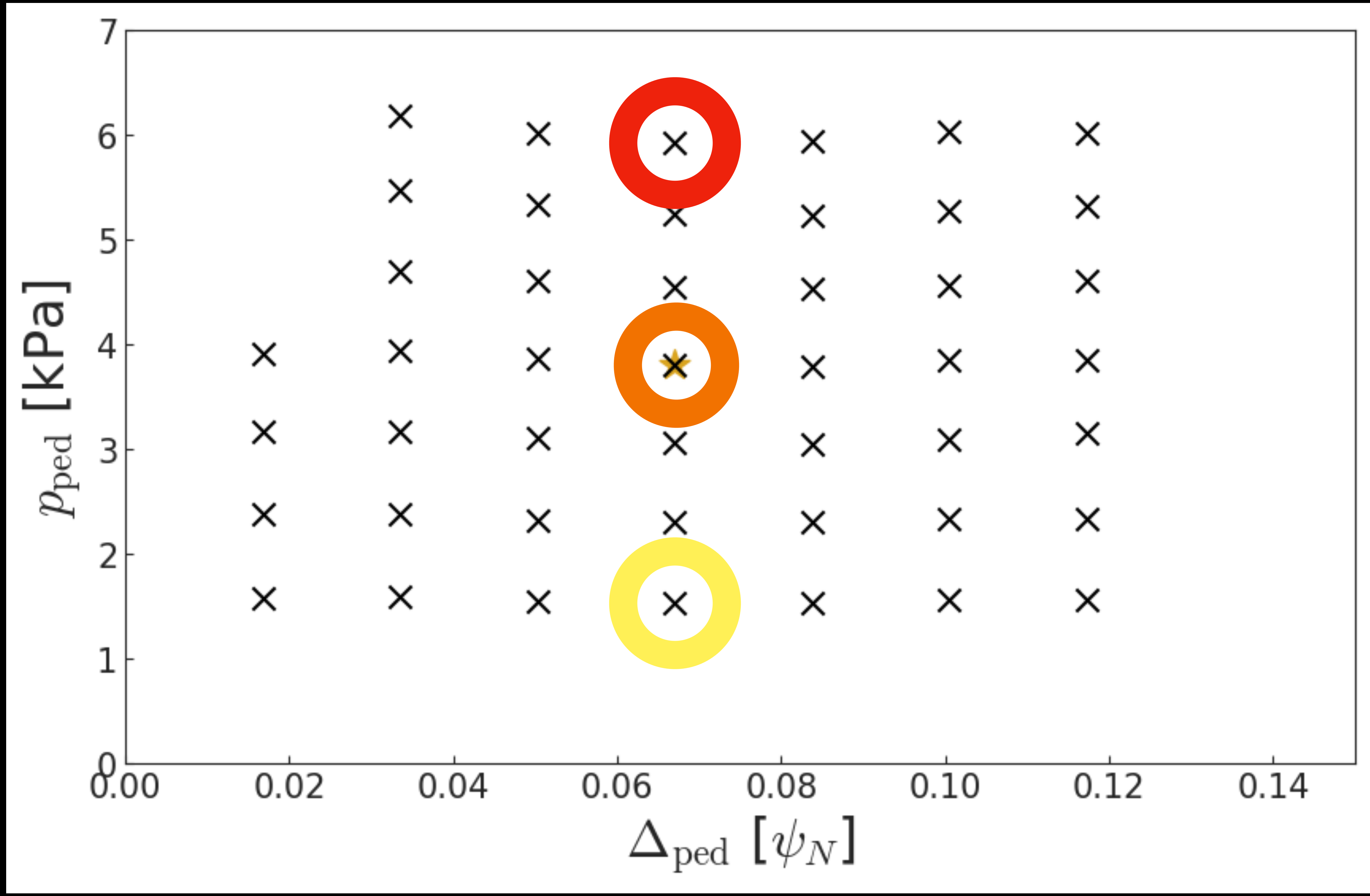


Finding the Gyrokinetic Critical Pedestal (GCP)

Pedestal Height Scan

$0.4 \times p_{ped}$ rescaling



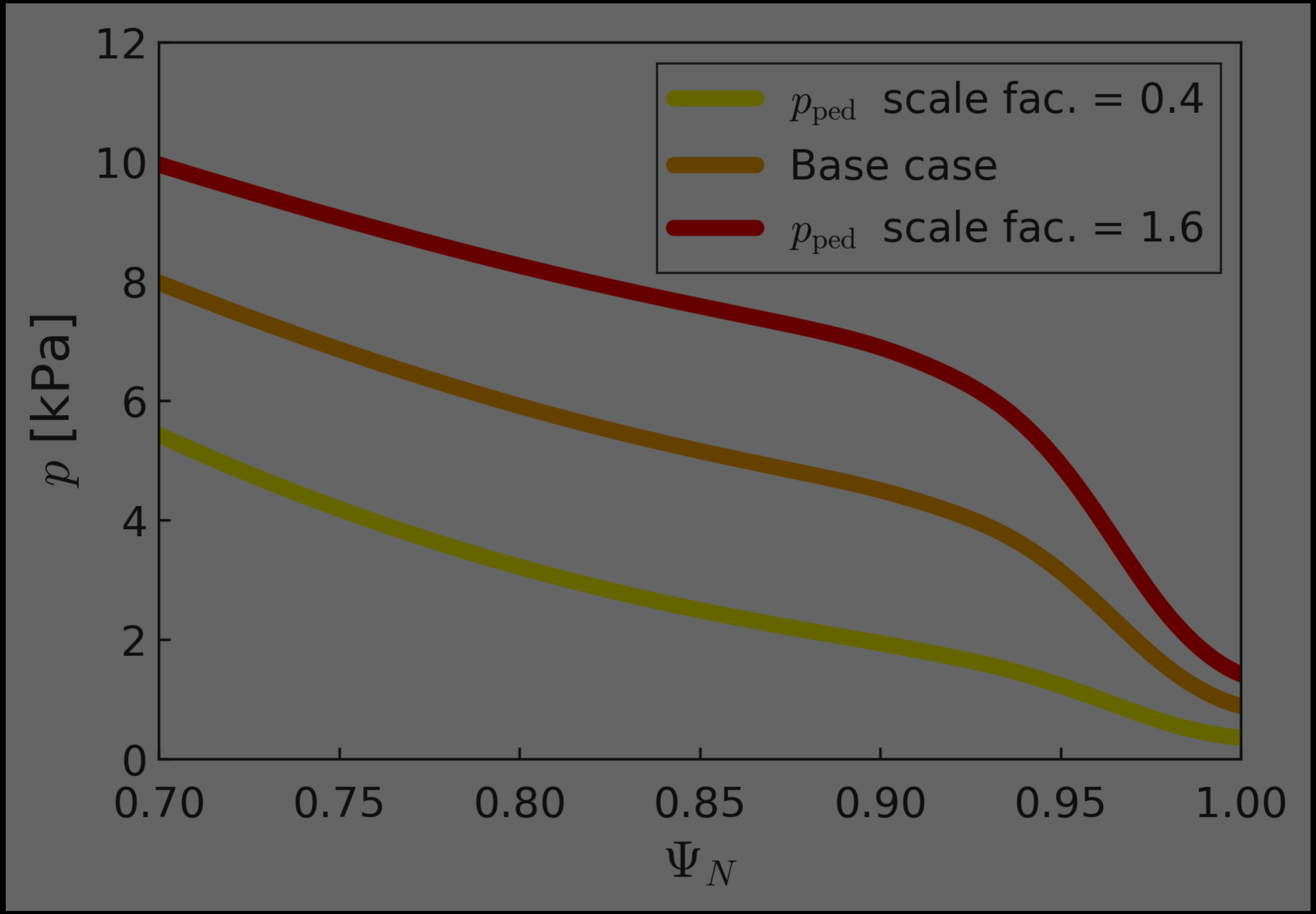


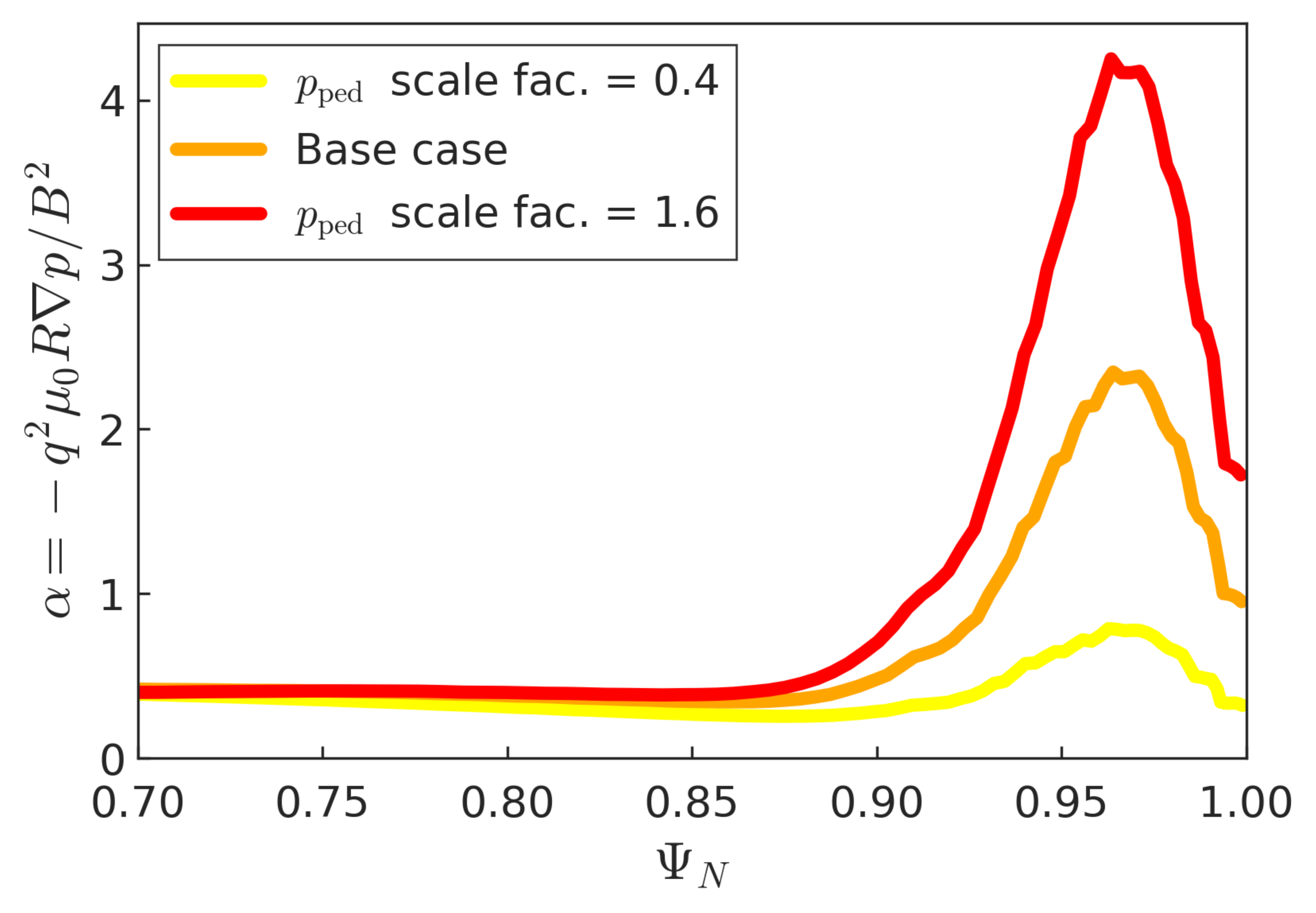
Finding the Gyrokinetic Critical Pedestal (GCP)

Pedestal Height Scan

rescale α —>

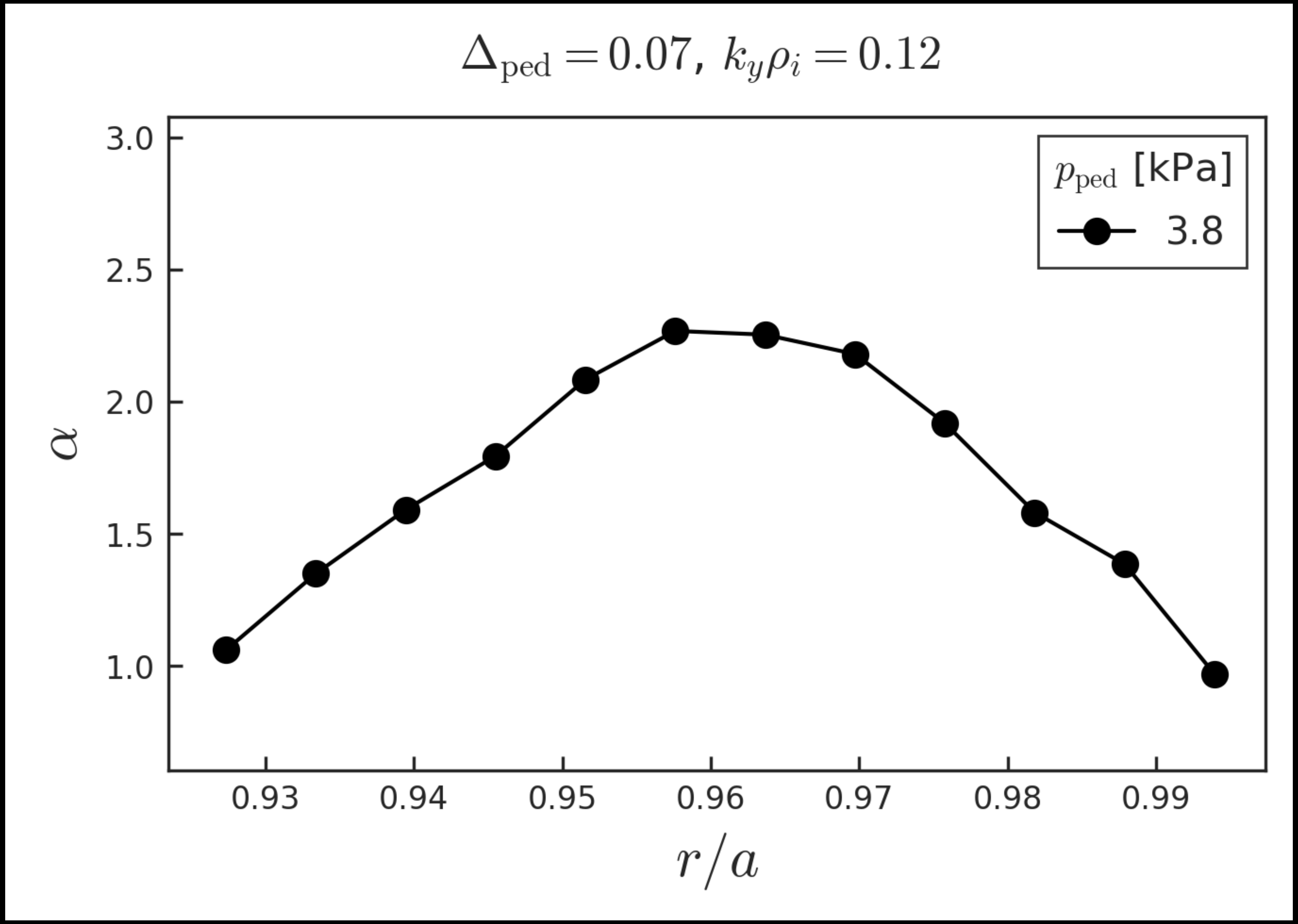
KBM stability changes





Finding the Gyrokinetic Critical Pedestal (GCP)

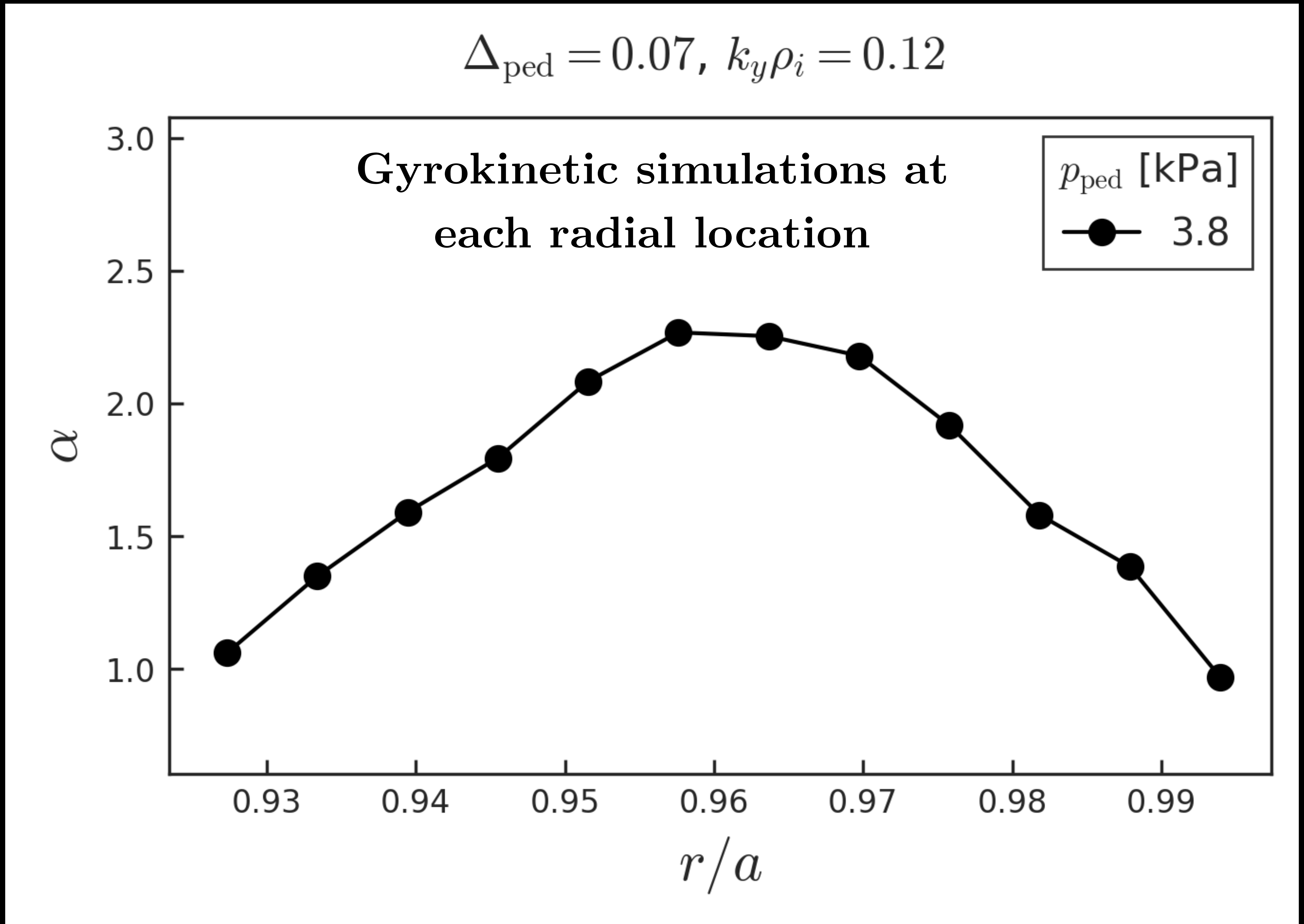
- α versus r/a for NSTX 132543 equilibrium.



$$\alpha = -q^2\mu_0 R \nabla P / B^2$$

Finding the Gyrokinetic Critical Pedestal (GCP)

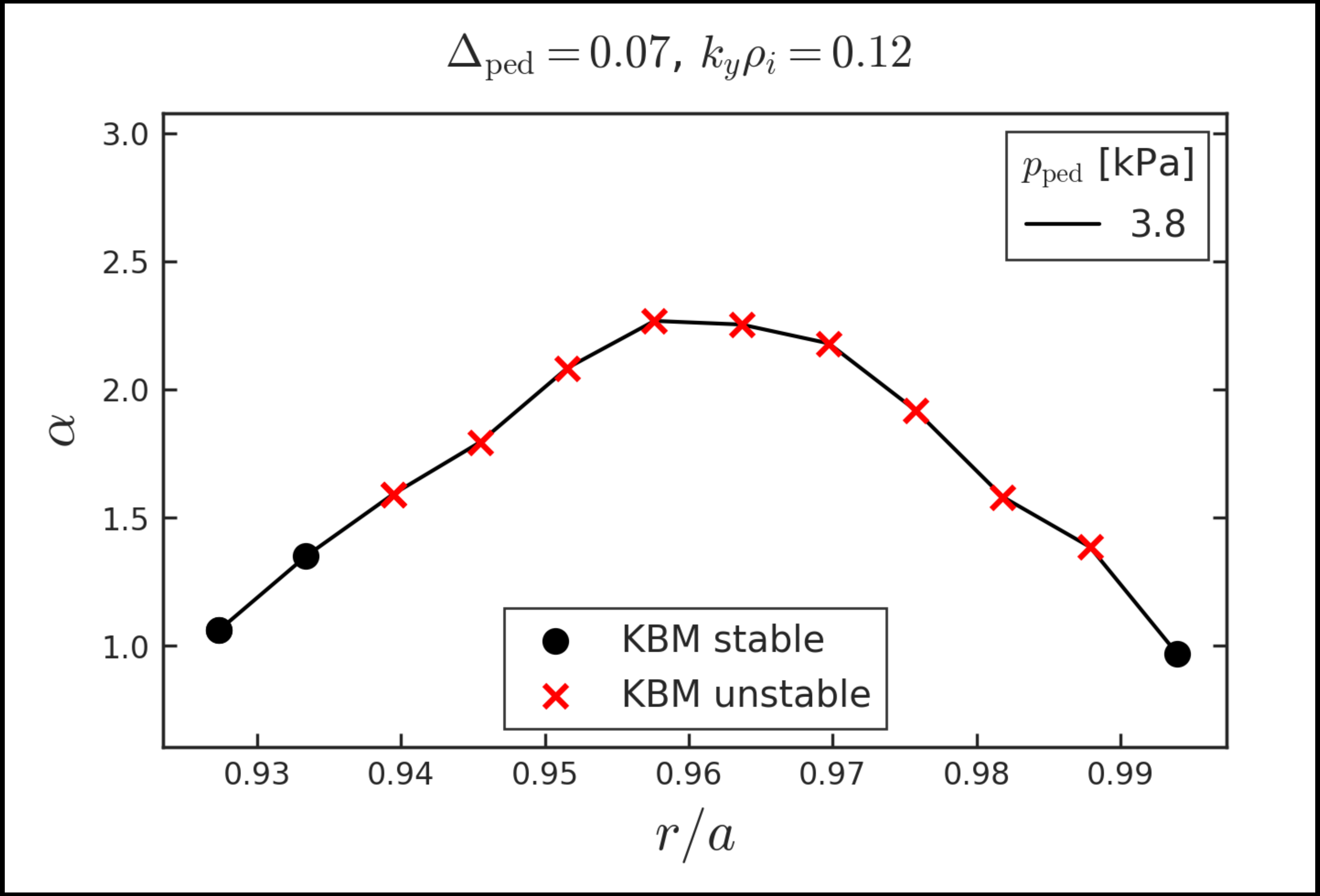
- α versus r/a for NSTX 132543 equilibrium.



$$\alpha = -q^2 \mu_0 R \nabla P / B^2$$

Finding the Gyrokinetic Critical Pedestal (GCP)

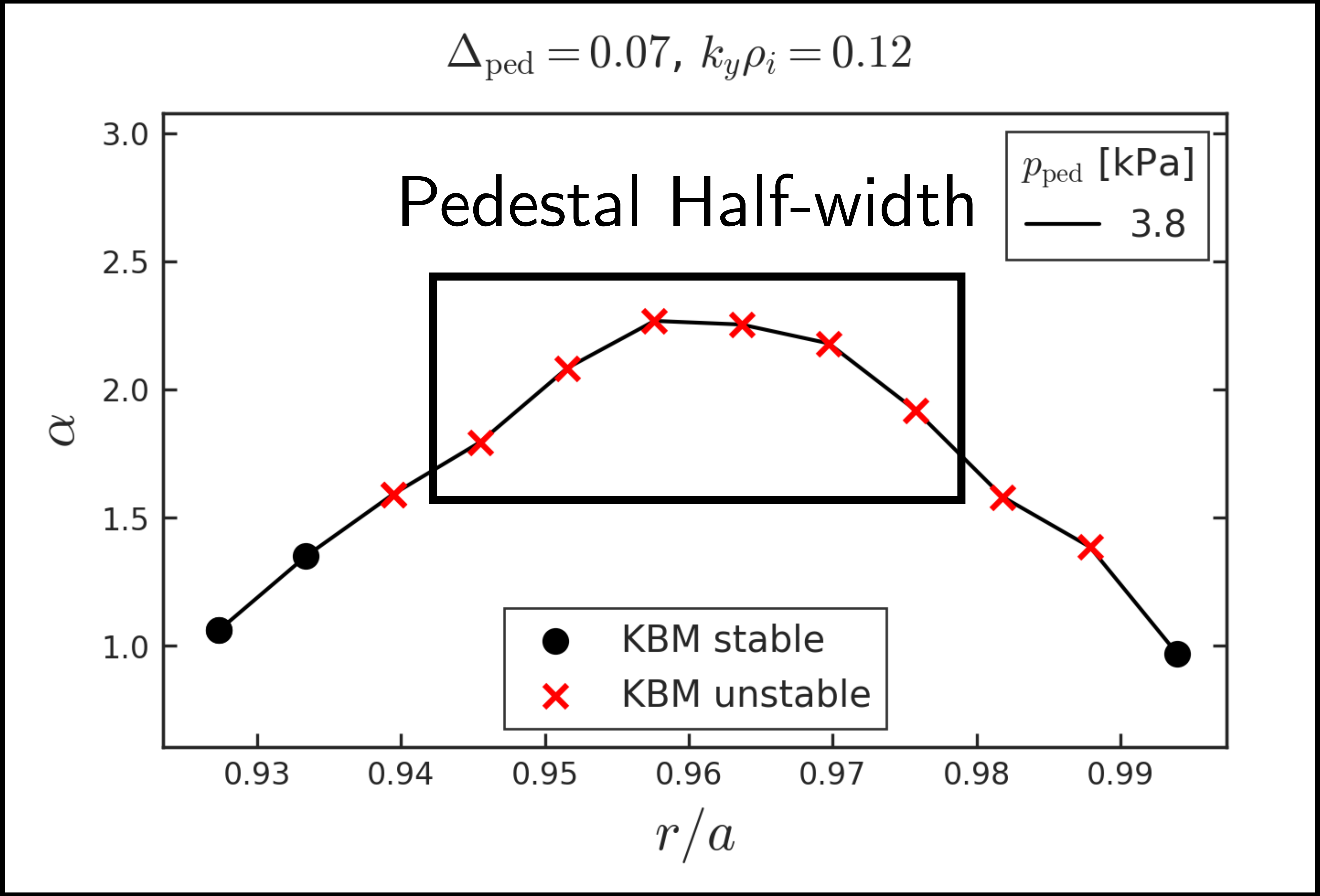
- α versus r/a for NSTX 132543 equilibrium.
- KBM unstable?



$$\alpha = -q^2 \mu_0 R \nabla P / B^2$$

Finding the Gyrokinetic Critical Pedestal (GCP)

- α versus r/a for NSTX 132543 equilibrium.
- **Pedestal GCP unstable to KBM!**

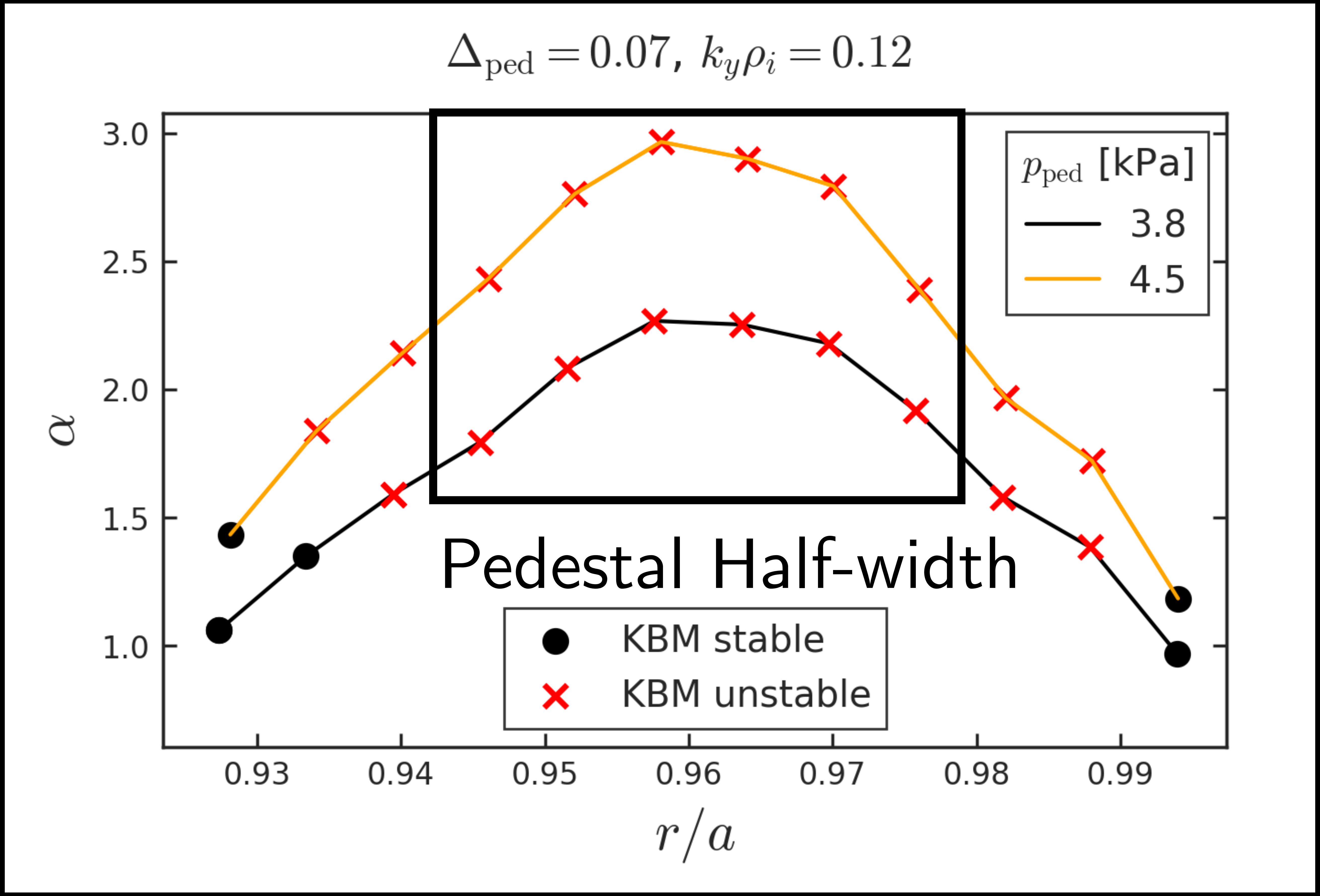


$$\alpha = -q^2 \mu_0 R \nabla P / B^2$$

Finding the Gyrokinetic Critical Pedestal (GCP)

Pedestal Pressure Buildup

- α versus r/a for NSTX 132543 equilibrium.
- Add larger p_{ped} profile.

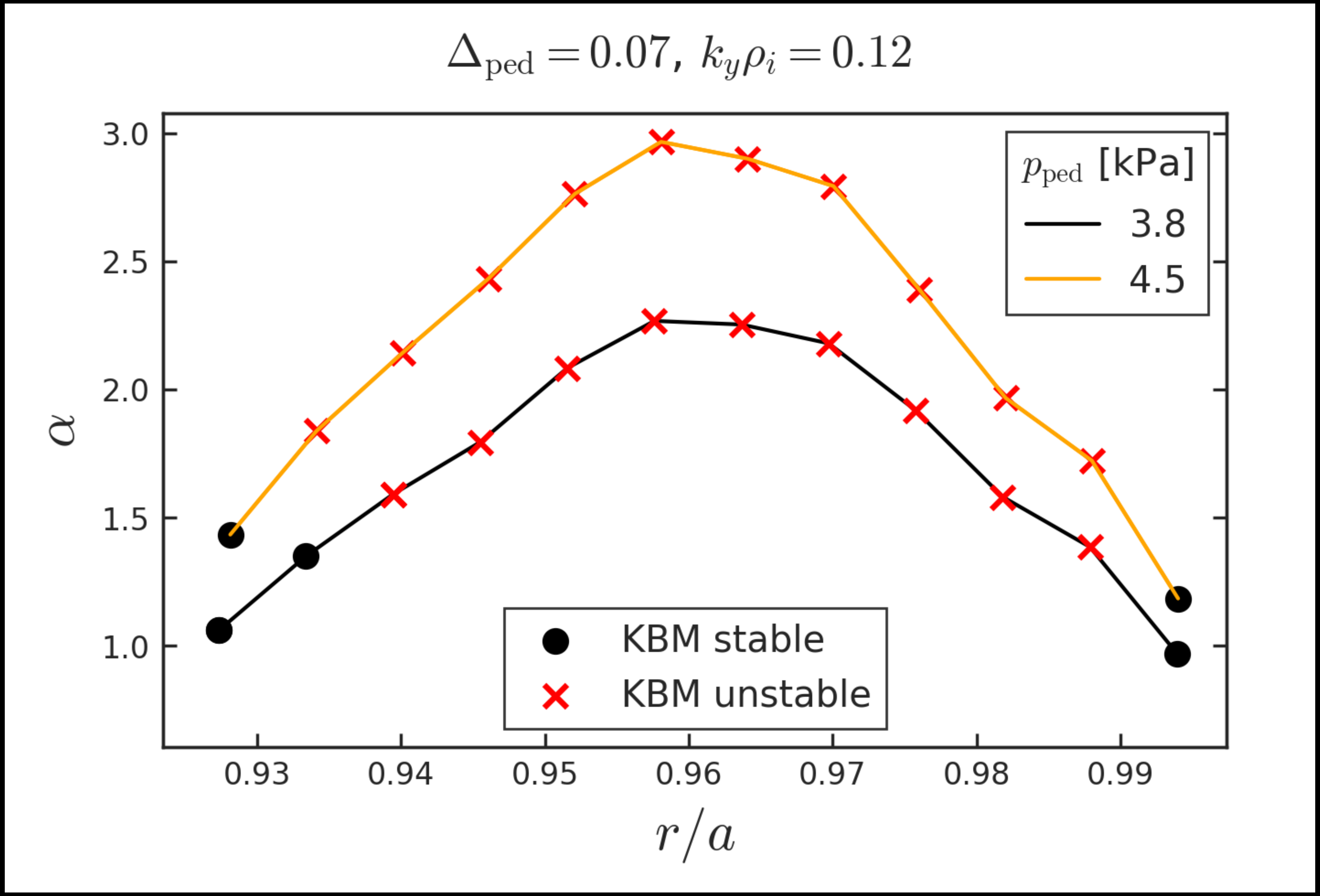


$$\alpha = -q^2 \mu_0 R \nabla P / B^2$$

Finding the Gyrokinetic Critical Pedestal (GCP)

Pedestal Pressure Buildup

- α versus r/a for NSTX 132543 equilibrium.
- Add larger p_{ped} profile.
- Both profiles GCP unstable to KBM.

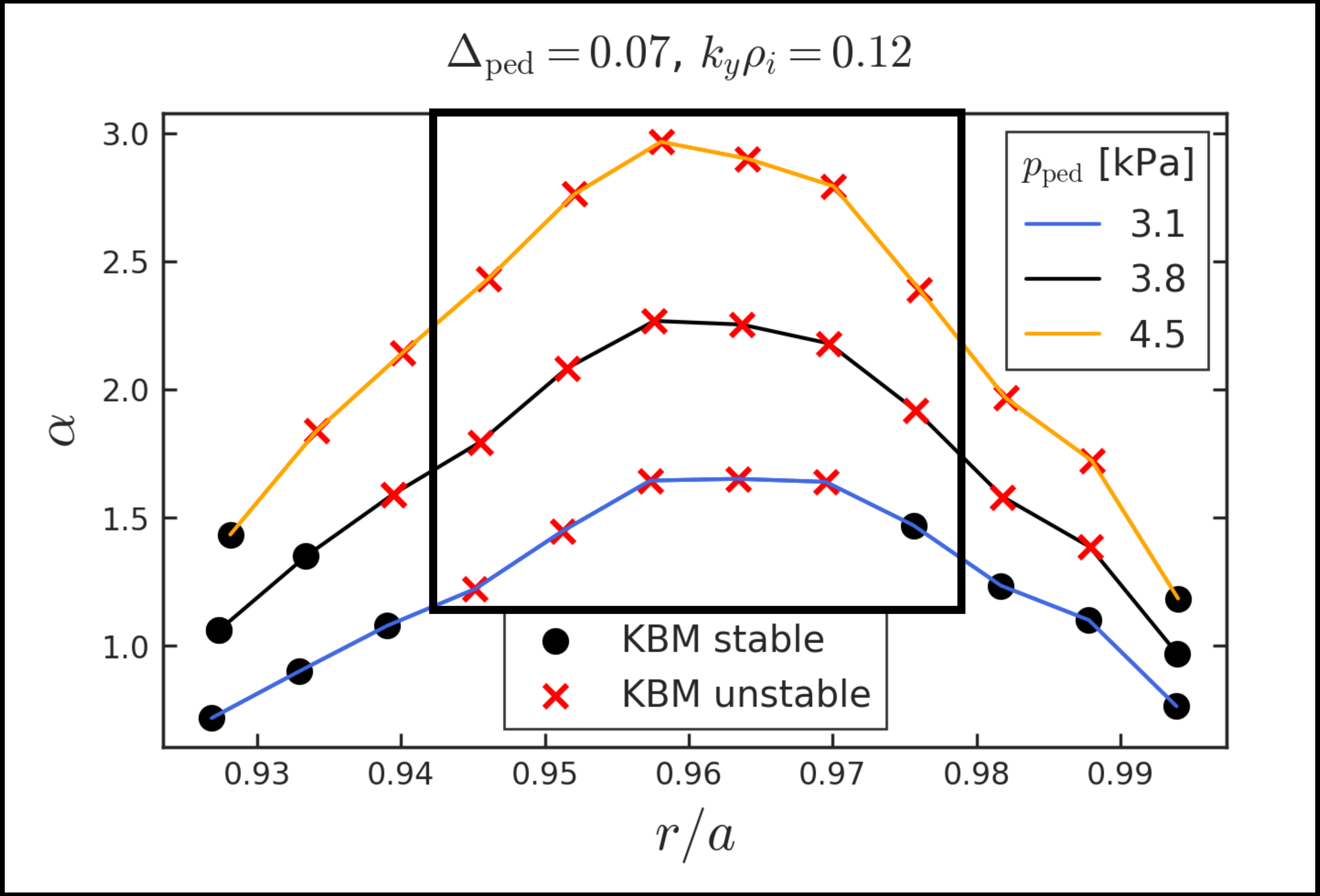


$$\alpha = -q^2 \mu_0 R \nabla P / B^2$$

Finding the Gyrokinetic Critical Pedestal (GCP)

Pedestal Pressure Buildup

- α versus r/a for NSTX 132543 equilibrium.
- Add larger p_{ped} profile.
- Both profiles GCP unstable to KBM.
- Add smaller p_{ped} profile.
- **Smaller p_{ped} GCP stable.**

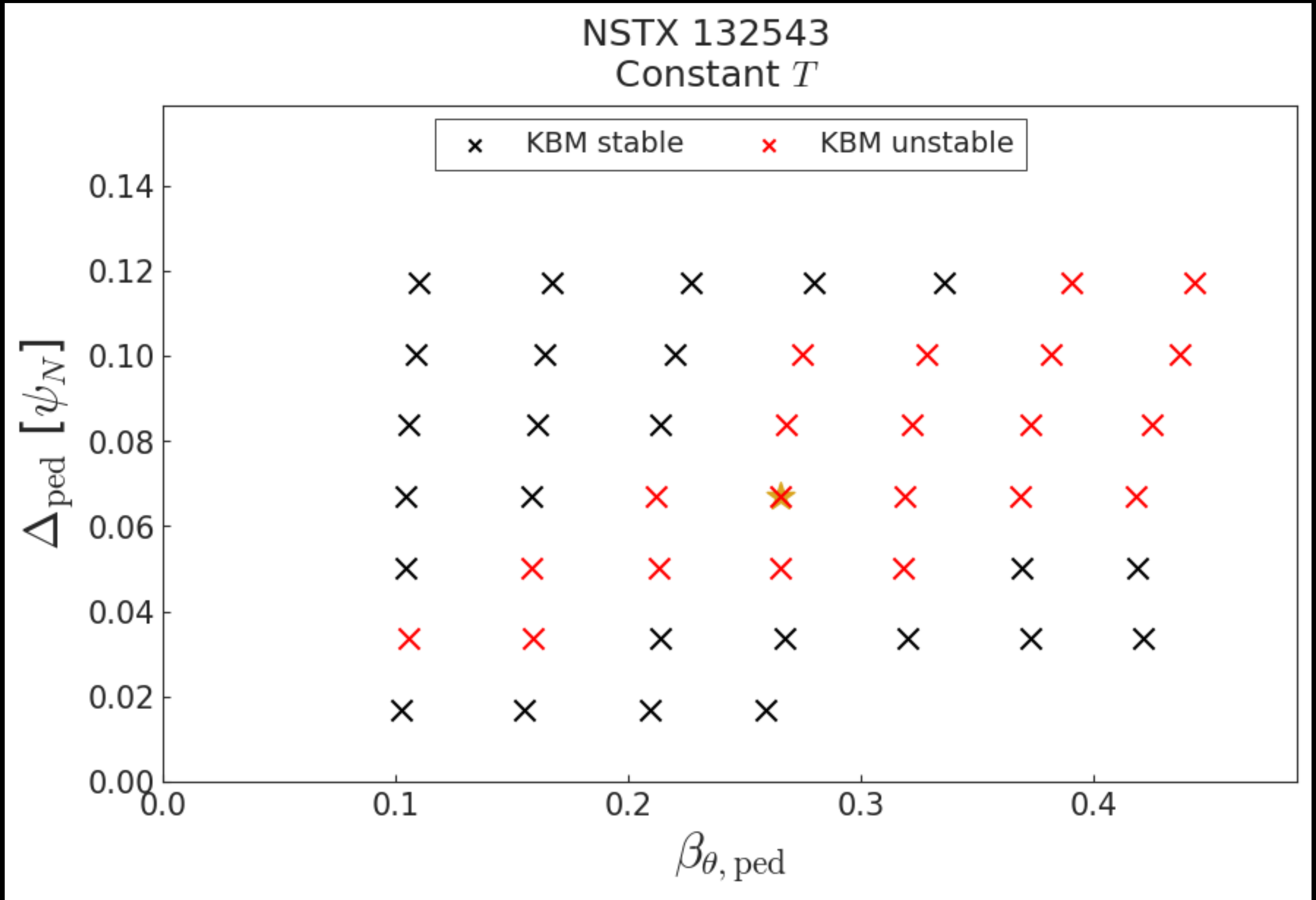


$$\alpha = -q^2\mu_0 R \nabla P / B^2$$

Kinetic, Ideal Comparison

Gyrokinetics

- KBM stability from CGYRO gyrokinetic calculation for NSTX discharge 132543.

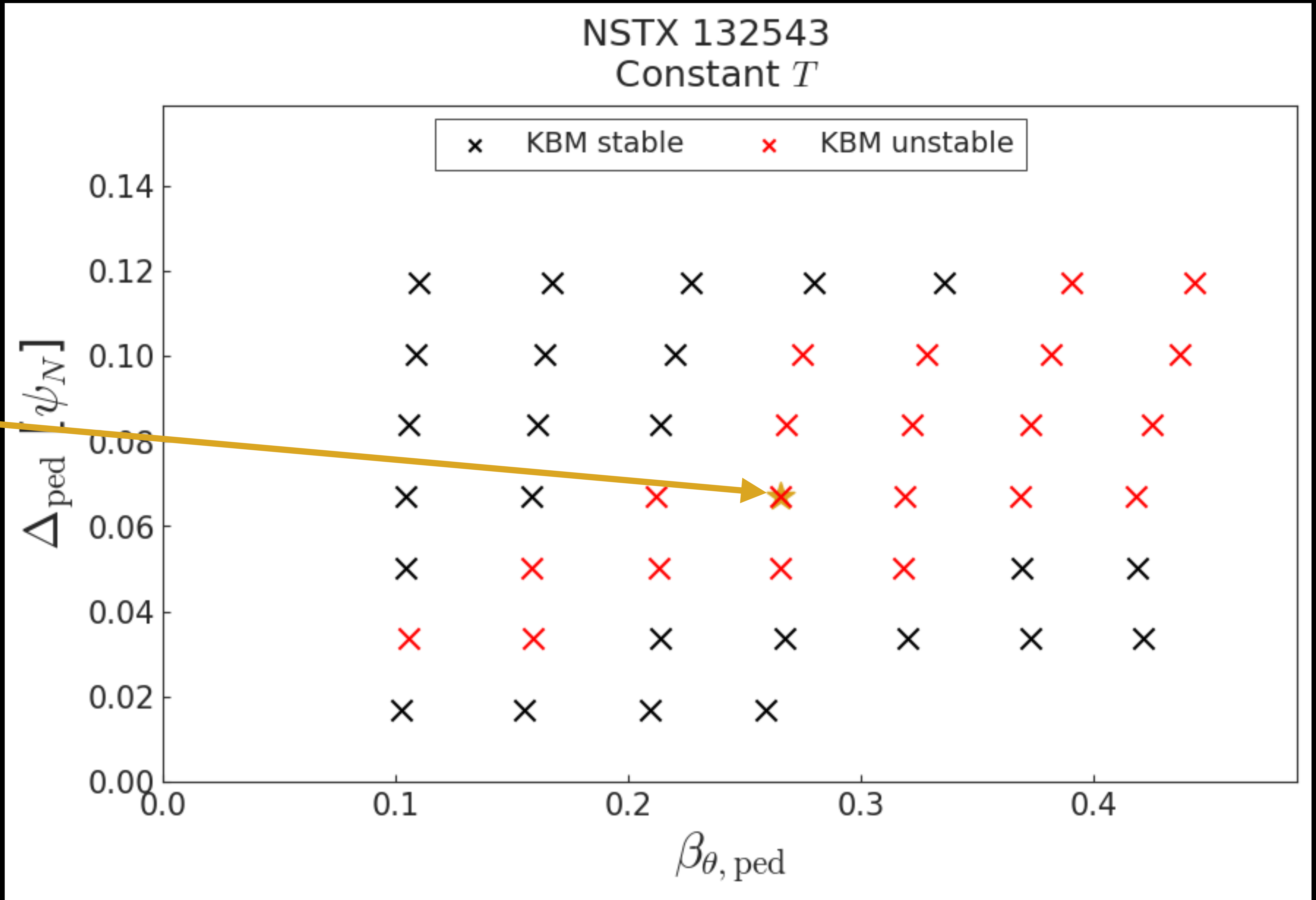


Kinetic, Ideal Comparison

Gyrokinetics

- KBM stability from CGYRO gyrokinetic calculation for NSTX discharge 132543.

- **Experimental point**



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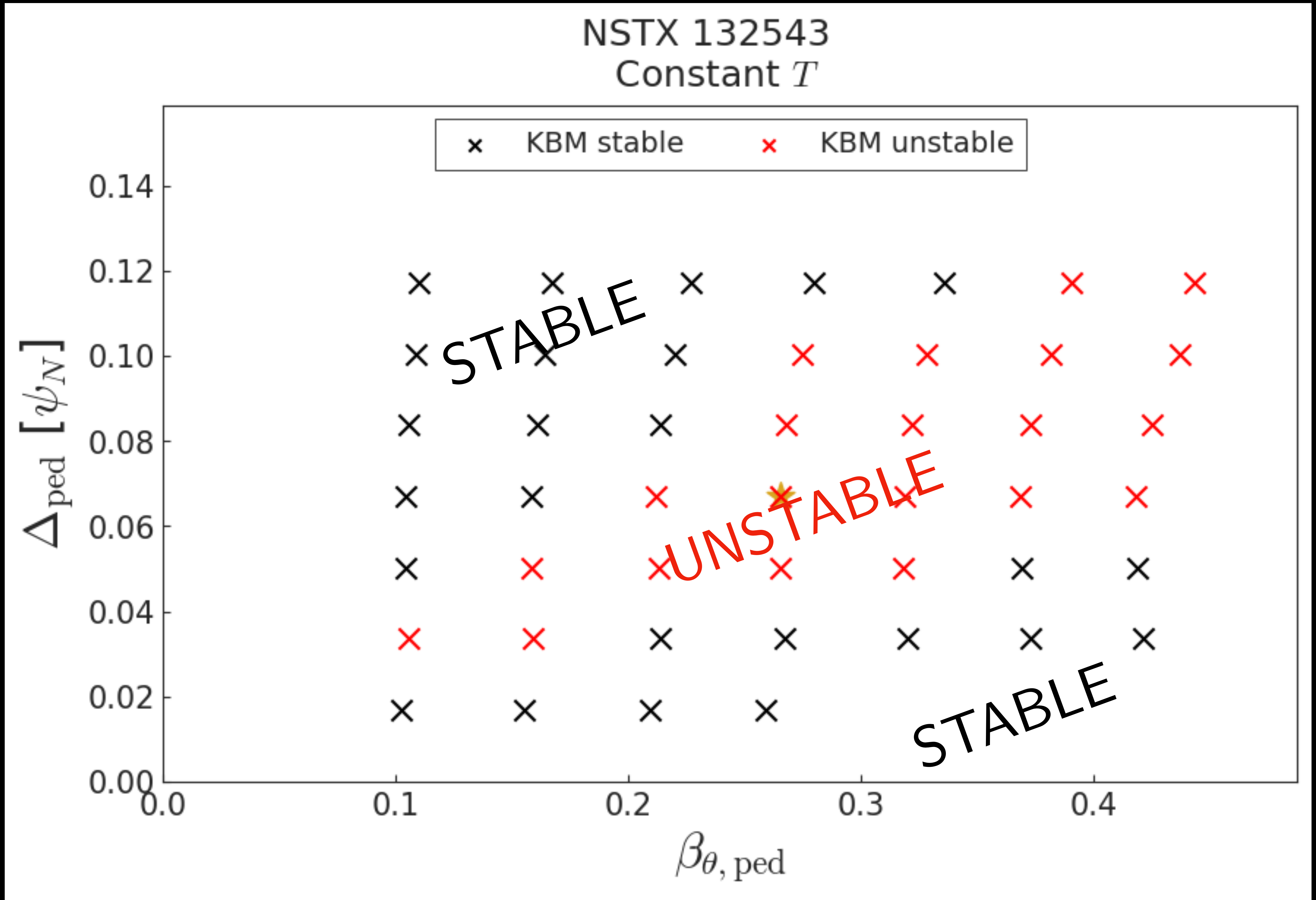
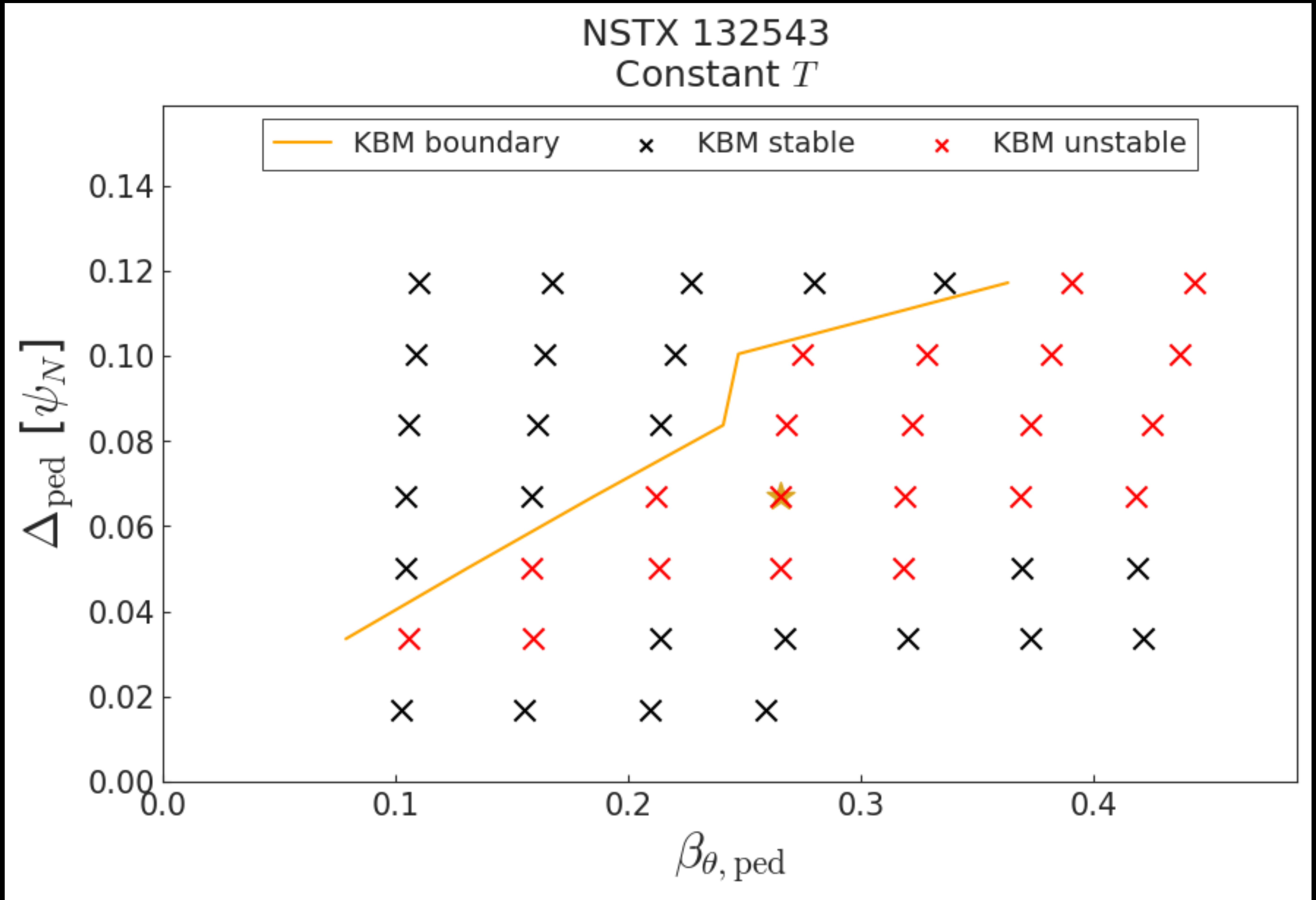


Kinetic, Ideal Comparison

Gyrokinetics

- Clear KBM stability boundary.



Kinetic, Ideal Comparison

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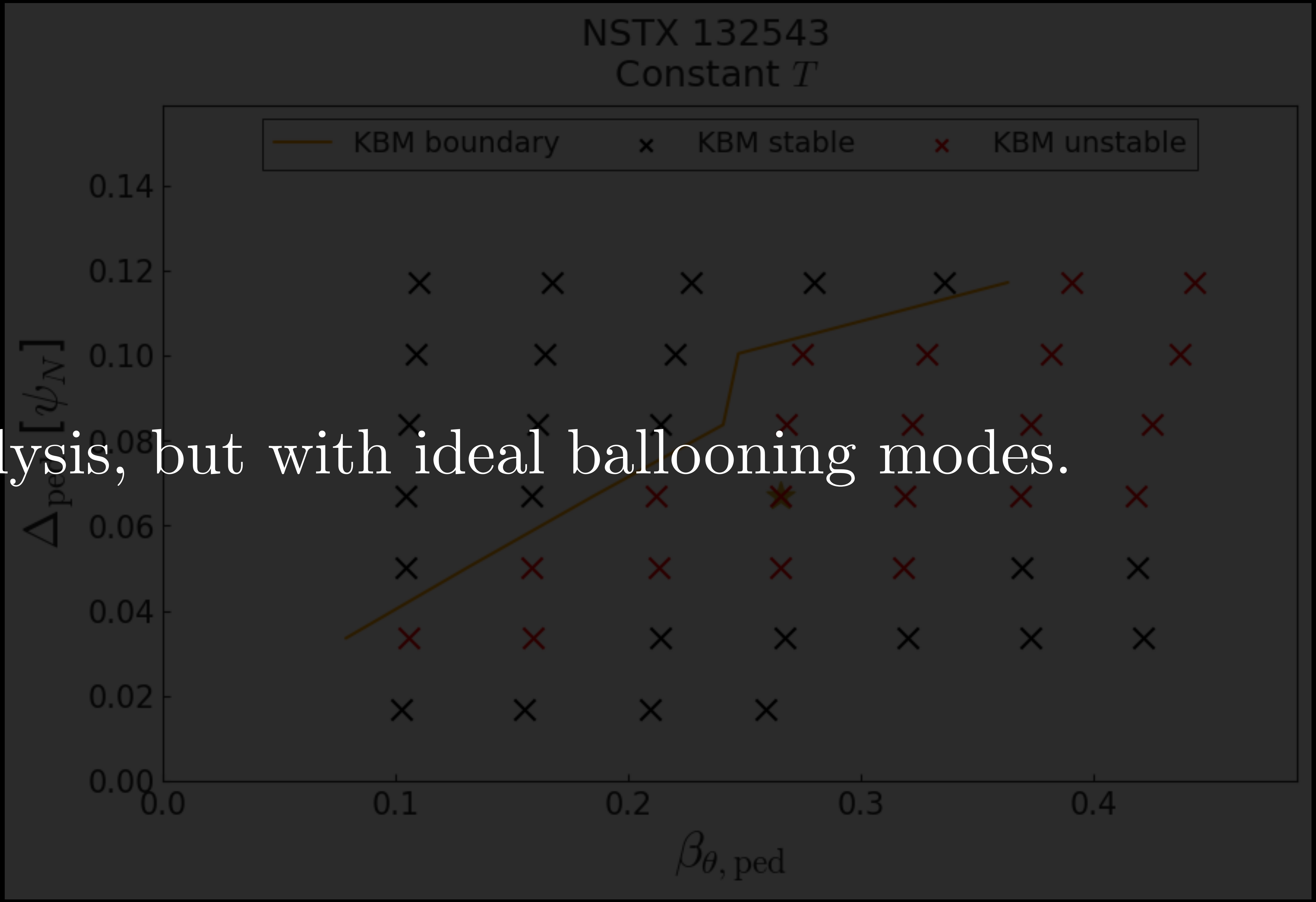
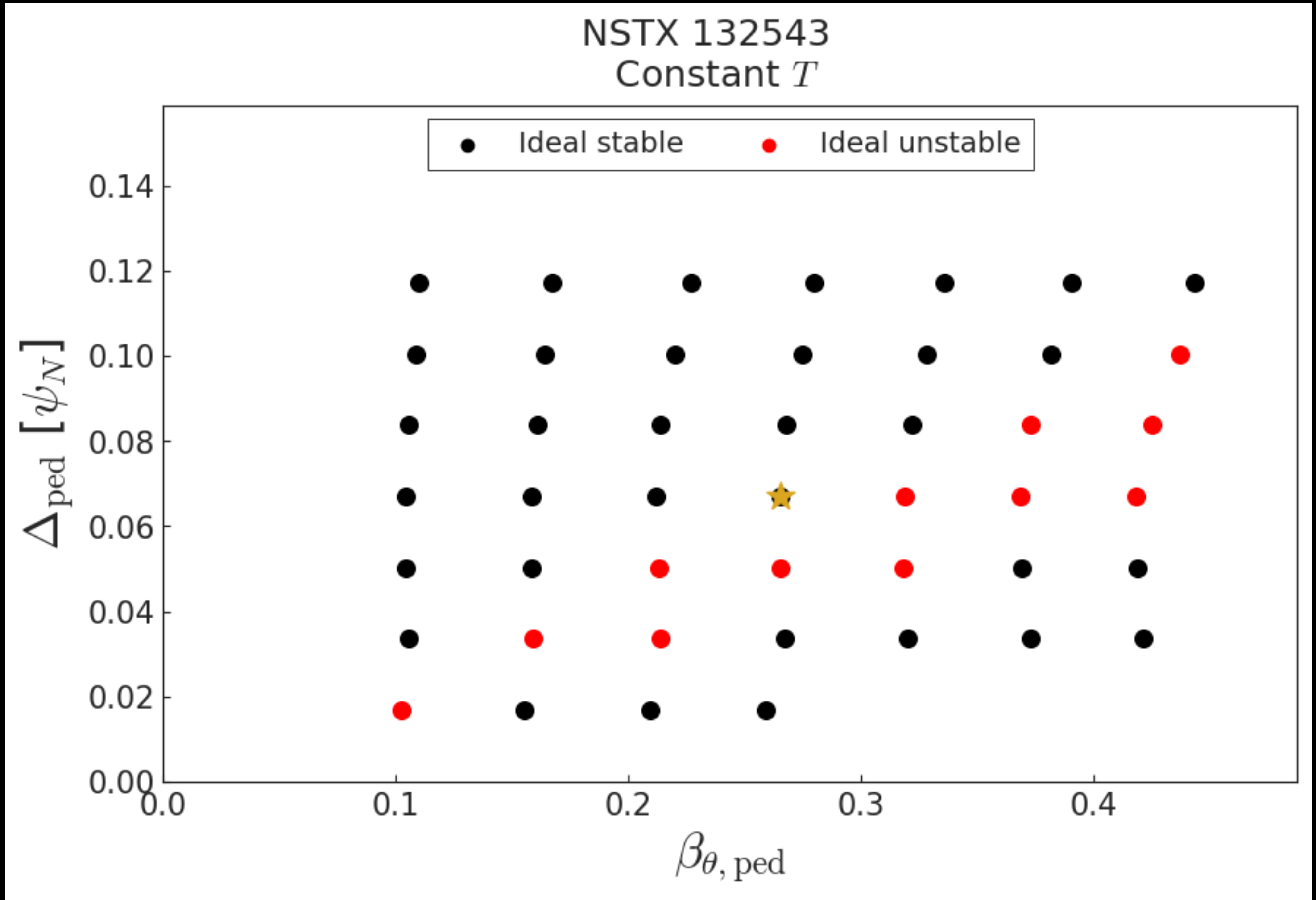


Let's perform the same analysis, but with ideal ballooning modes.

Kinetic, Ideal Comparison
Ideal MHD

- Ideal ballooning stability from BALOO calculation.



Kinetic, Ideal Comparison

Ideal MHD

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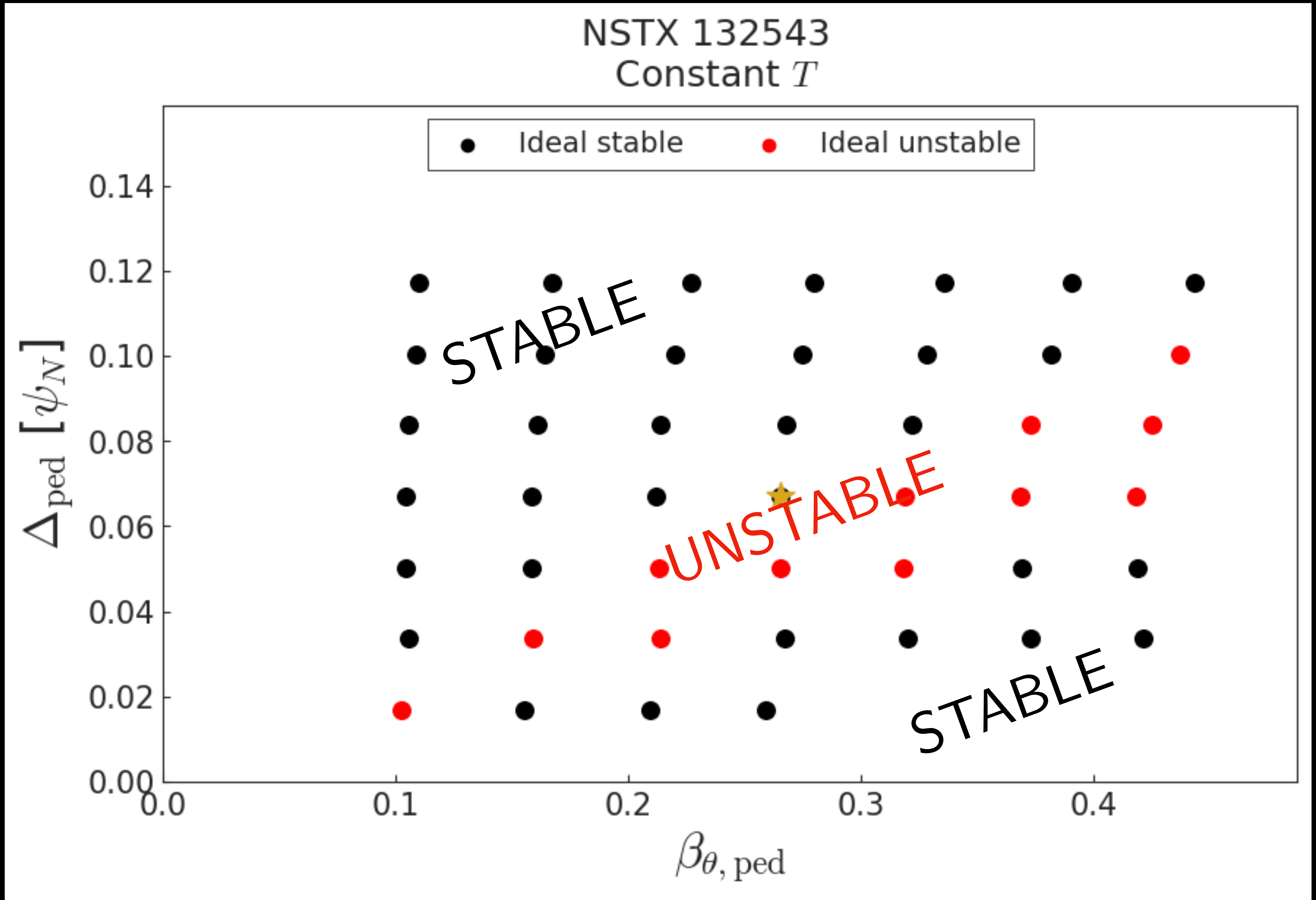
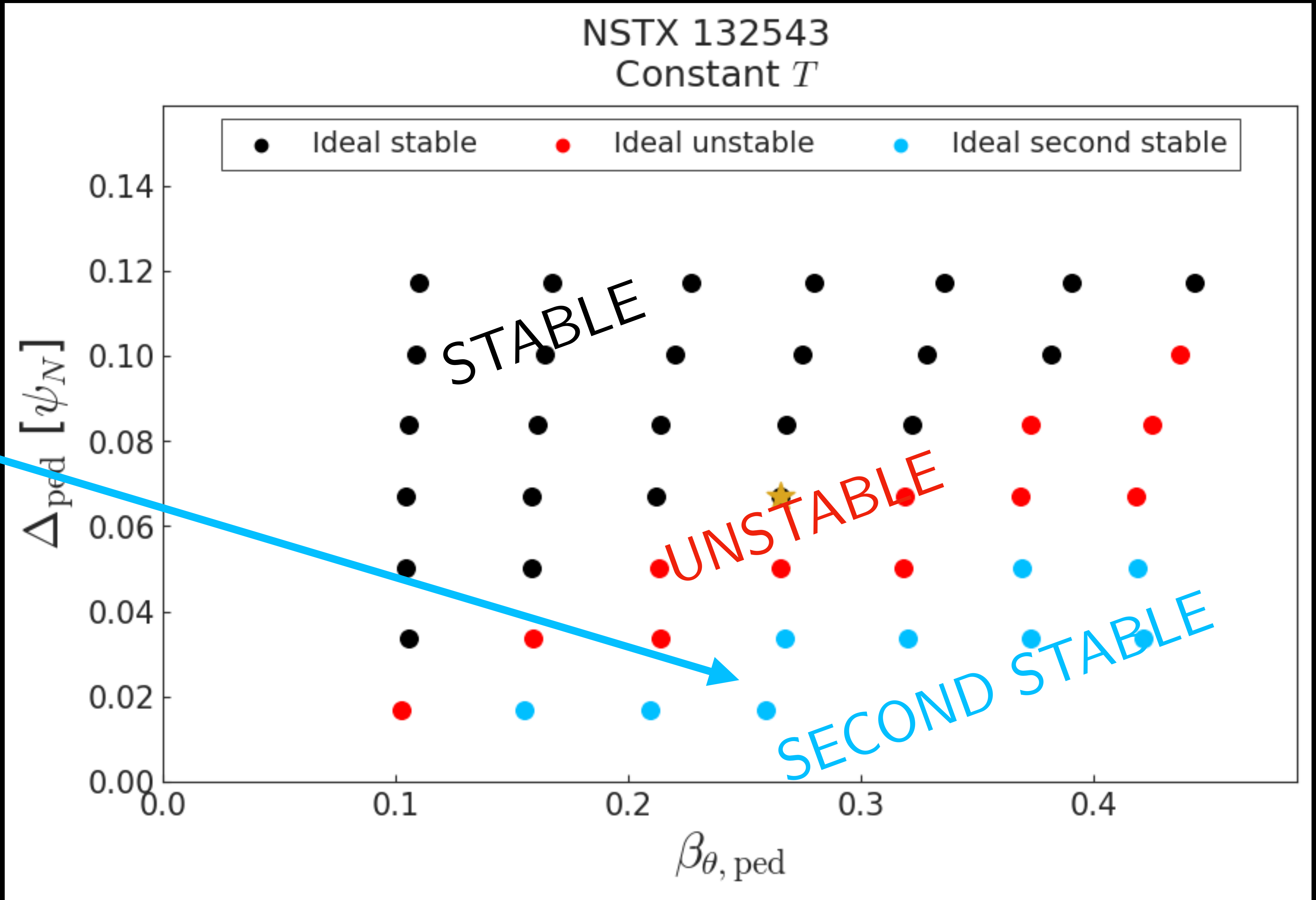


Kinetic, Ideal Comparison
Ideal MHD

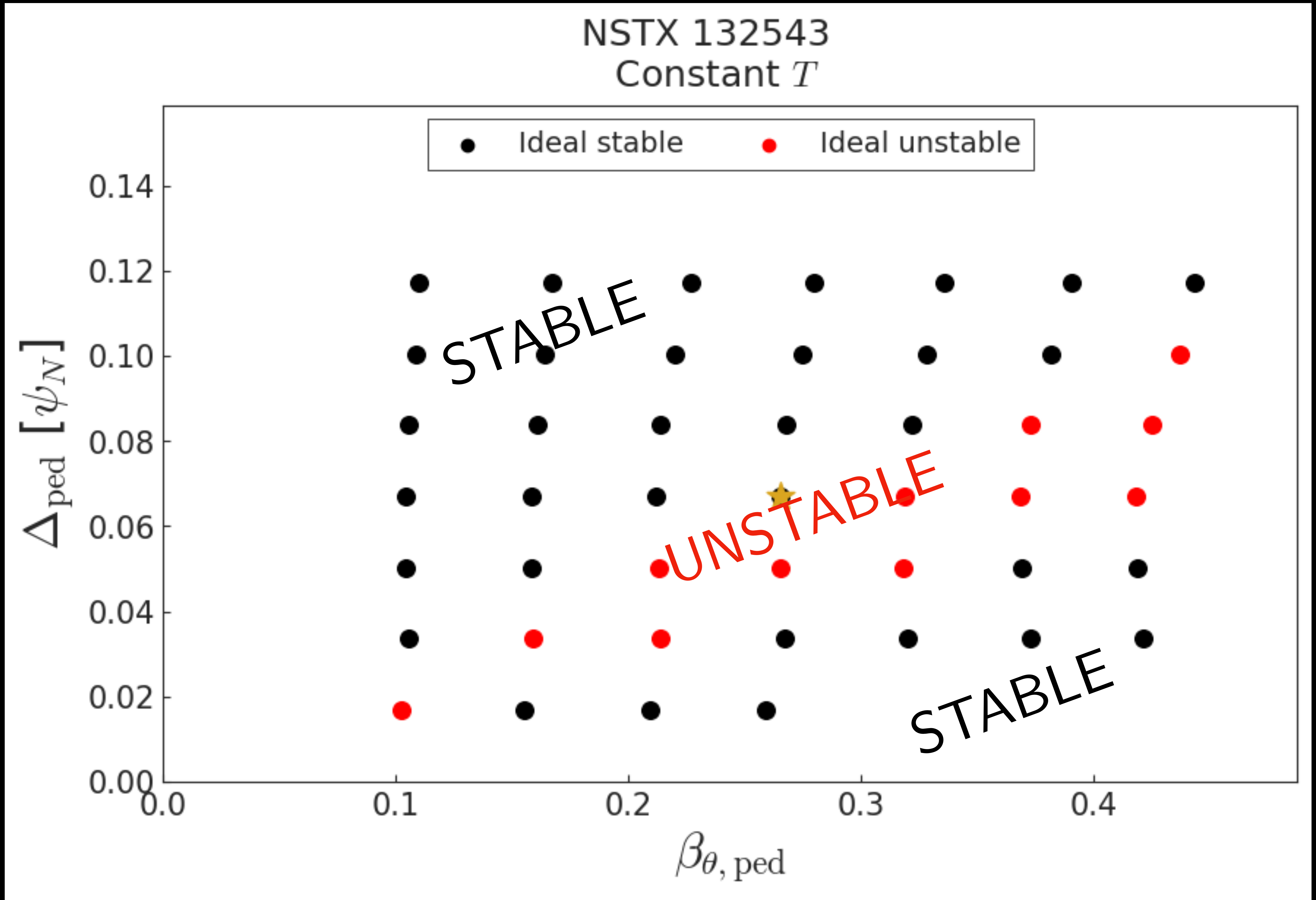
- Ideal ballooning stability from BALOO calculation.
- Second stable region: we count as stable.



Kinetic, Ideal Comparison

Ideal MHD

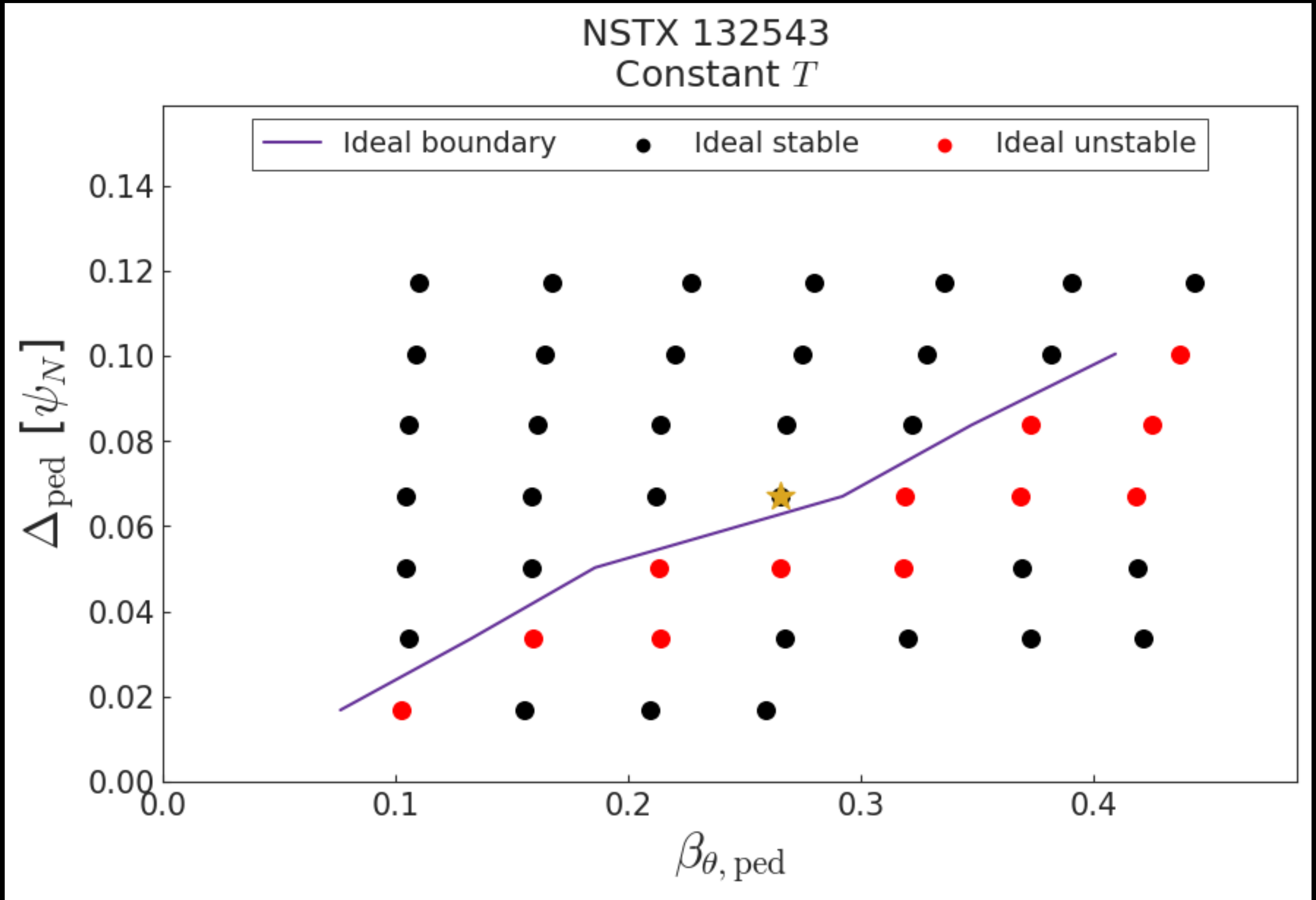
- Ideal ballooning stability from BALOO calculation.
- Ideal stability criteria **identical to GCP**: all half-width points ideal unstable.



Kinetic, Ideal Comparison

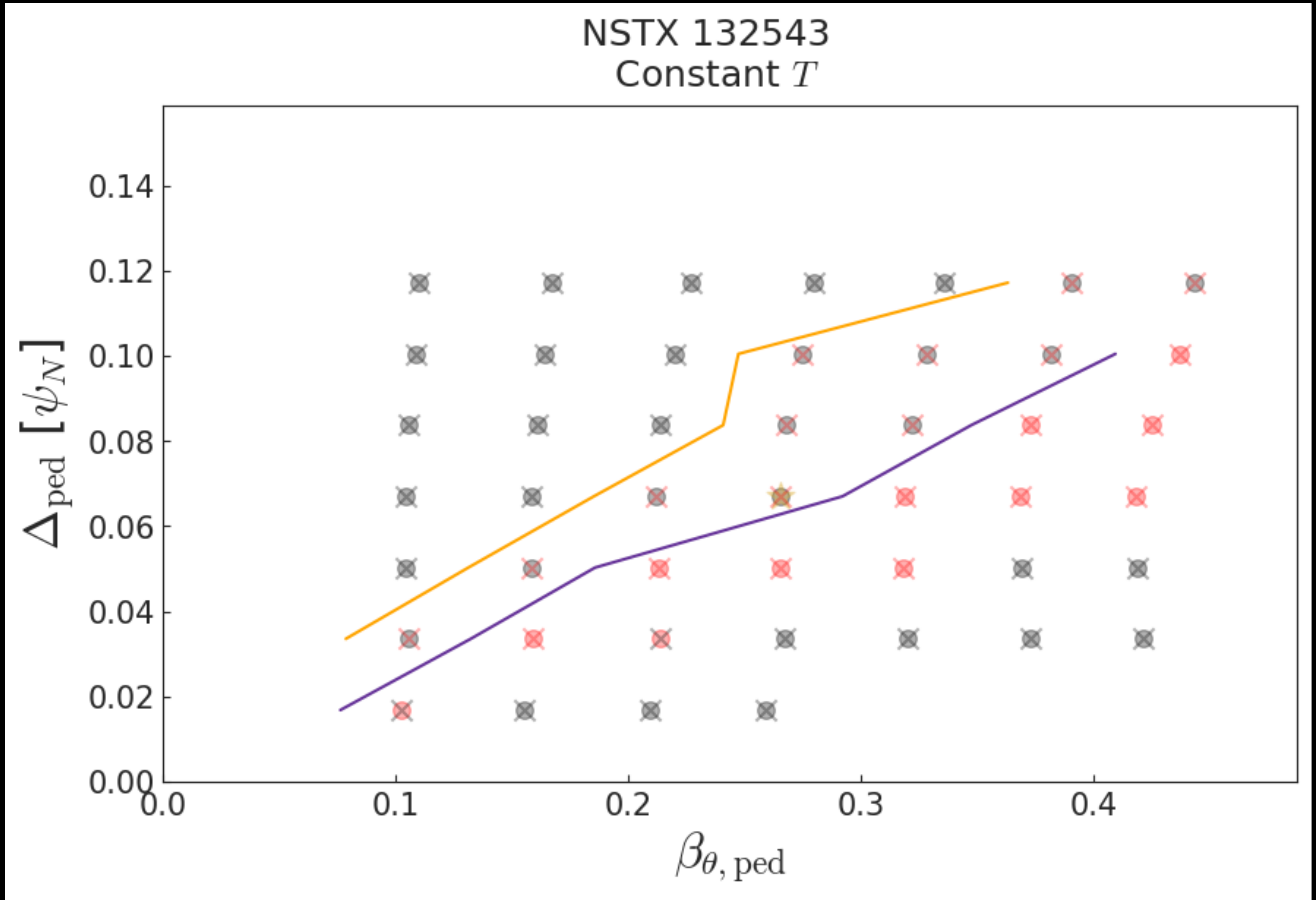
Ideal MHD

- Ideal ballooning stability from BALOO calculation.
- **Clear ideal stability boundary.**



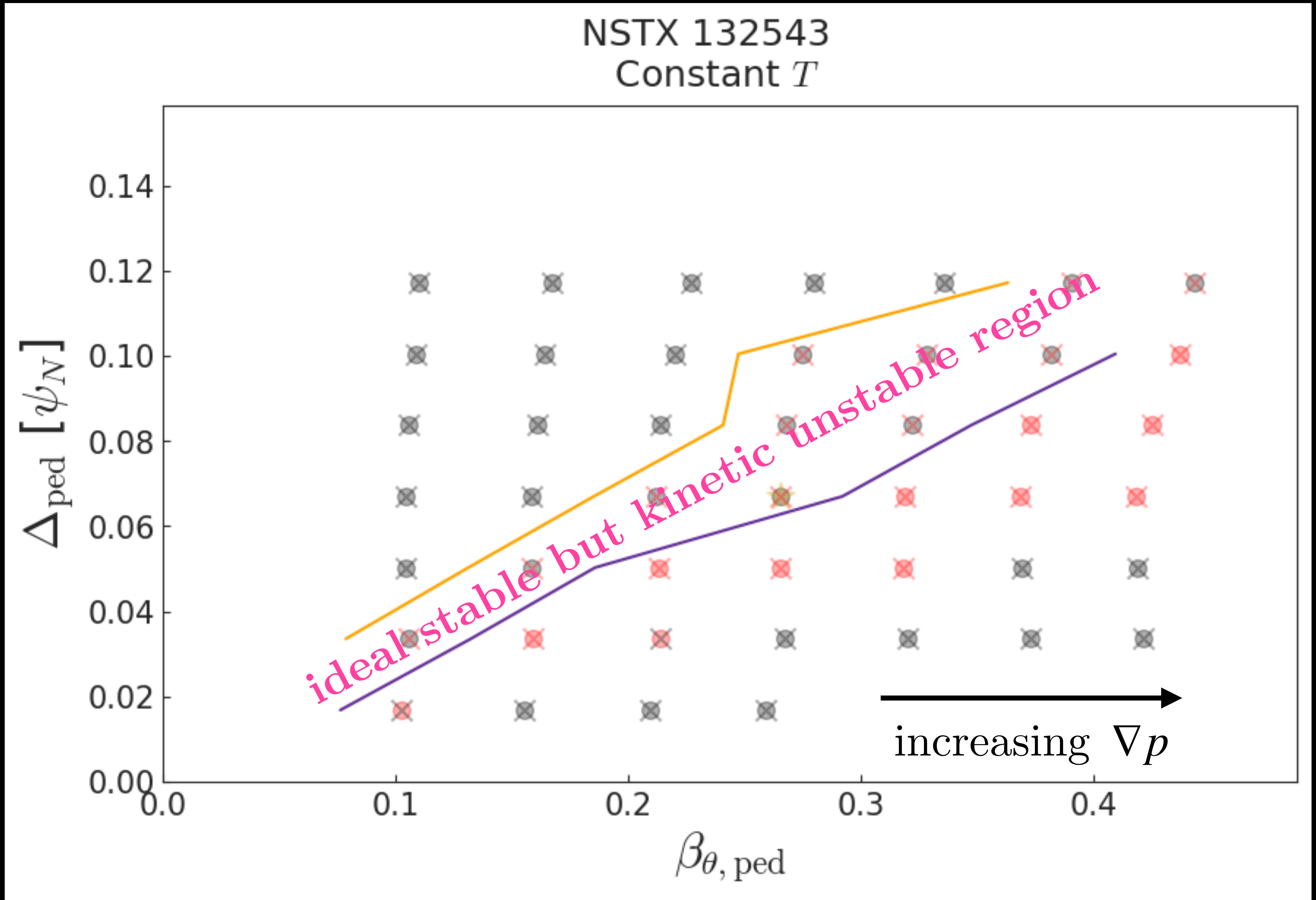
Kinetic, Ideal Comparison

- KBM has lower pressure gradient stability boundary.



Kinetic, Ideal Comparison

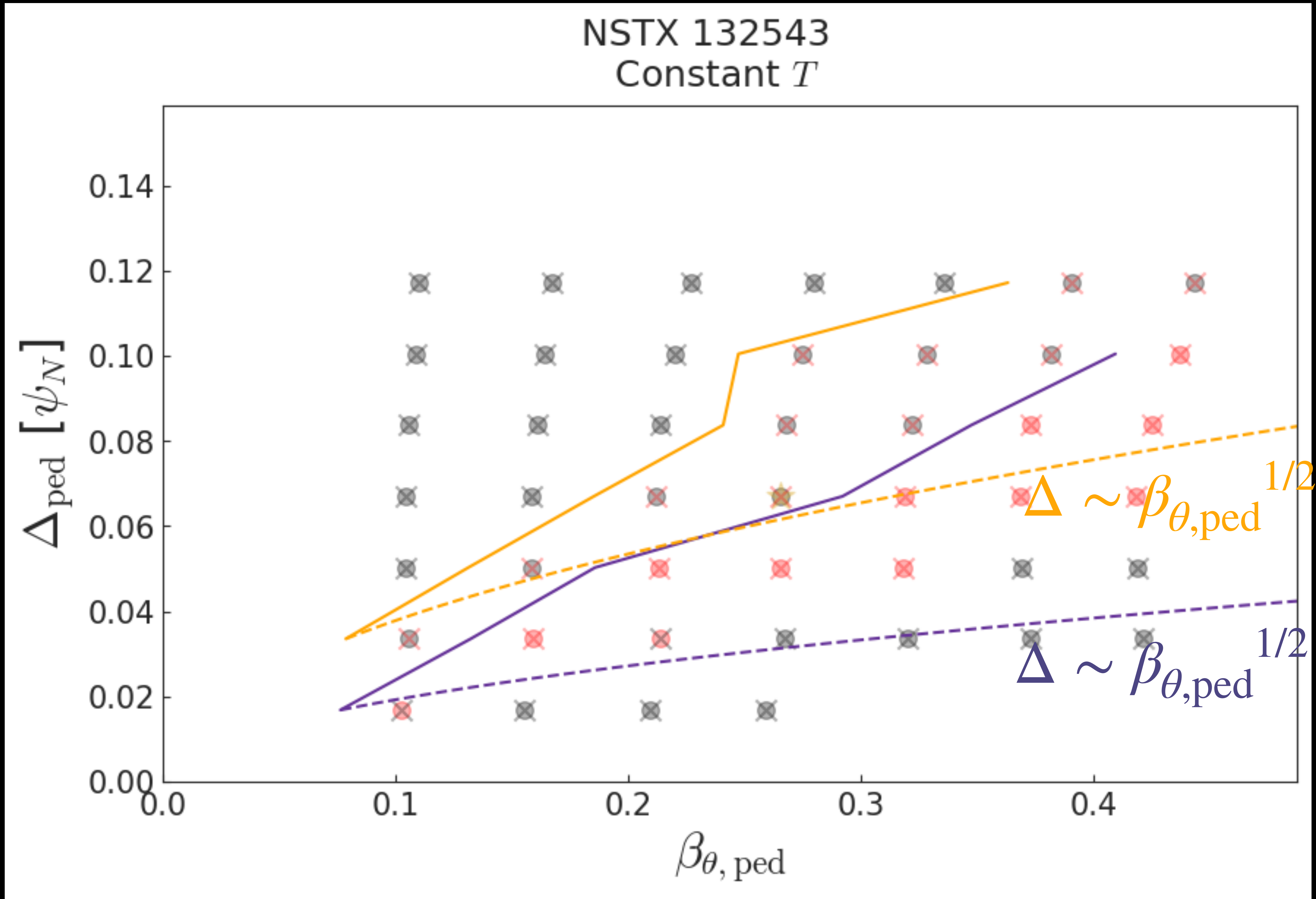
- KBM has lower pressure gradient stability boundary.
- **Region where ideal stable, but kinetic unstable.**



Kinetic, Ideal Comparison

$\Delta = \alpha(\beta_{\theta,\text{ped}})^{\beta}$ Scaling Law

- Both **kinetic** and **ideal** boundaries far from conventional-A BCP: $\Delta \sim \beta_{\theta,\text{ped}}^{1/2}$.

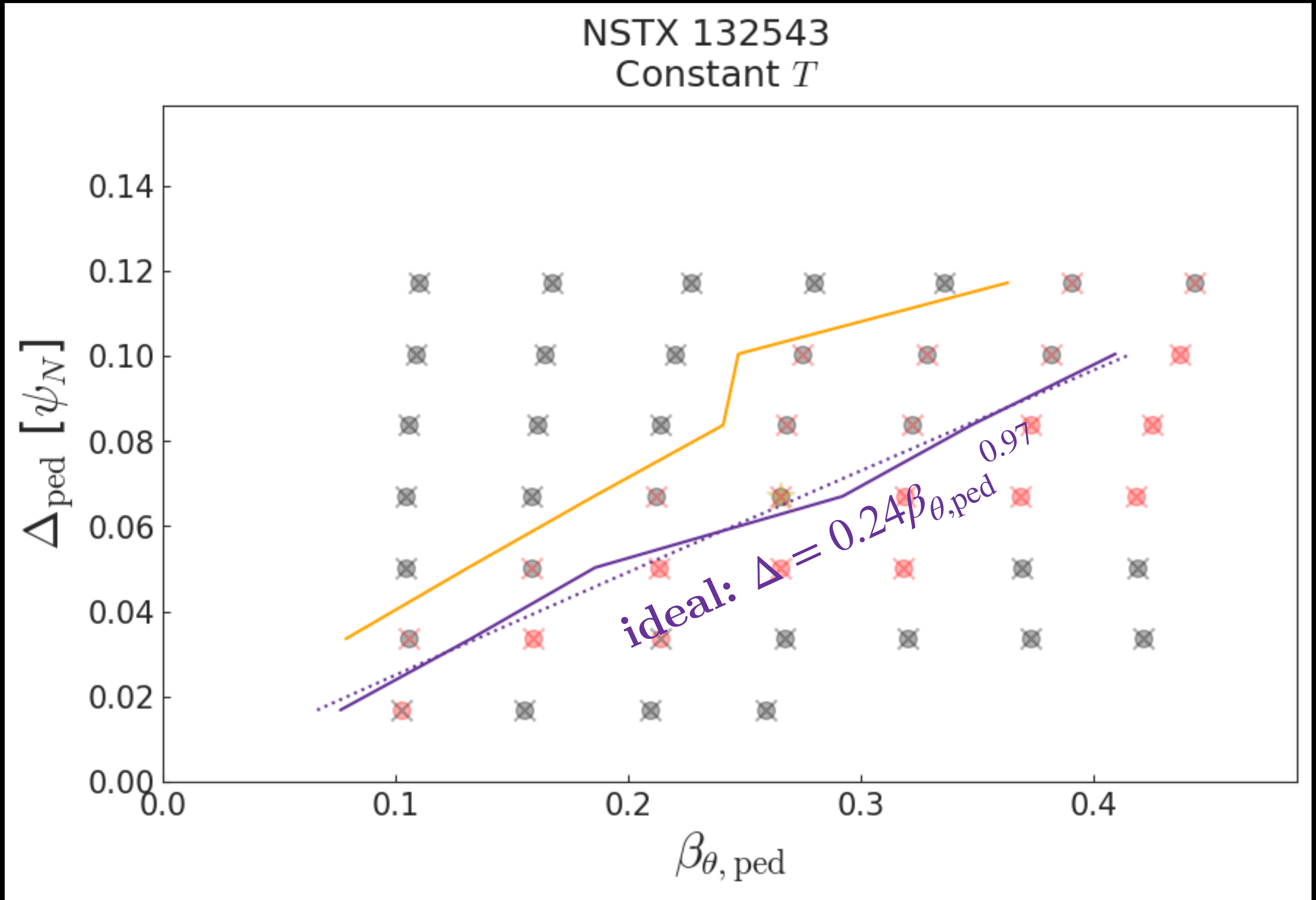


Kinetic, Ideal Comparison

$\Delta = \alpha(\beta_{\theta,\mathrm{ped}})^{\beta}$ Scaling Law

- Both kinetic and ideal boundaries far from standard aspect ratio EPED: $\Delta \sim {\beta_{\theta,\mathrm{ped}}}^{1/2}$.

- Ideal boundary fit: $\Delta = 0.24{\beta_{\theta,\mathrm{ped}}}^{0.97}$.



Kinetic, Ideal Comparison

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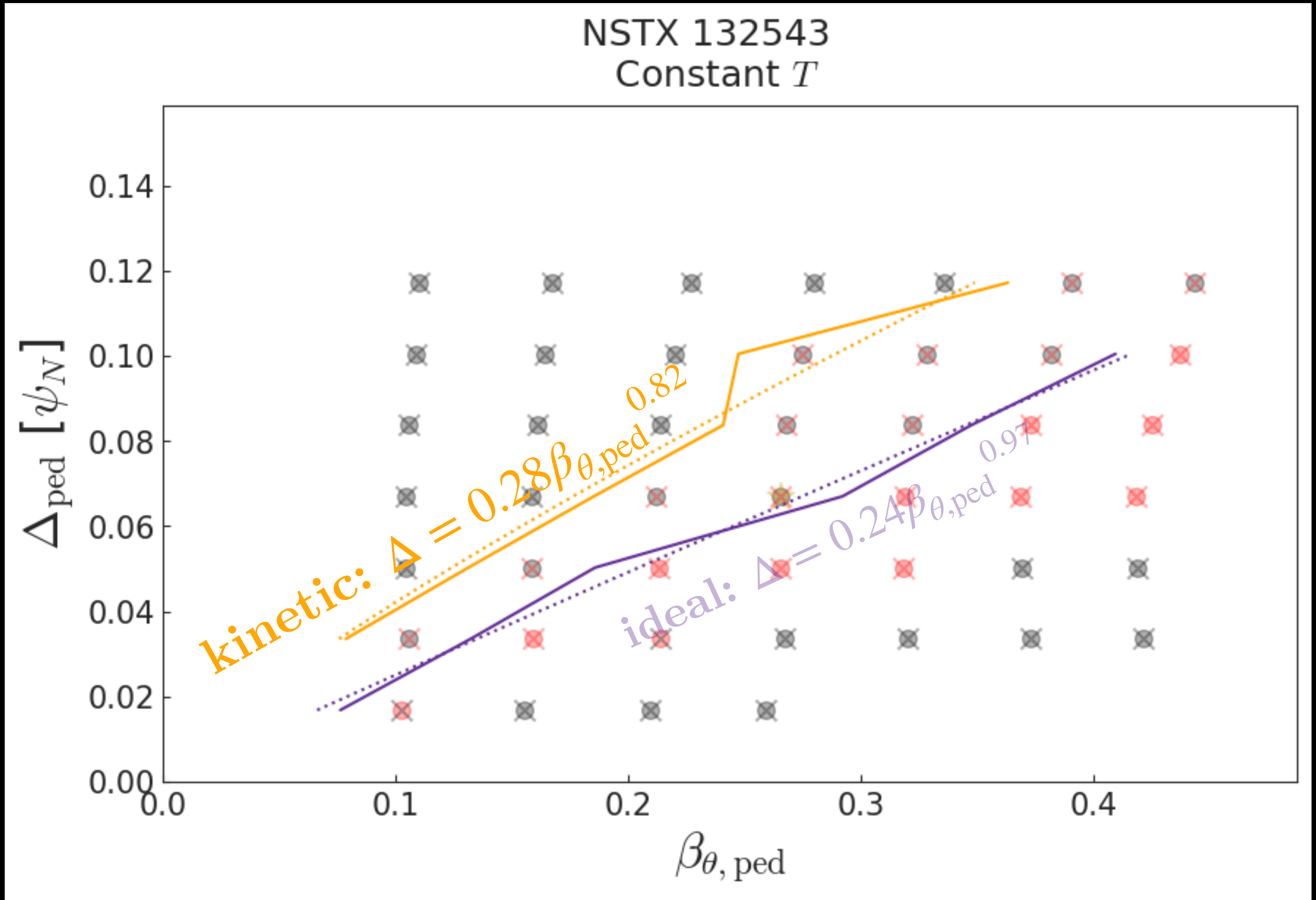
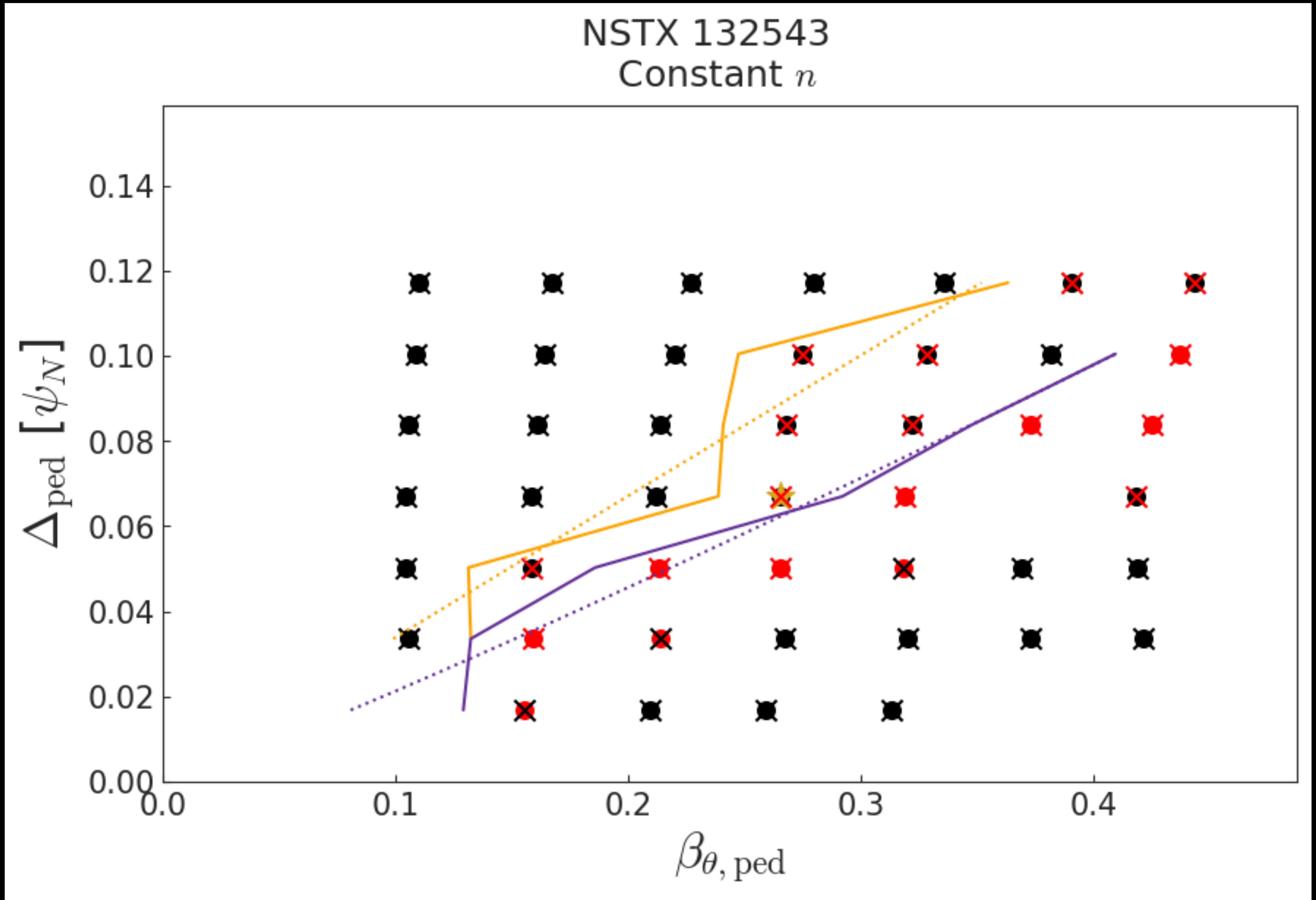
- Both kinetic and ideal boundaries far from standard aspect ratio EPED: $\Delta \sim {\beta_{\theta,\mathrm{ped}}}^{1/2}$.
- Ideal boundary fit: $\Delta = 0.24{\beta_{\theta,\mathrm{ped}}}^{0.97}$.
- Kinetic boundary fit: $\Delta = 0.28{\beta_{\theta,\mathrm{ped}}}^{0.82}$.



Kinetic, Ideal Comparison

$\Delta = \alpha(\beta_{\theta,\text{ped}})^{\beta}$ **Scaling Law**

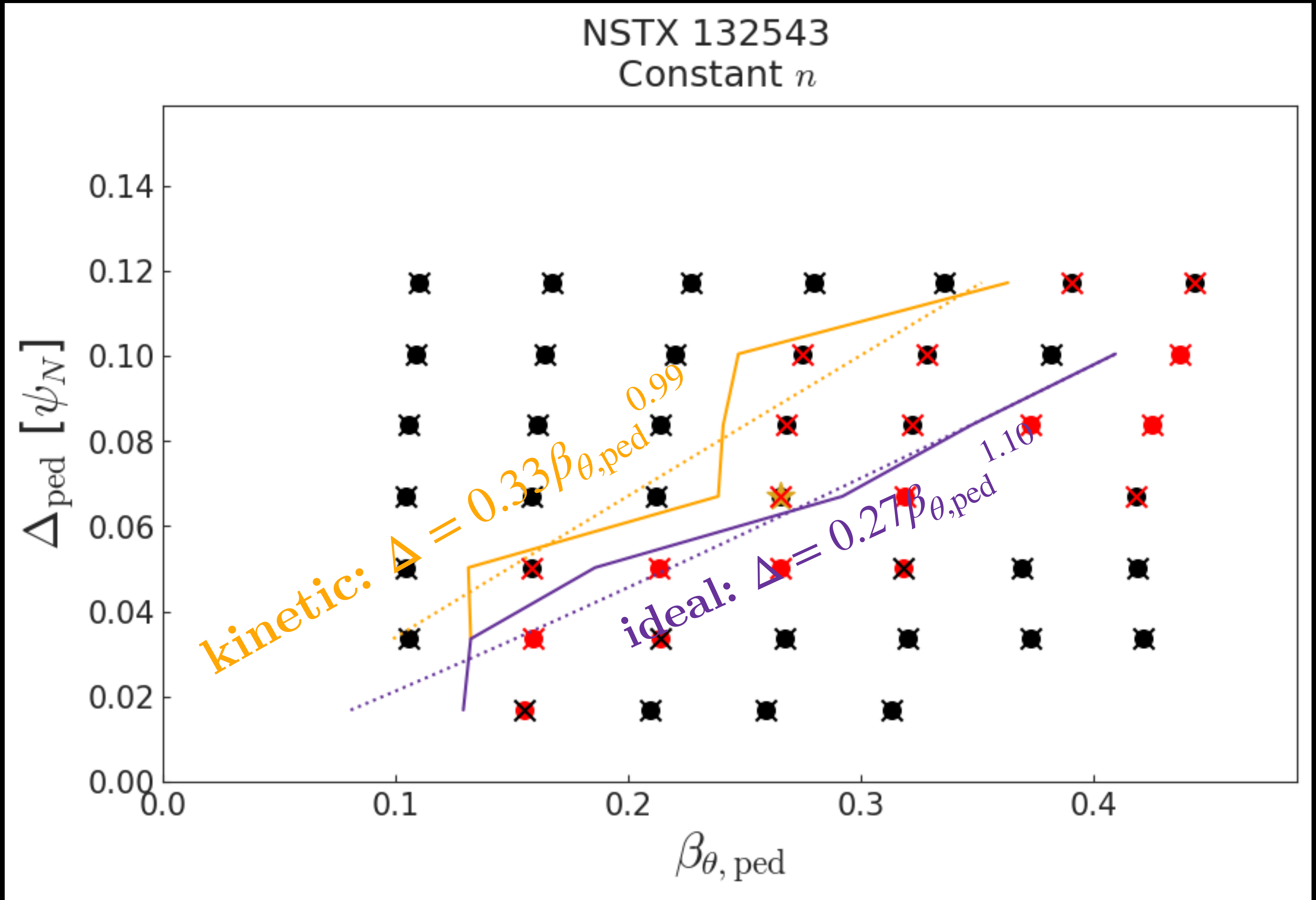
- Perform same exercise with pressure varied with **constant n**.



Kinetic, Ideal Comparison

$\Delta = \alpha(\beta_{\theta,\text{ped}})^{\beta}$ Scaling Law

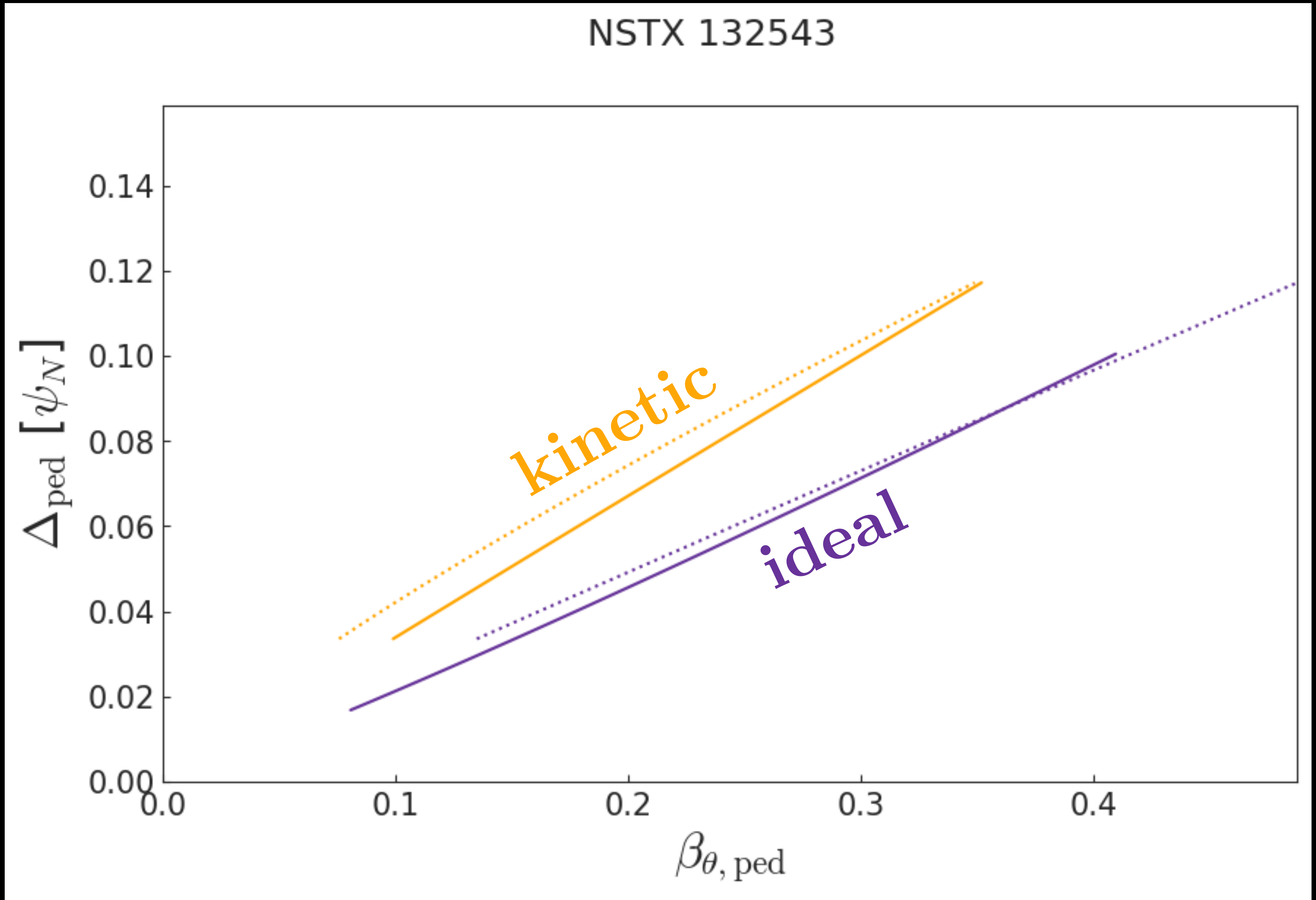
- Perform same exercise with pressure varied with **constant n**.
- Ideal boundary fit: $\Delta = 0.27\beta_{\theta,\text{ped}}{}^{1.10}$.
- Kinetic boundary fit: $\Delta = 0.33\beta_{\theta,\text{ped}}{}^{0.99}$.



Kinetic, Ideal Comparison

$\Delta = \alpha(\beta_{\theta,\text{ped}})^{\beta}$ Scaling Law

- Significant difference between ideal and kinetic scaling.



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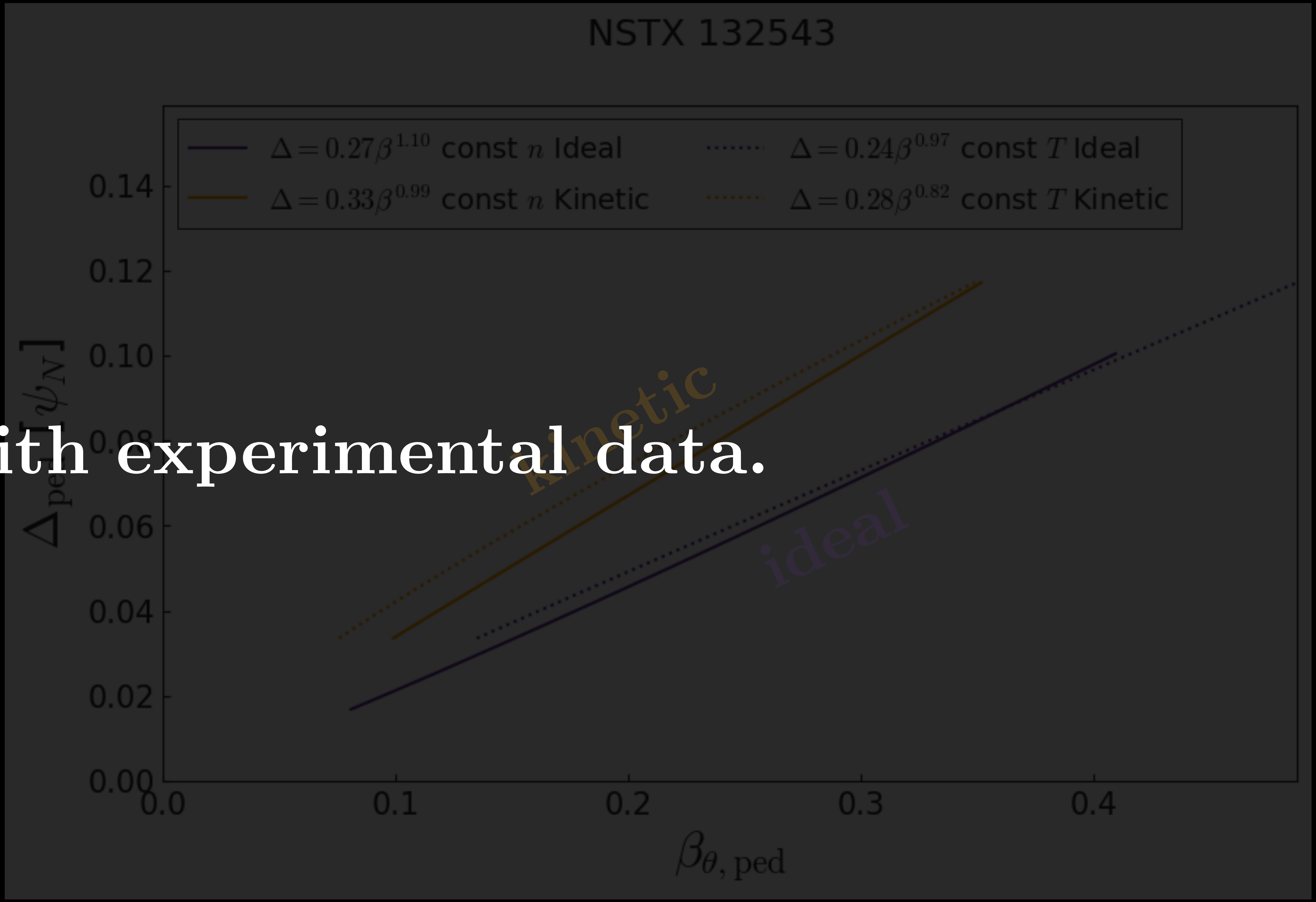
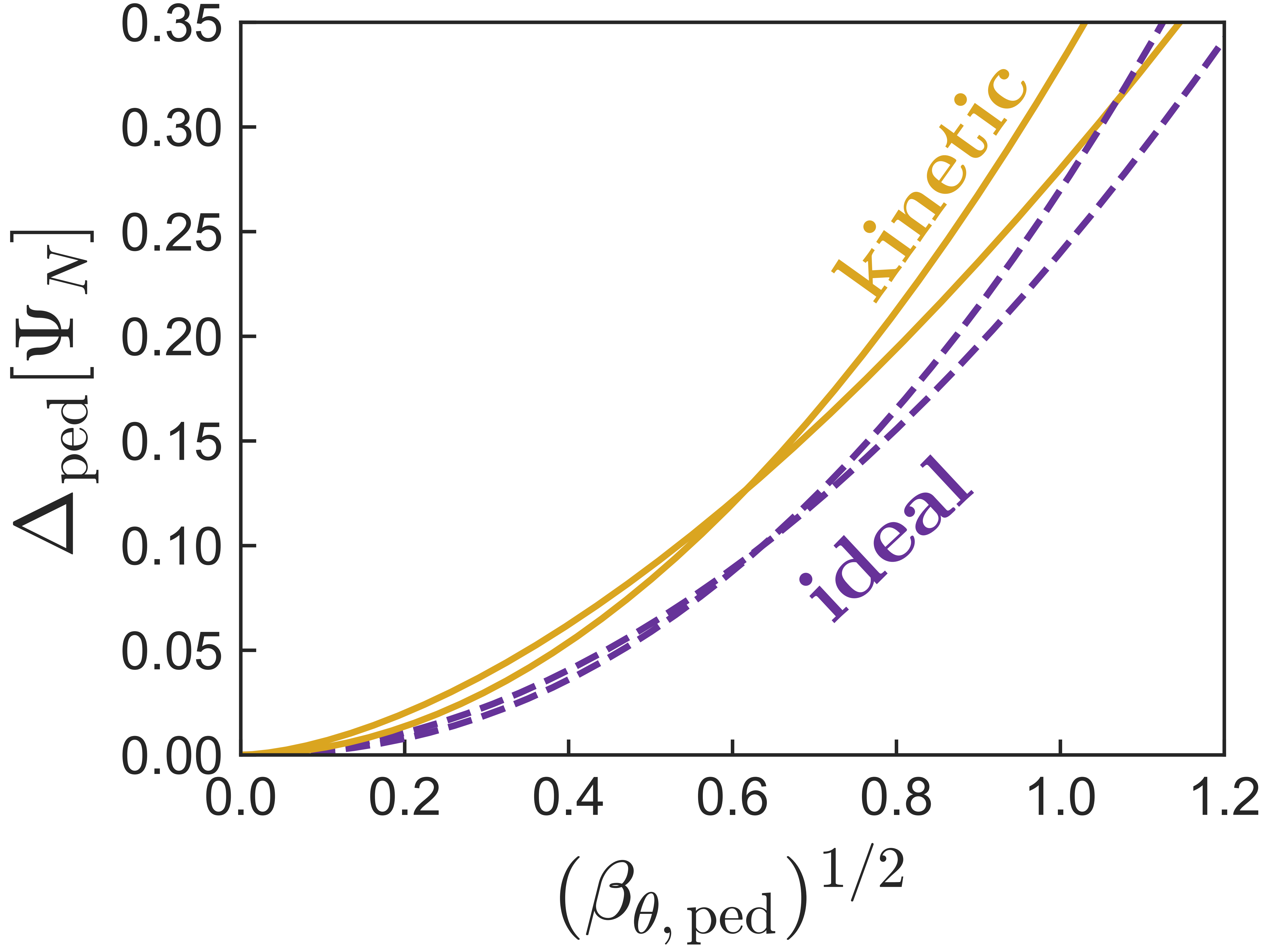


Comparing with experimental data.

Kinetic, Ideal Comparison

$\Delta = \alpha(\beta_{\theta,\text{ped}})^{\beta}$ **Scaling Law**

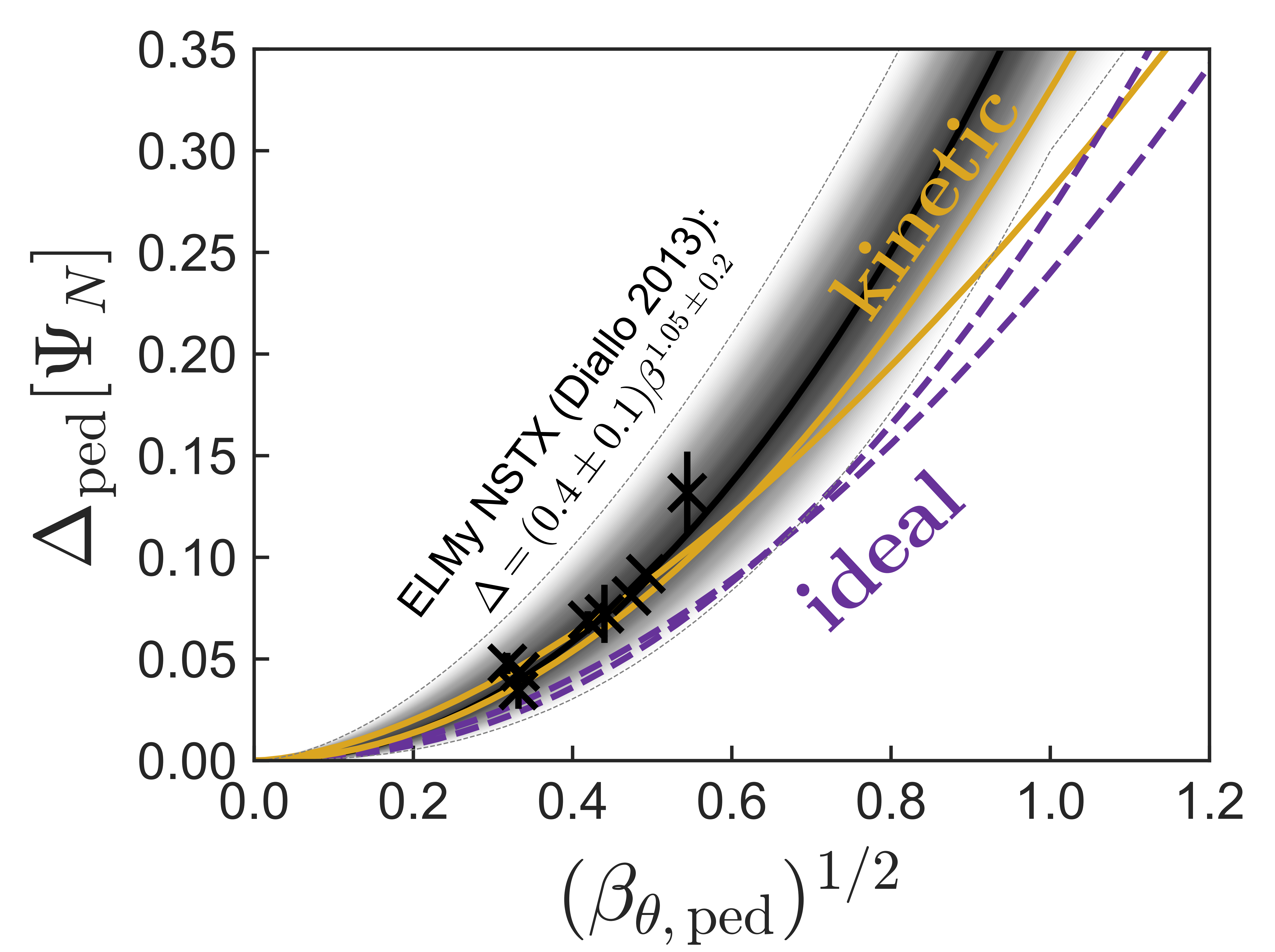
- Ideal scalings tend to over-predict pedestal height.



Kinetic, Ideal Comparison

$\Delta = \alpha(\beta_{\theta,\mathrm{ped}})^{\beta}$ **Scaling Law**

- Ideal scalings tend to over-predict pedestal height.
- **Kinetic boundary** closer to NSTX experiment.



Test original hypothesis: KBM reproduces NSTX scaling

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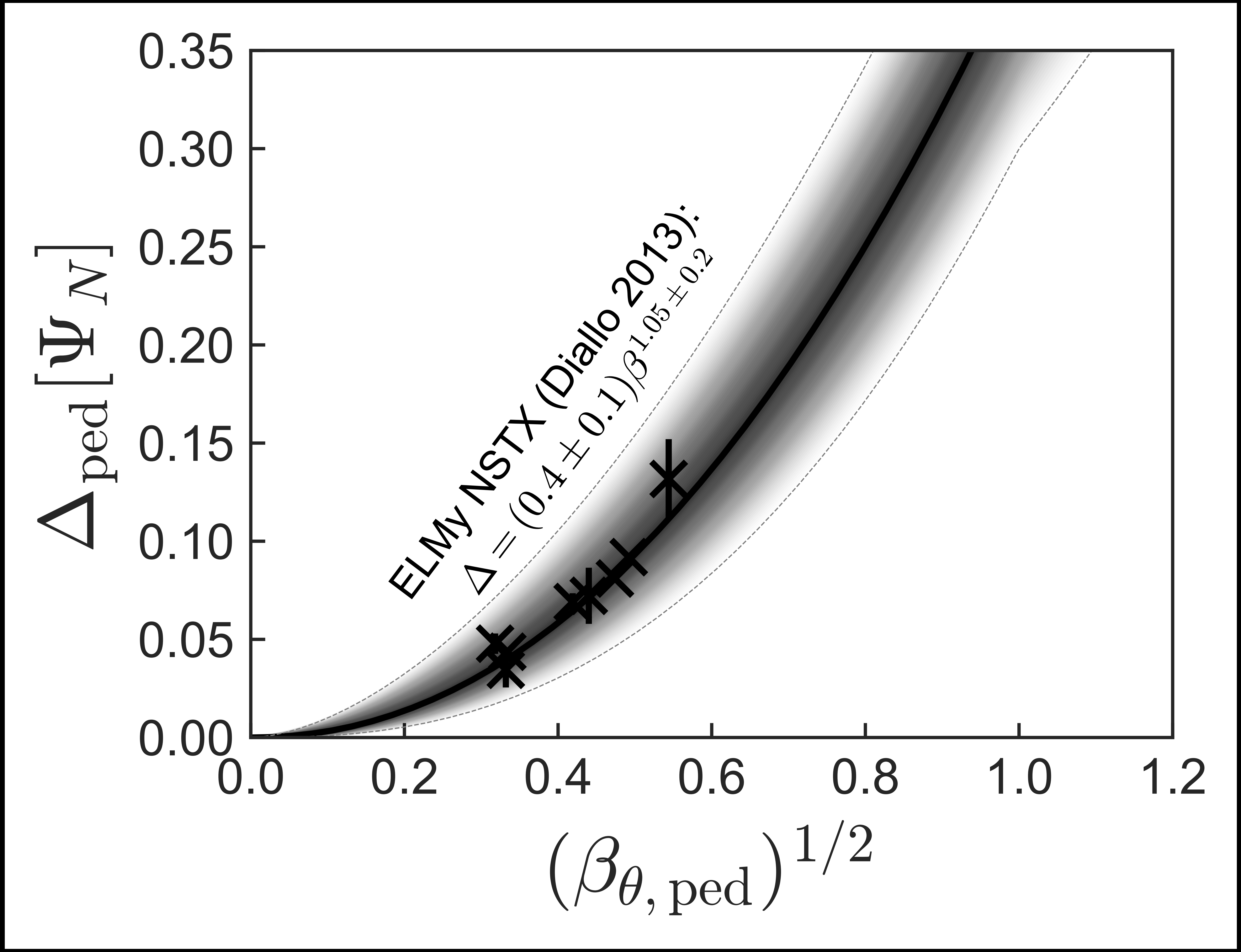
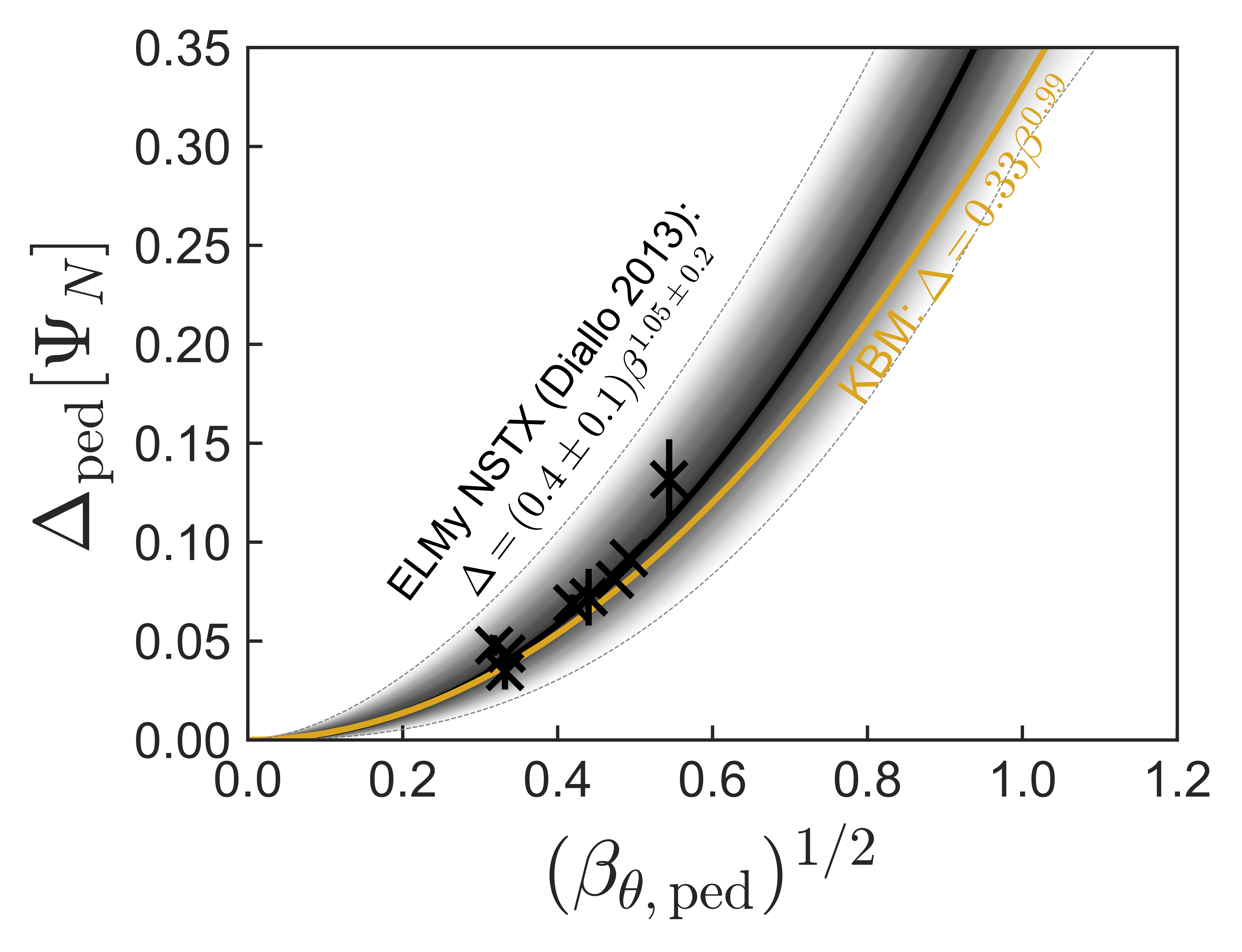


Test original hypothesis: KBM reproduces NSTX scaling

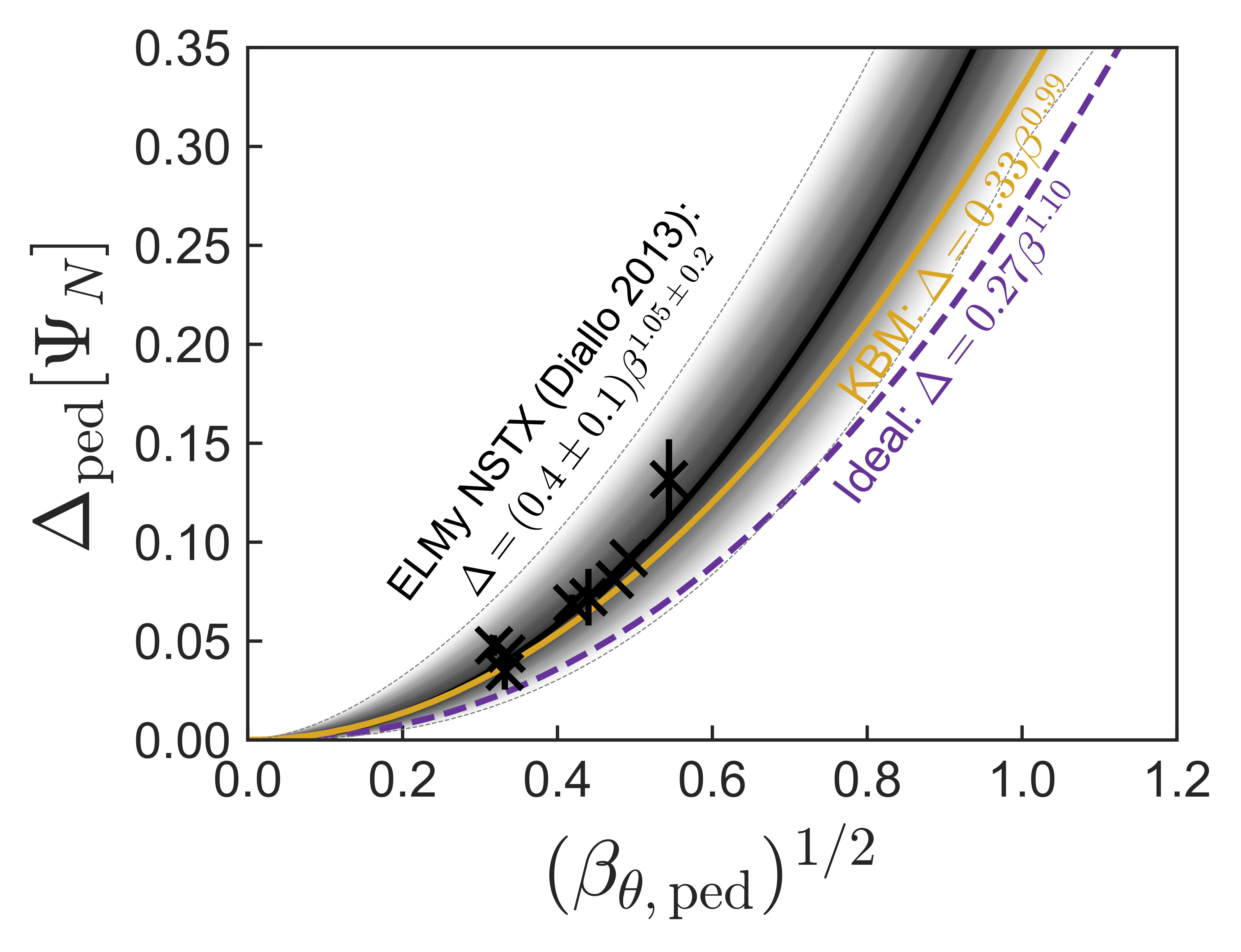
KBM scaling at constant n, consistent with NSTX experiment.



Test original hypothesis: KBM reproduces NSTX scaling

KBM scaling at constant n, **consistent with NSTX experiment.**

Ideal scaling ~inconsistent.

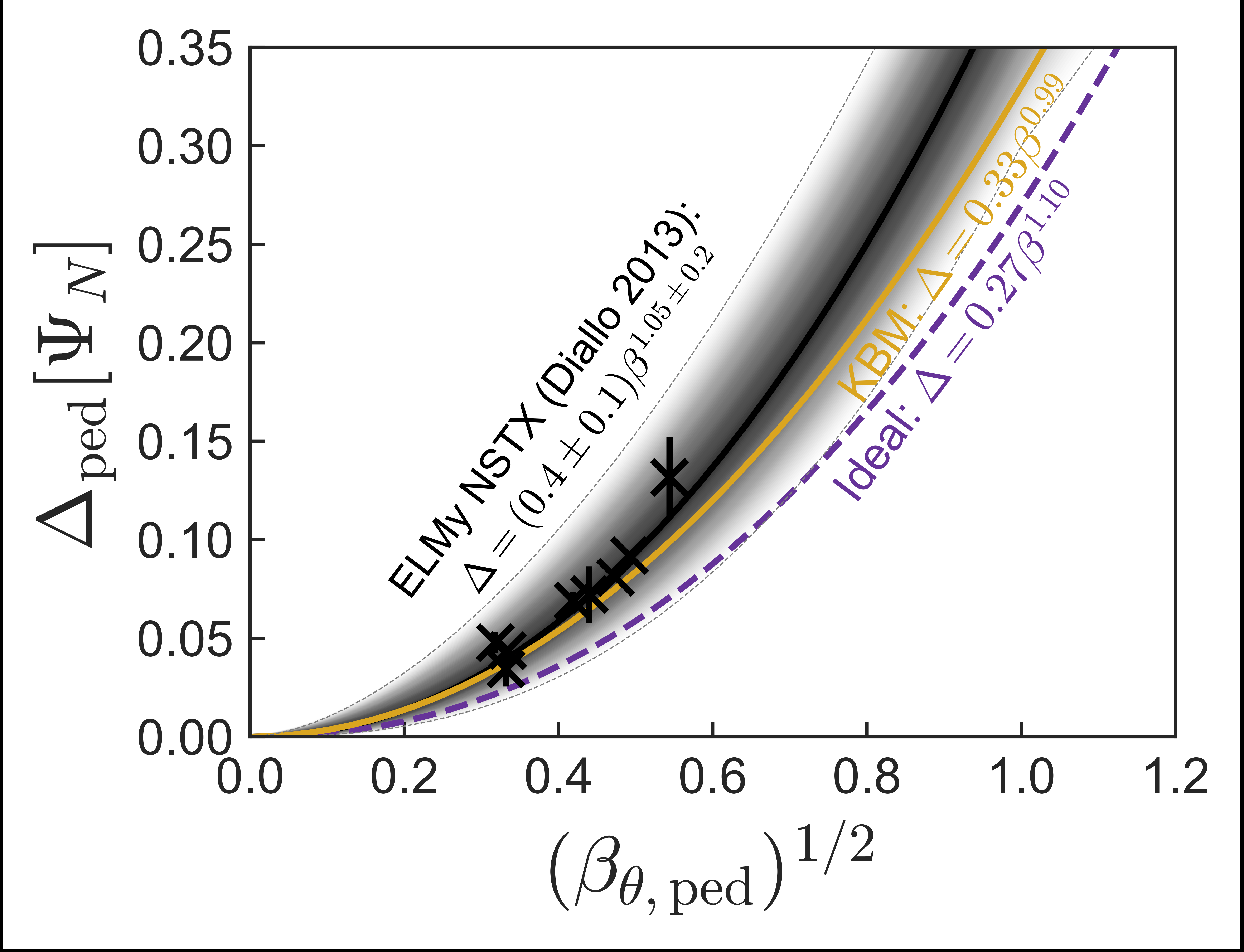


Test original hypothesis: KBM reproduces NSTX scaling

KBM scaling at constant n, **consistent with NSTX experiment.**

Ideal scaling ~inconsistent.

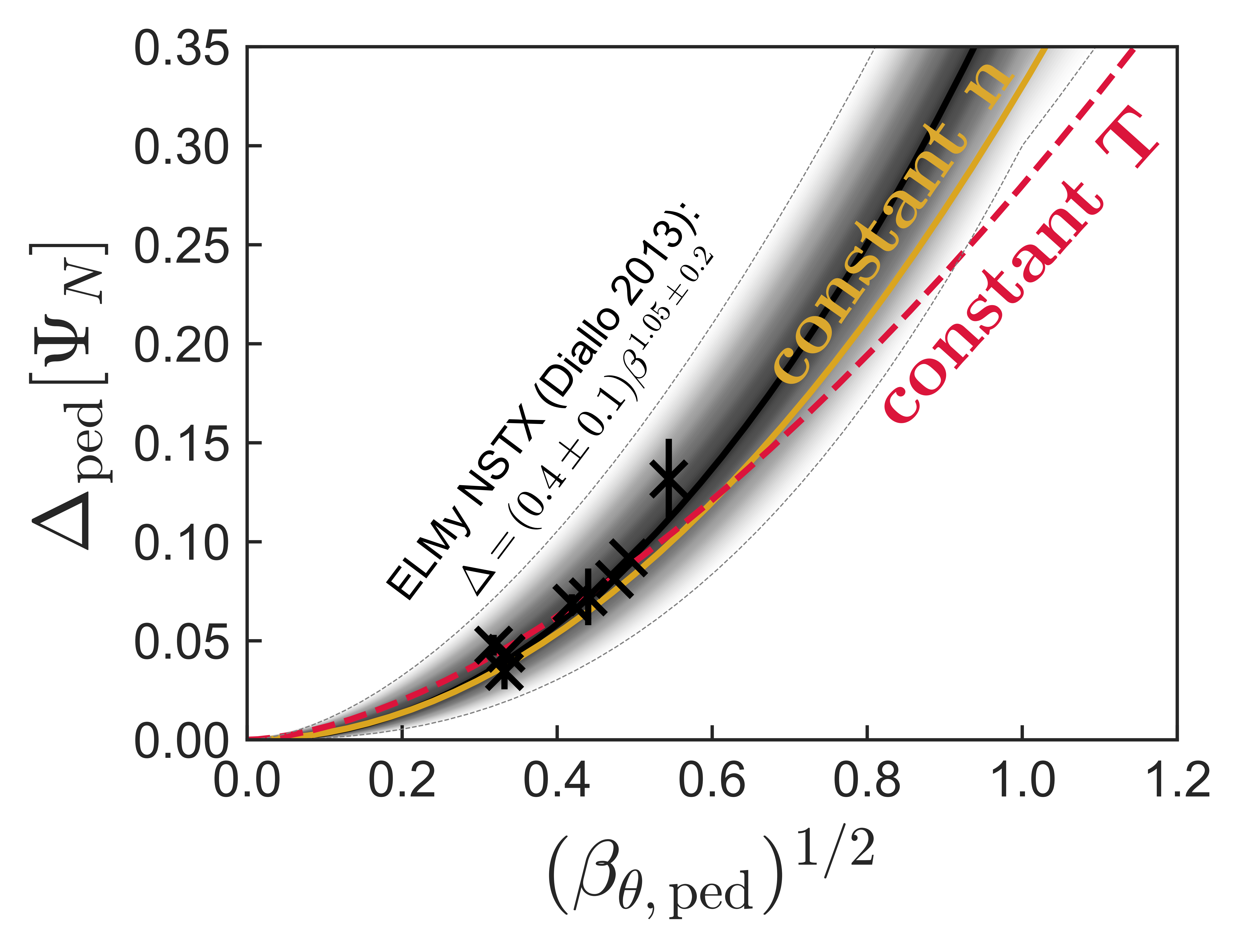
—> kinetic physics important for NSTX pedestal prediction.



Test original hypothesis: KBM reproduces NSTX scaling

KBM constant n **consistent.**

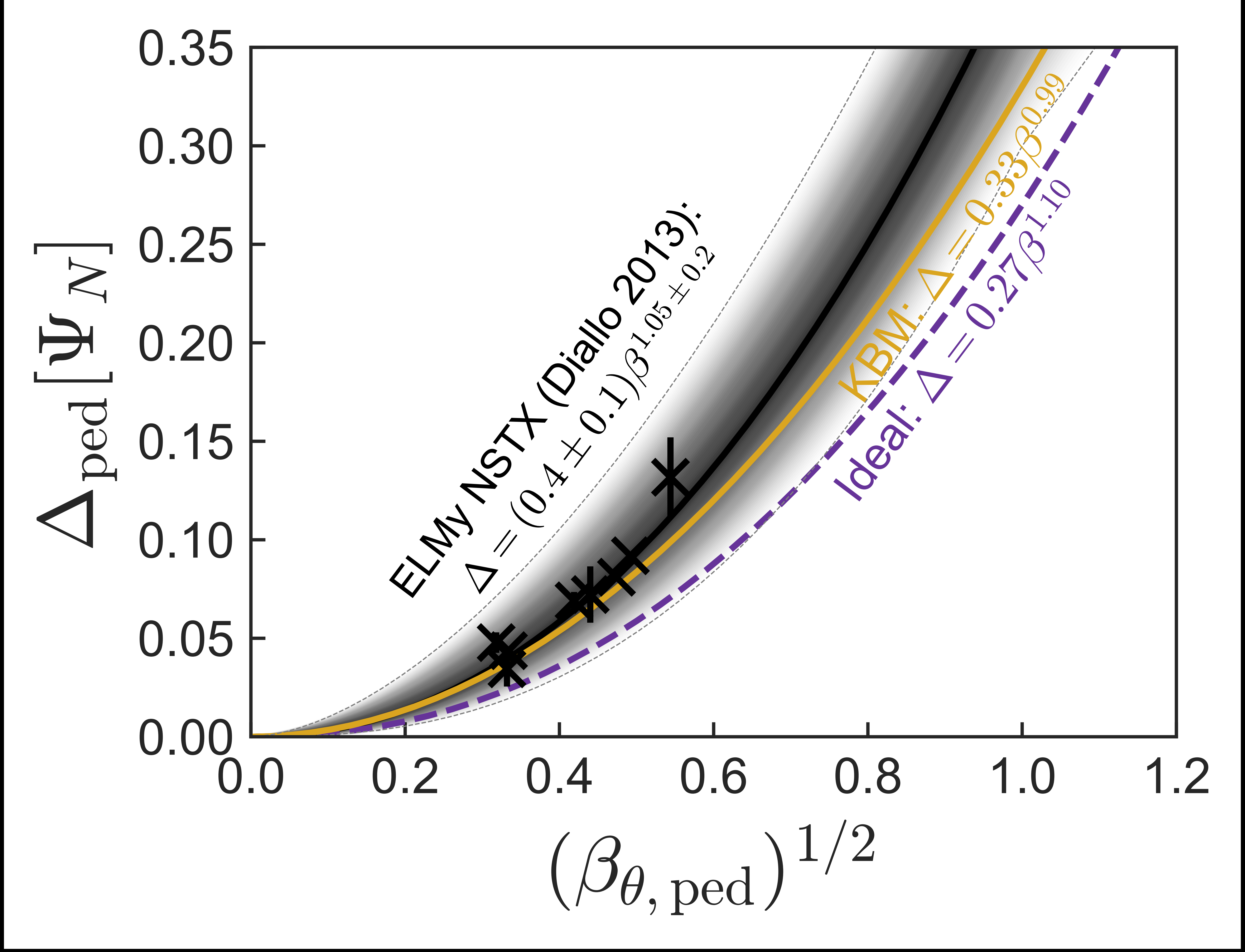
KBM constant T **~inconsistent.**



Test original hypothesis: KBM reproduces NSTX scaling

Important caveat:

No errorbars for our KBM/ideal scalings, so possible ideal scaling also consistent.



Testing the critical pedestal criteria

How many radial points for a ‘critical’ pedestal?

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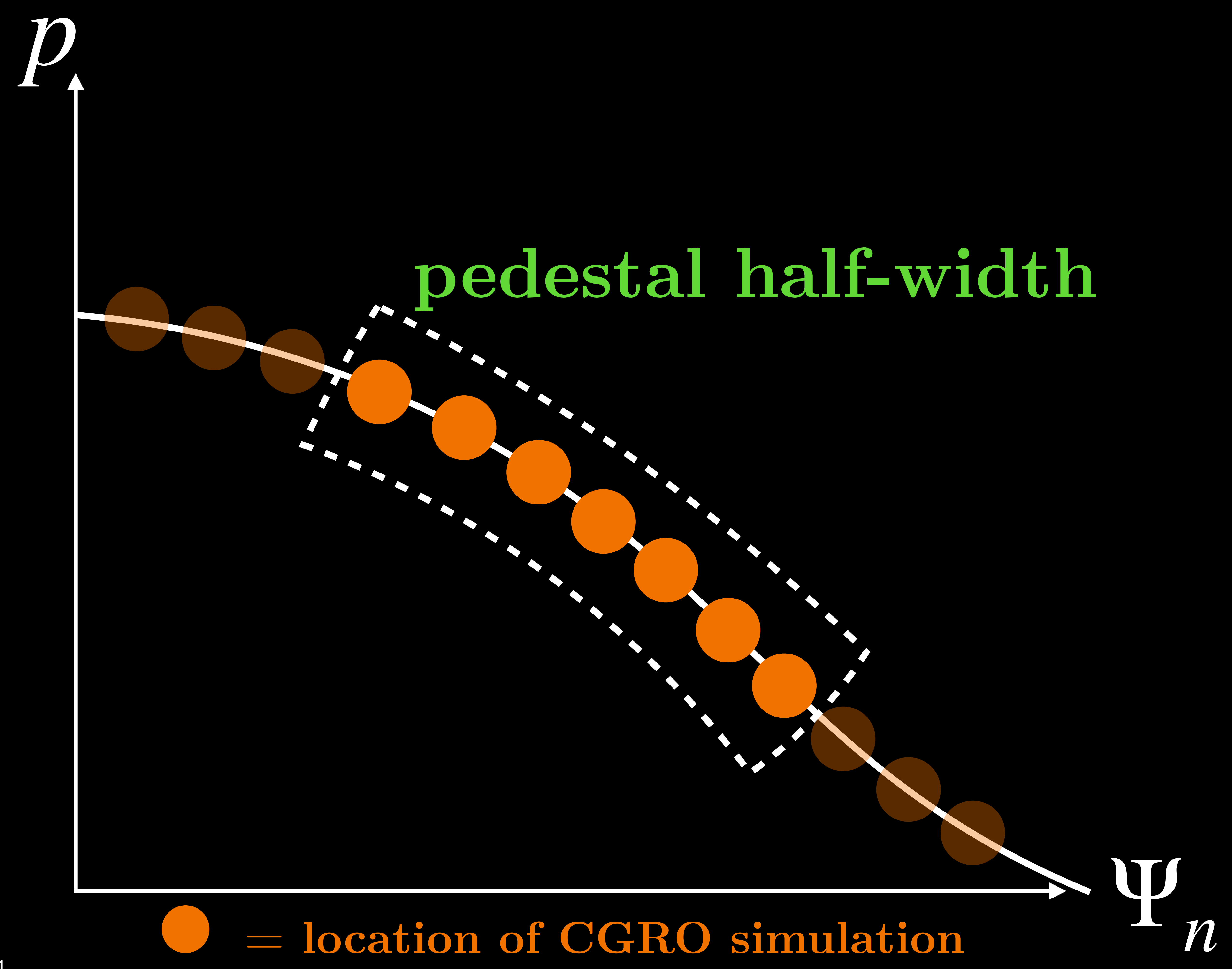
- Recall: for a pedestal to be 'unstable', **100% of radial locations** in pedestal half-width to be KBM/ideal unstable.

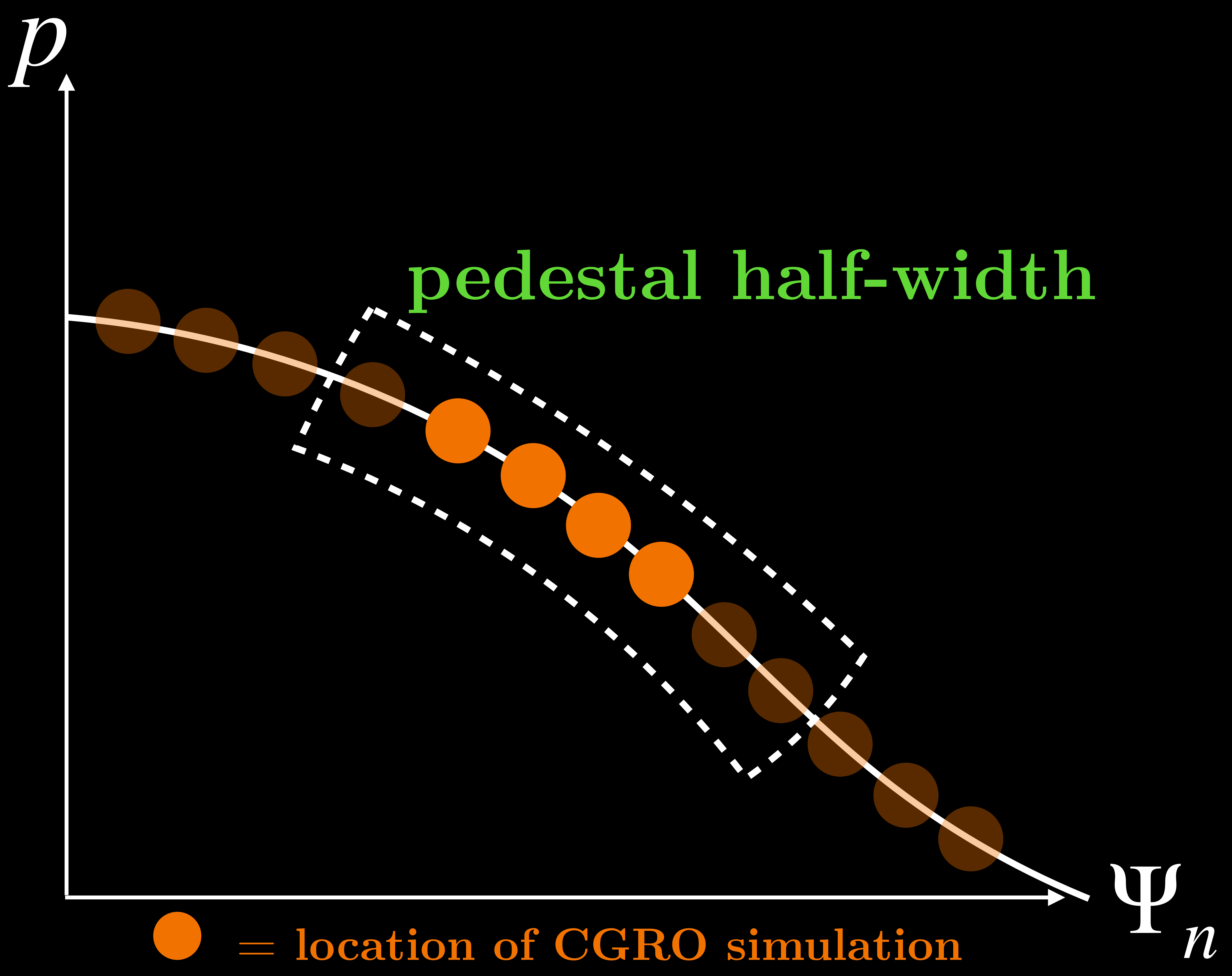


Testing the critical pedestal criteria

How many radial points for a 'critical' pedestal?

- Recall: for a pedestal to be 'unstable', **100% of radial locations** in pedestal half-width to be KBM/ideal unstable.

- What if we relaxed this criterion?



Testing the critical pedestal criteria

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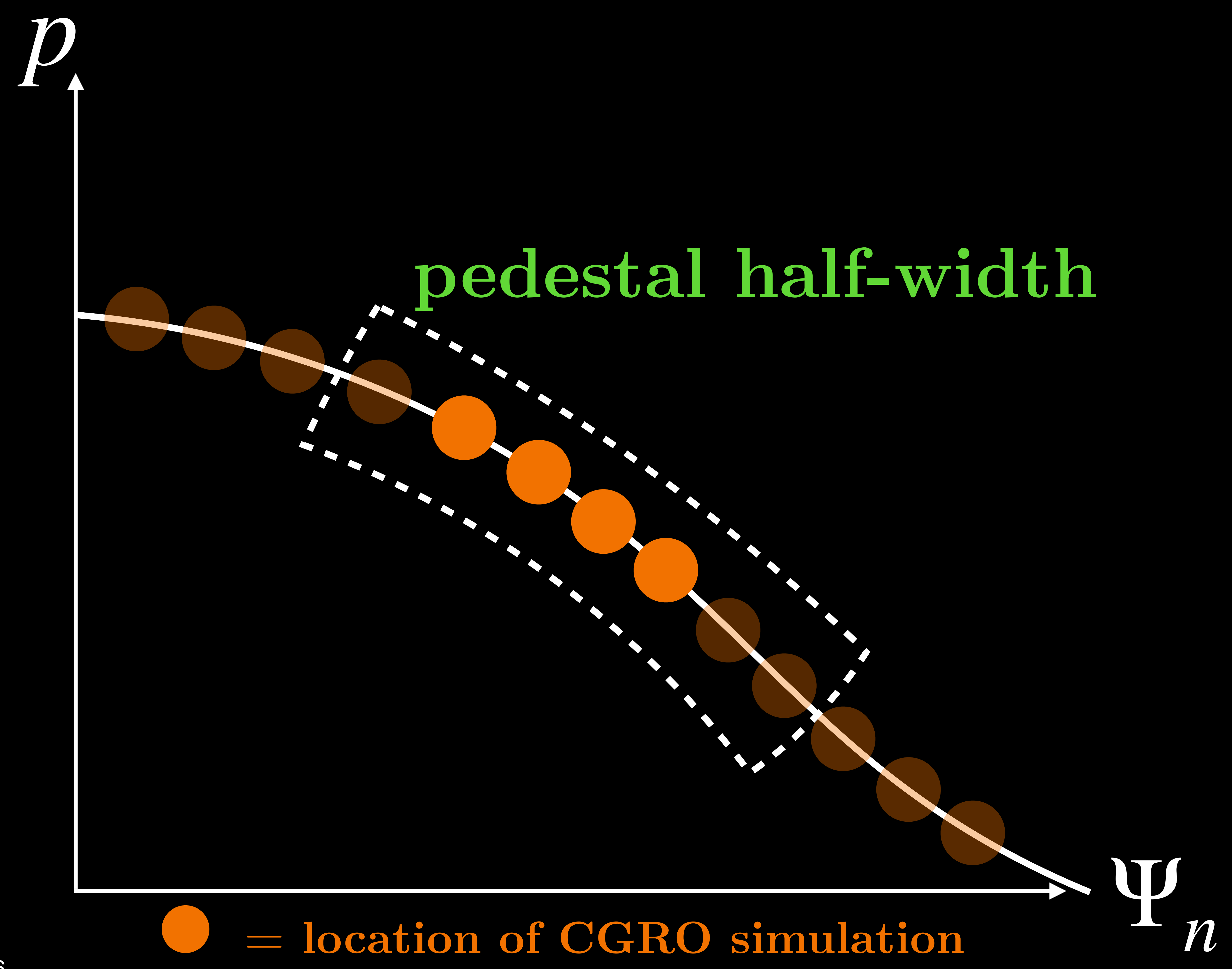
- Recall: for a pedestal to be 'unstable', **100% of radial locations** in pedestal half-width to be KBM/ideal unstable.
- Generalizing criterion to **xx%** of radial locations unstable, we measure error between GCP/BCP scaling and experiment.



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- Find:
  1) **KBM** Δ scaling improves as **xx**→100%

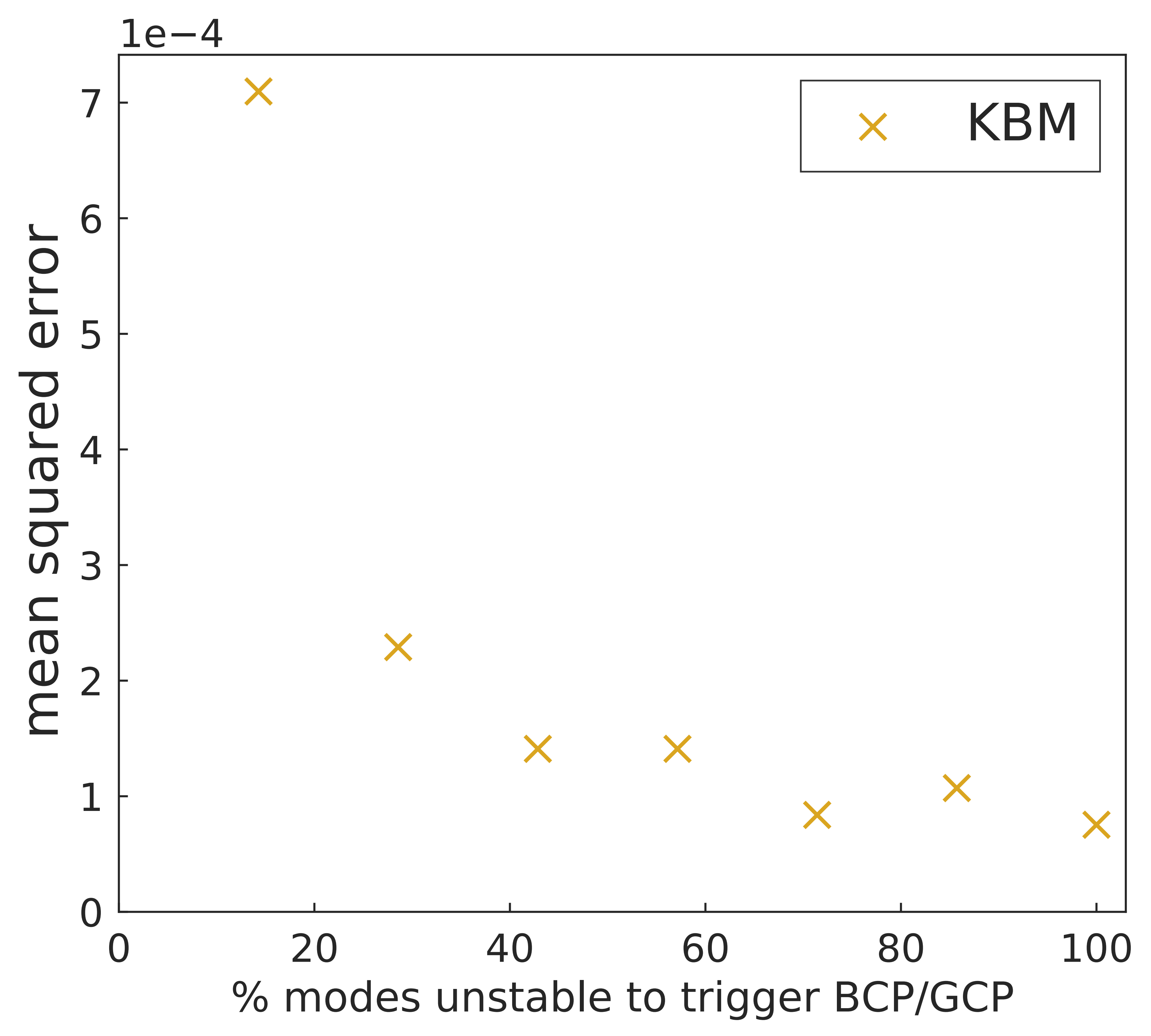


Fig: Mean squared error versus % of modes needed to trigger BCP/GCP. Error calculated from theory and ELMy NSTX experiments.

Testing the critical pedestal criteria

How many radial points for a 'critical' pedestal?

- Recall: for a pedestal to be 'unstable', **100% of radial locations** in pedestal half-width to be KBM/ideal unstable.
- Generalizing criterion to **xx%** of radial locations unstable, we measure error between GCP/BCP scaling and experiment.
- Find:
  1) **KBM** Δ scaling improves as **xx**→100%
  2) **ideal** Δ scaling degrades as **xx**→100%

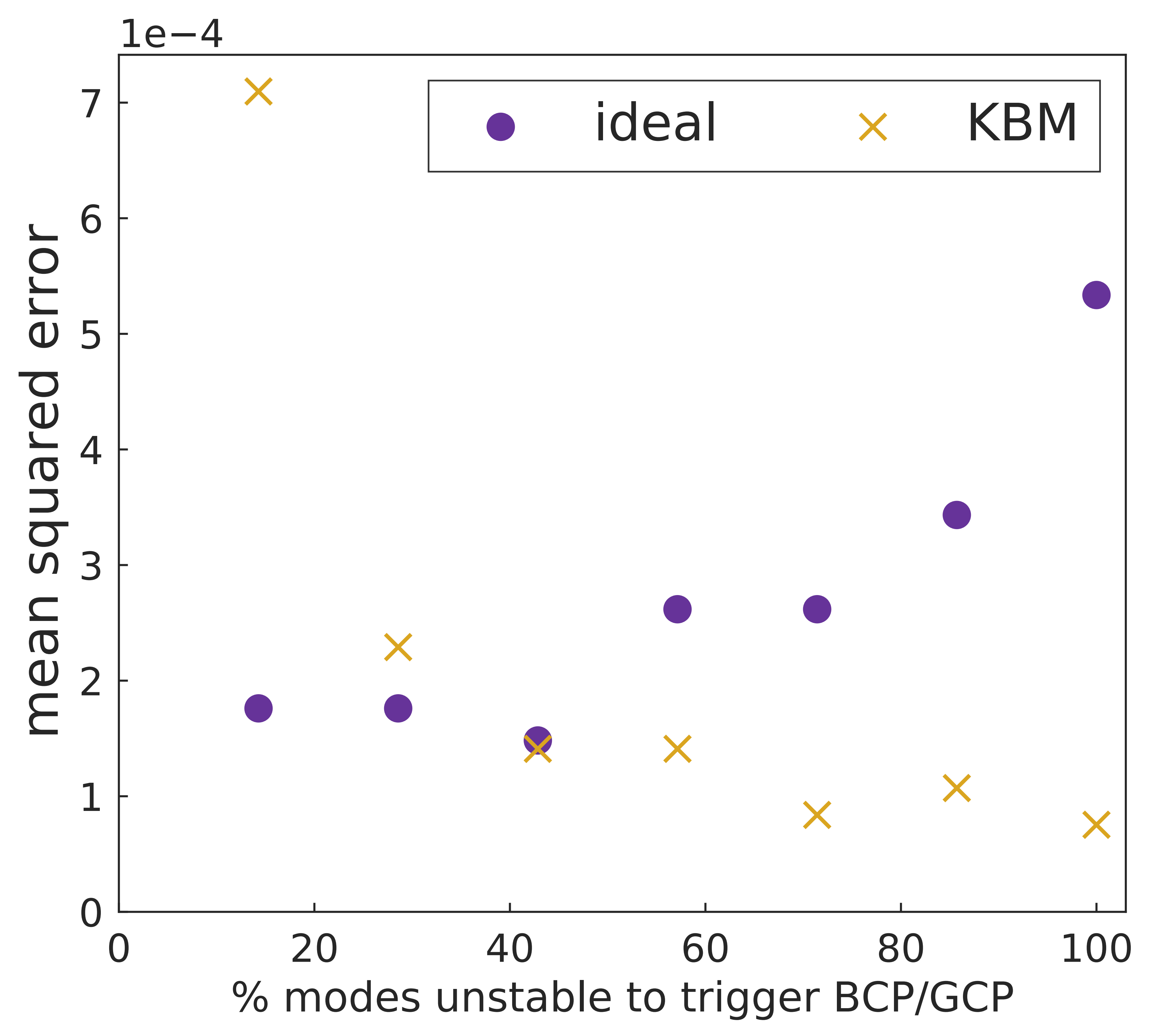


Fig: Mean squared error versus % of modes needed to trigger BCP/GCP. Error calculated from theory and ELMy NSTX experiments.

Testing the critical pedestal criteria

How many radial points for a 'critical' pedestal?

occurs because **ideal** **overpredicts NSTX** p_{ped}

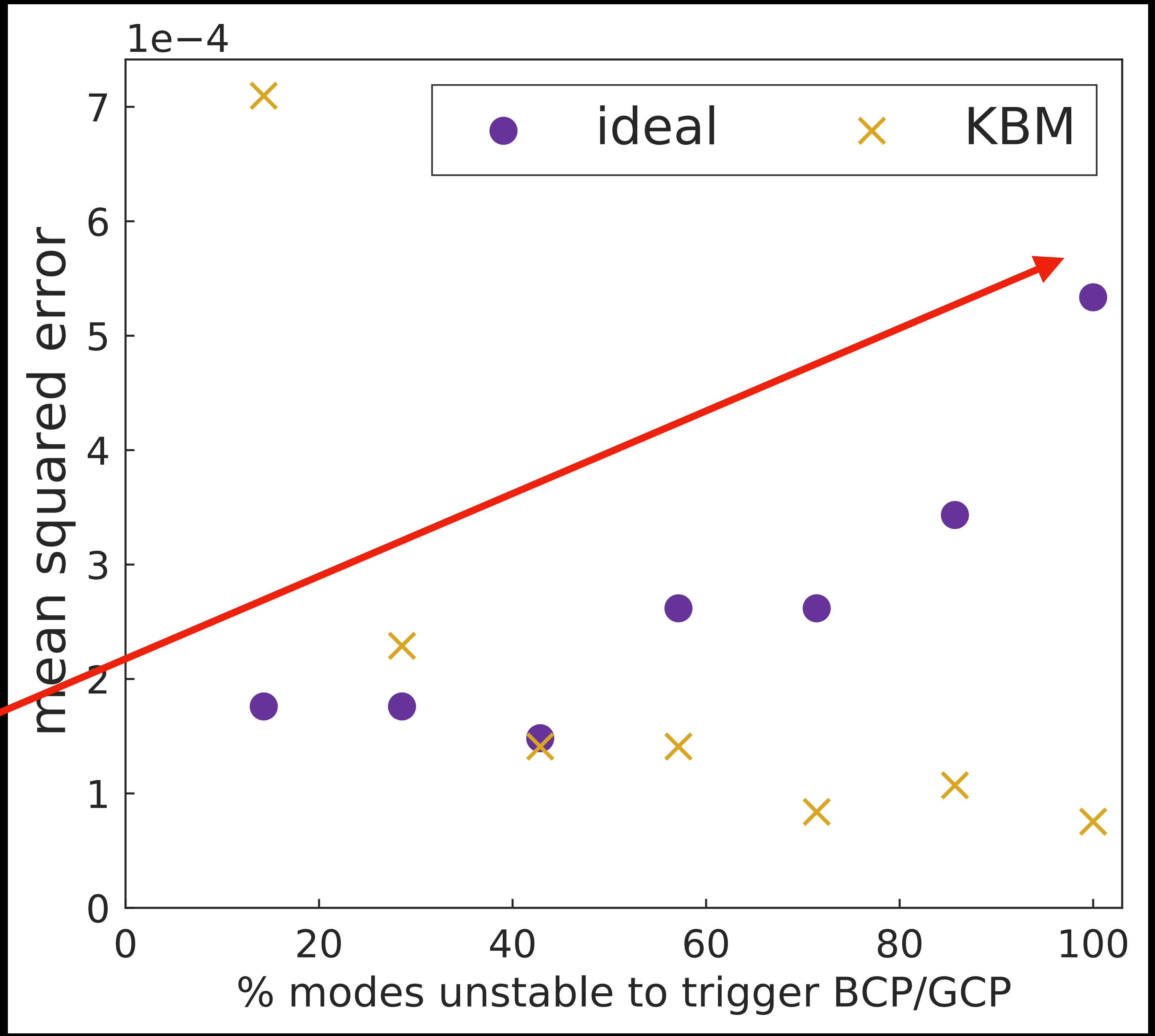
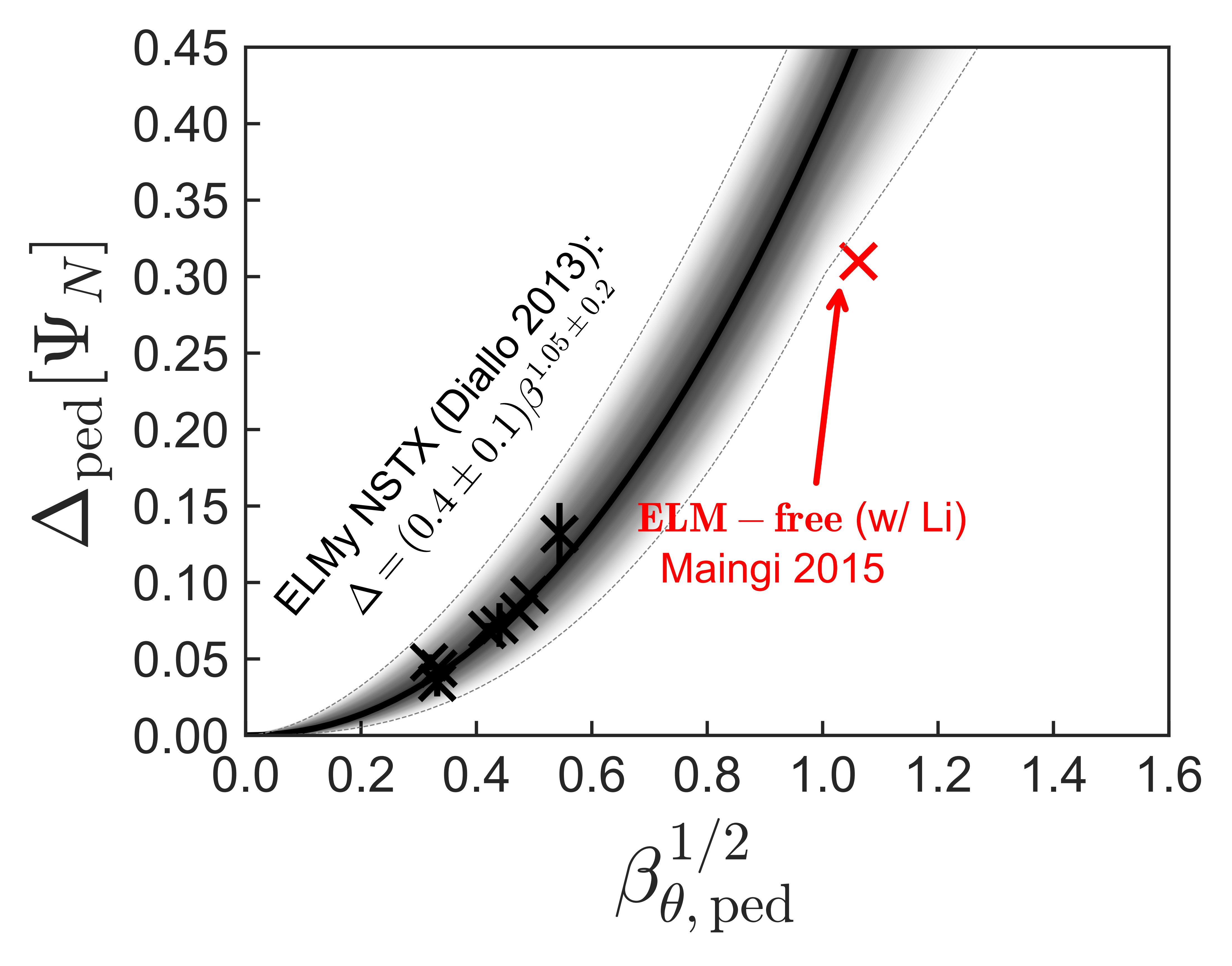


Fig: Mean squared error versus % of modes needed to trigger BCP/GCP. Error calculated from theory and ELMy NSTX experiments.

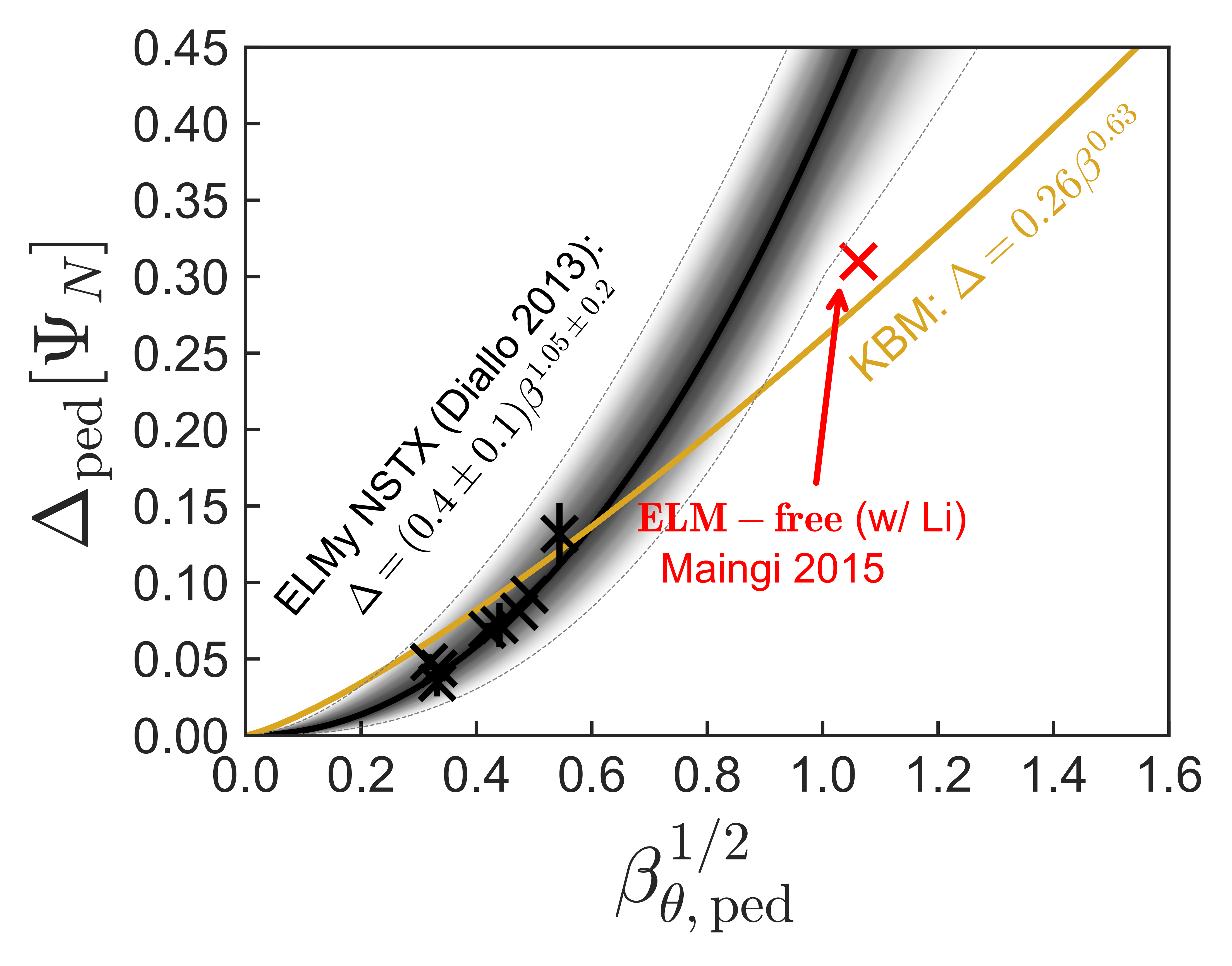
Wide Pedestal KBM Scaling

- ELM-free lithiated NSTX discharges can have wider, higher pedestals [Maingi, 2015, 2017].



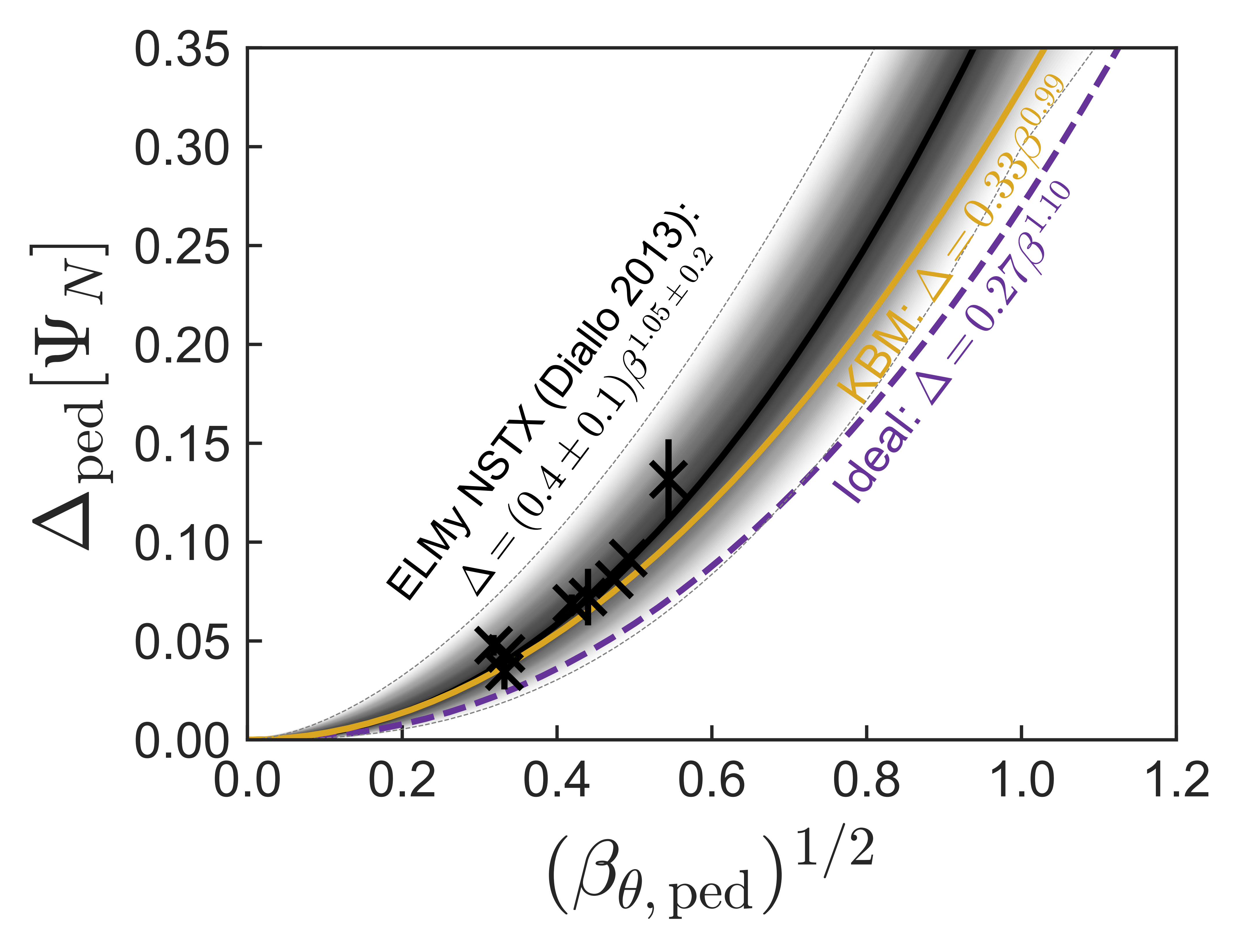
Wide Pedestal KBM Scaling

- ELM-free lithiated NSTX discharges can have wider, higher pedestals [Maingi, 2015, 2017].
- **KBM GCP** for NSTX 132588 gives weaker Δ scaling, likely within experimental uncertainty.



Part I Summary

- **Original hypothesis:** **KBM** can predict pedestal height and width ∇p constraint for NSTX.



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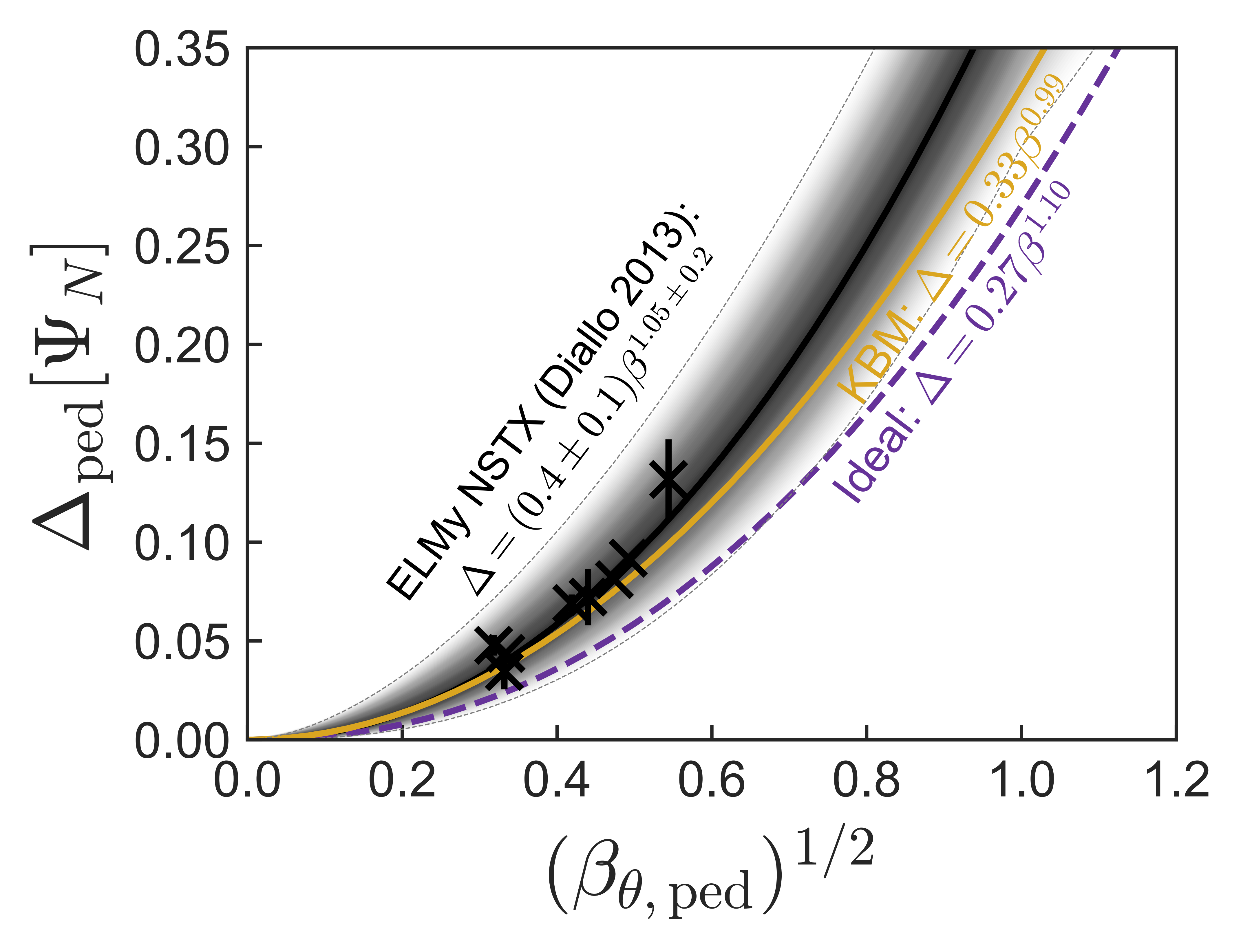

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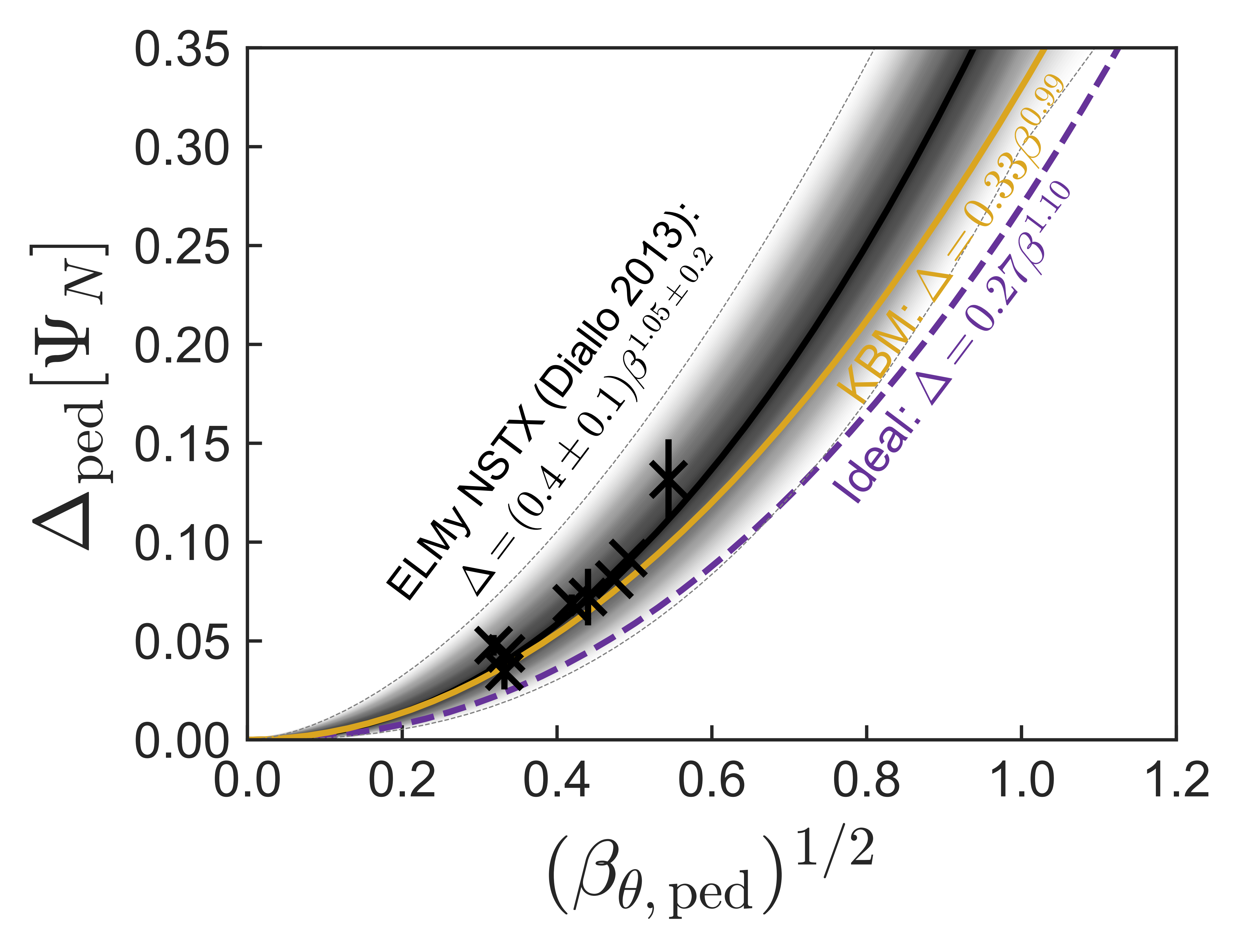
- **Good news: ideal** ballooning stability with sufficient equilibrium information *might* be good enough for future ST devices.



Part II: Transport

Transport

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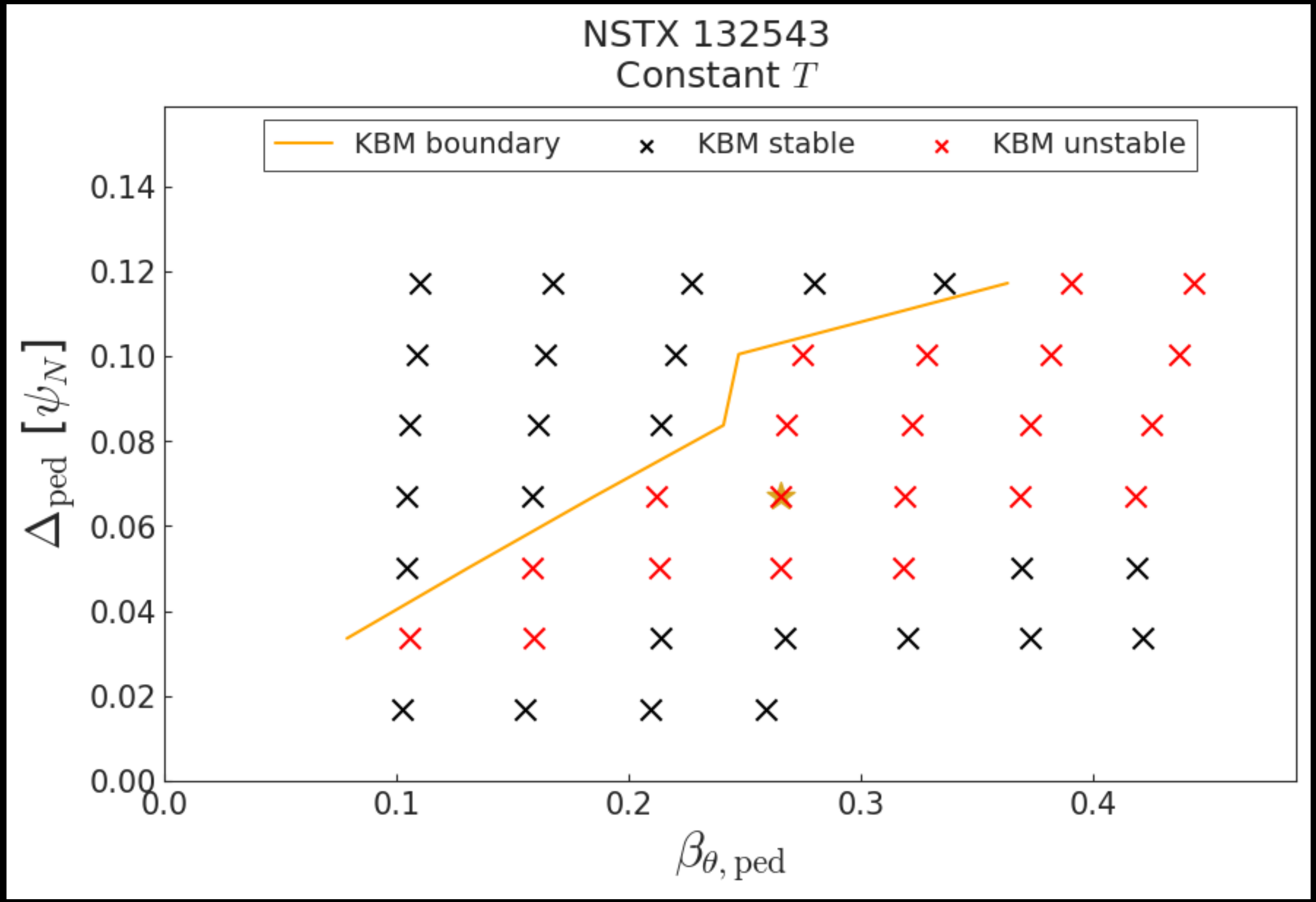

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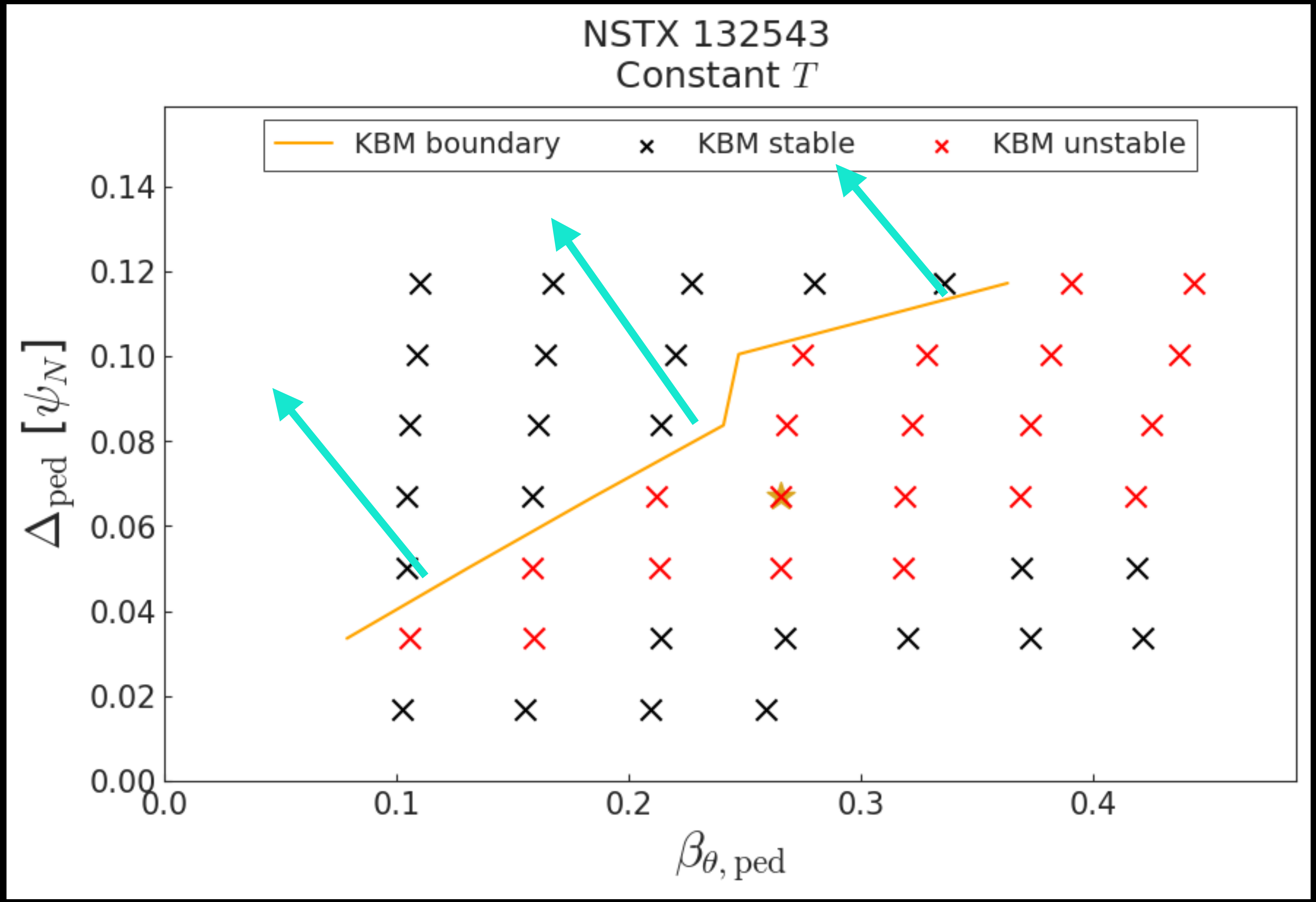
Accessible equilibria during pedestal buildup



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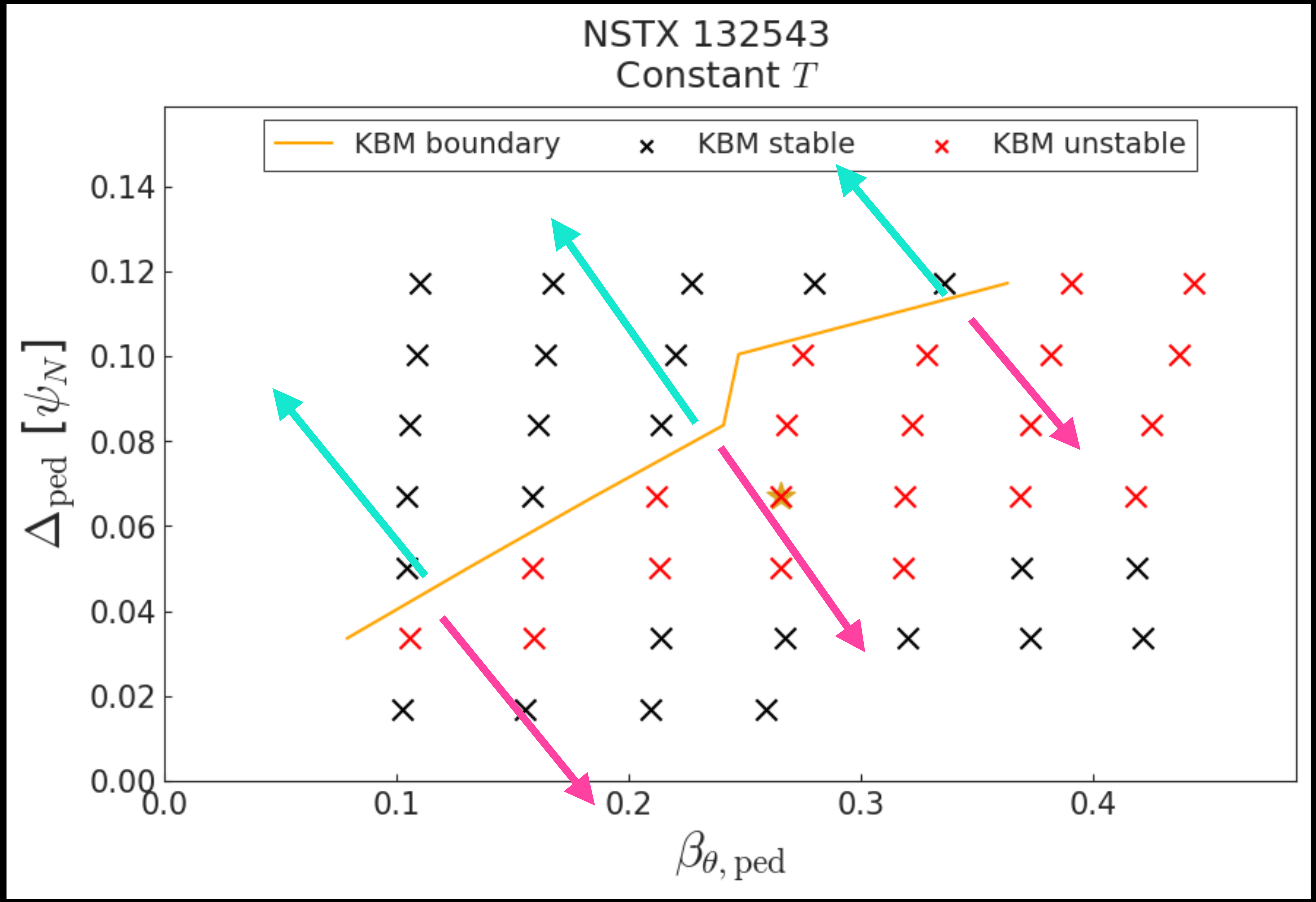

Inaccessible equilibria?...

Transport

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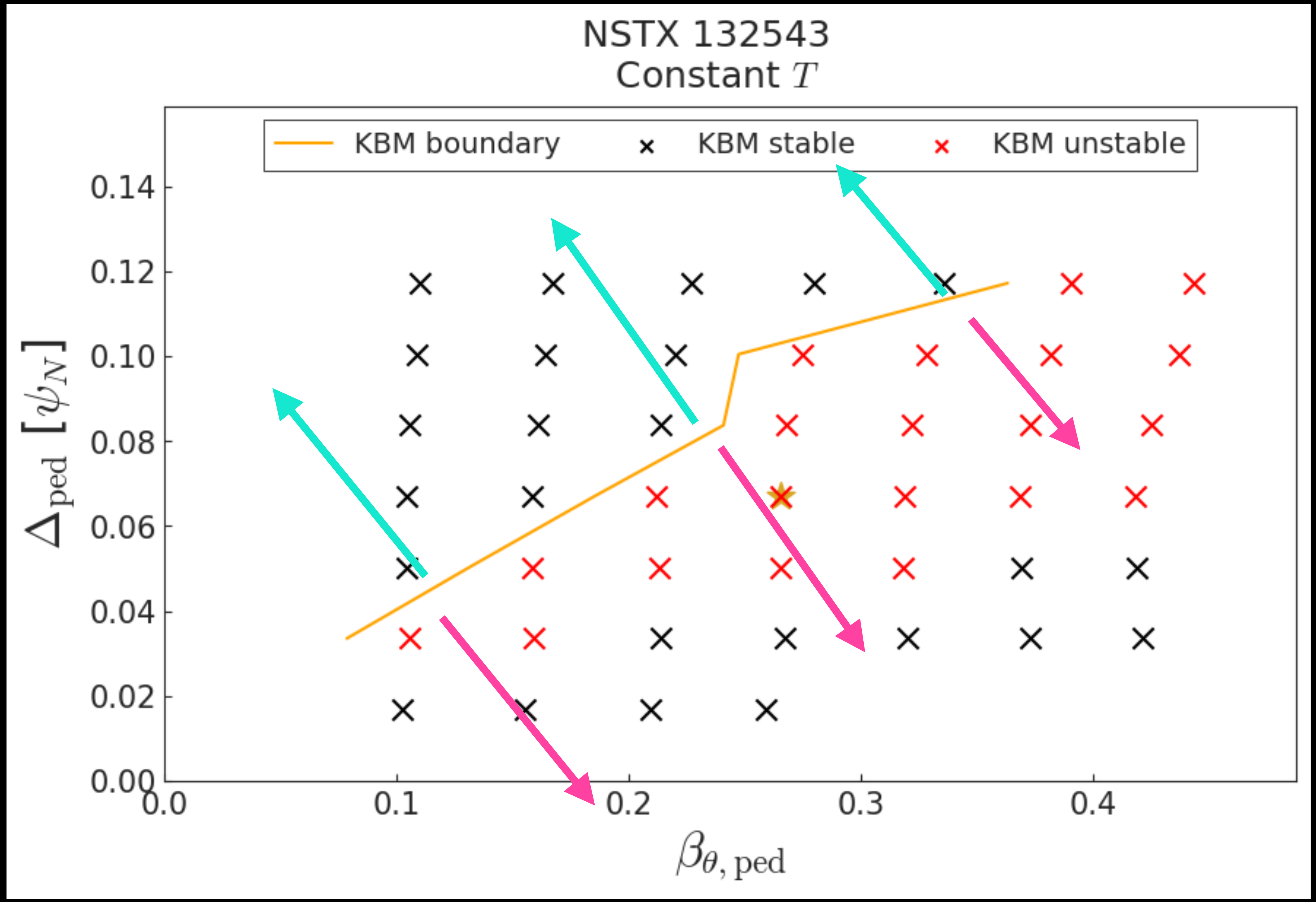

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  $\rightarrow$
  Affects pedestal profile evolution.

Transport Picture: Particle Vs. Heat

Constant n

- As pedestal pressure builds up, D_e/χ_e increases.

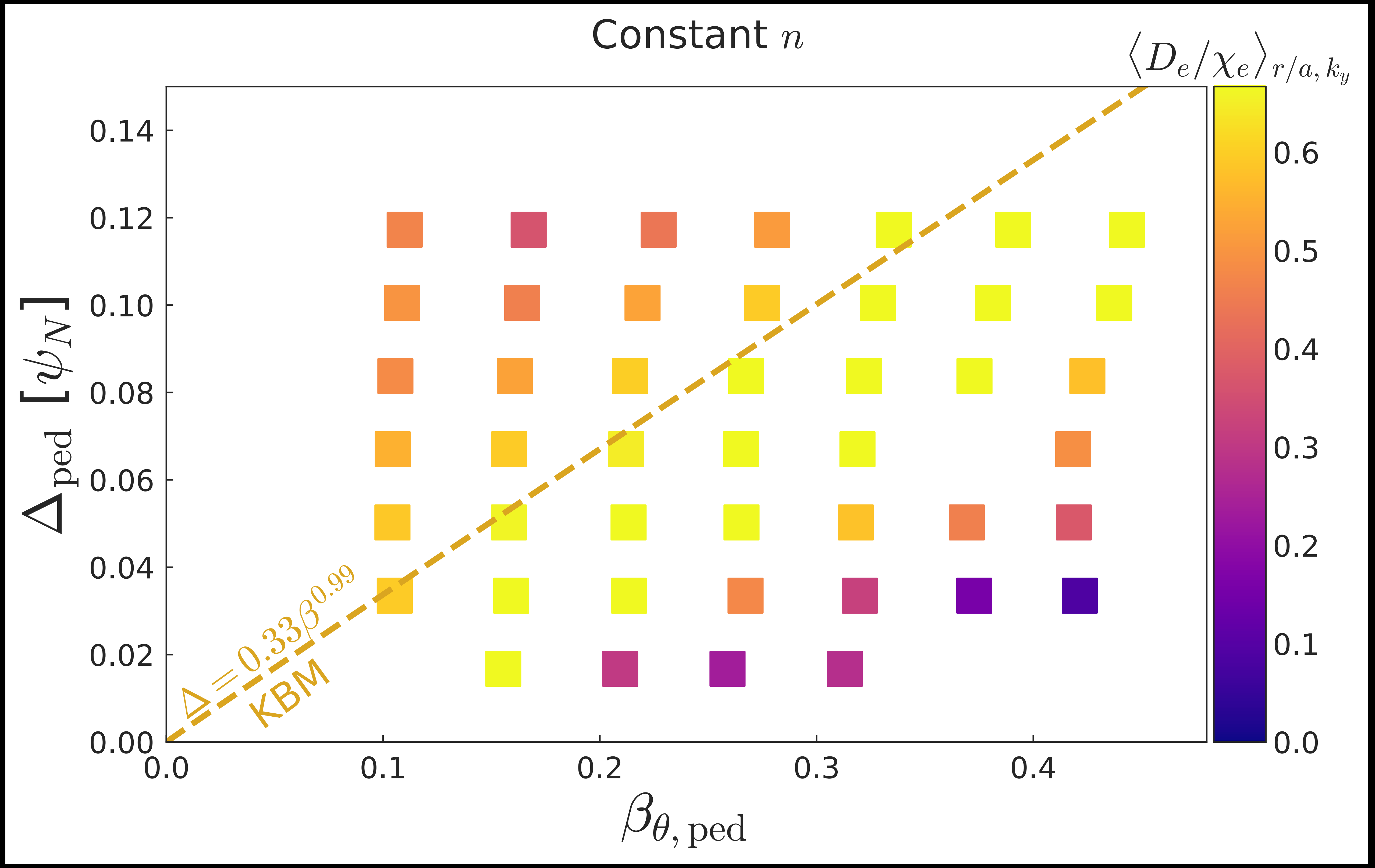

Fig 1: D_e/χ_e versus Δ_{ped} and $\beta_{\theta,\text{ped}}$ for NSTX 132543 with constant n. D_e/χ_e averaged over half-width and all $k_y\rho_i$.

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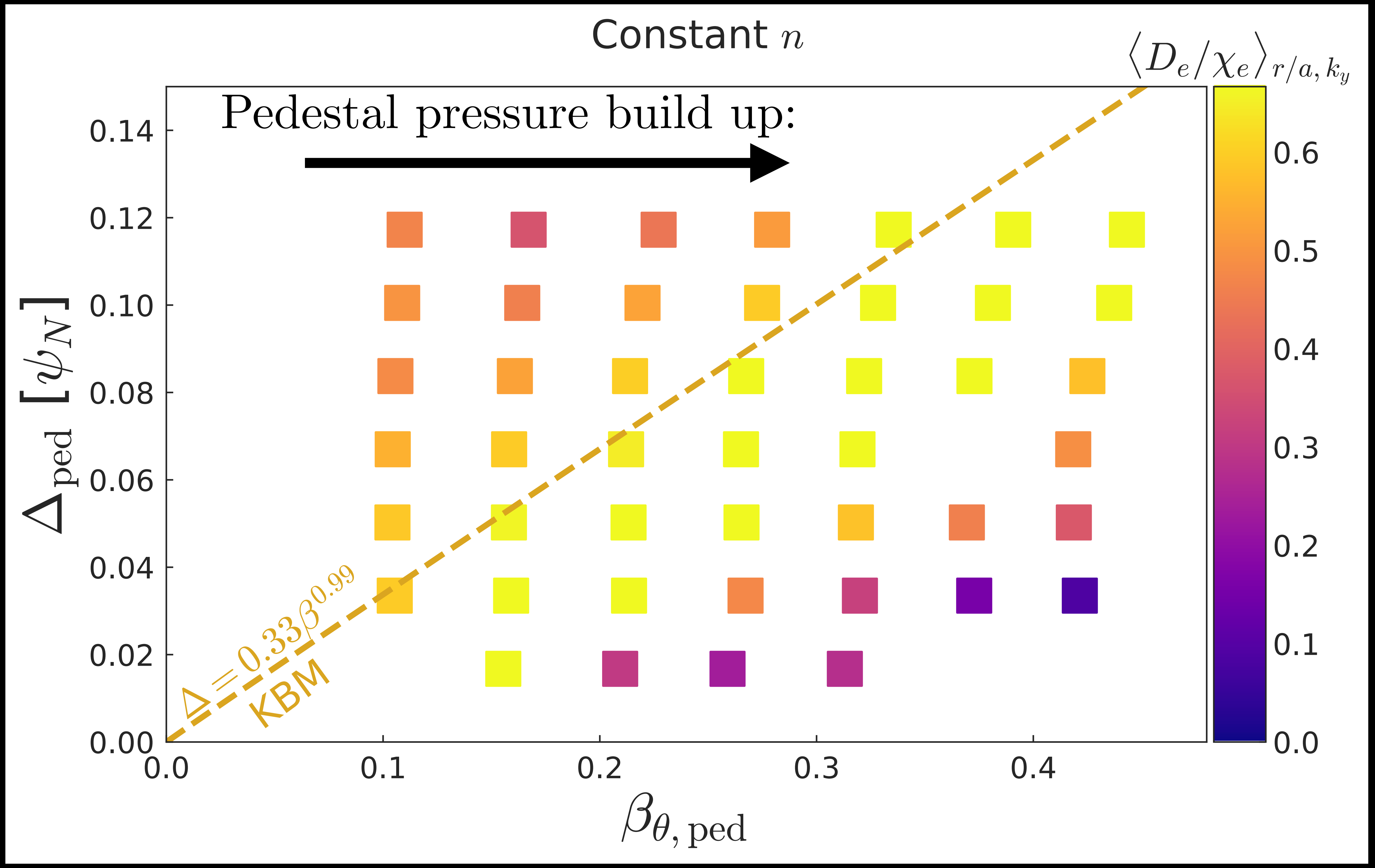

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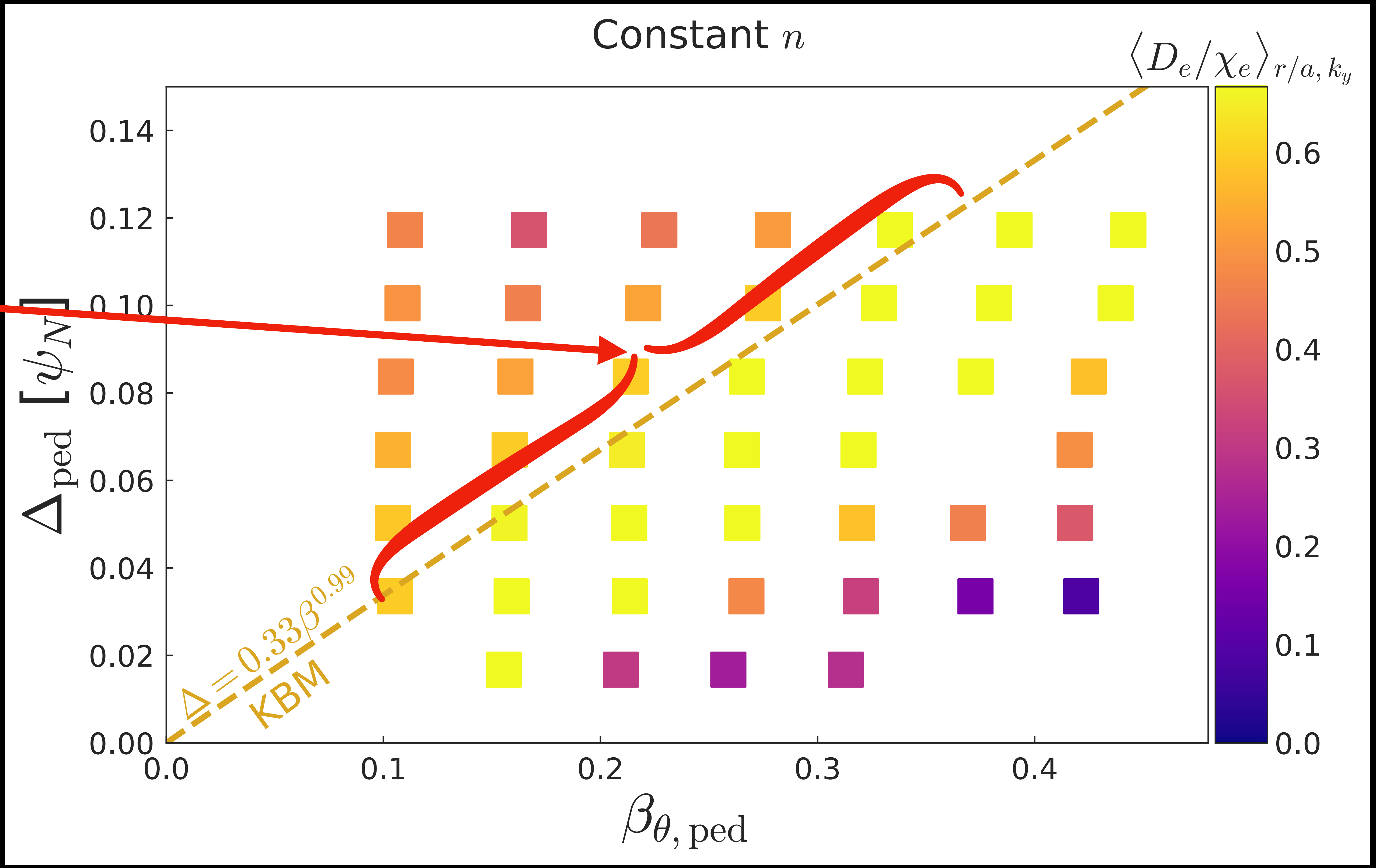

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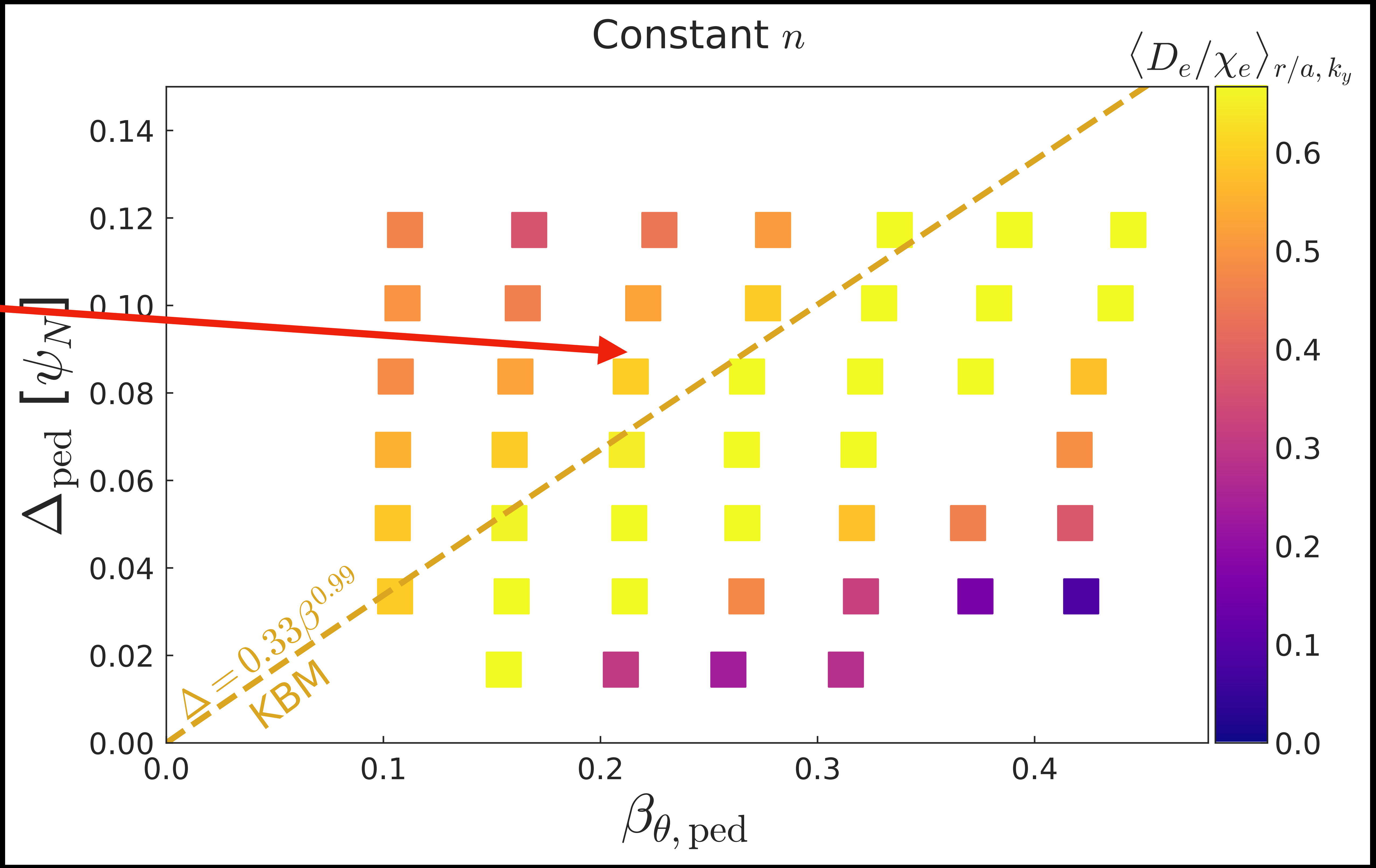
Constant n

Add information about most common mode type



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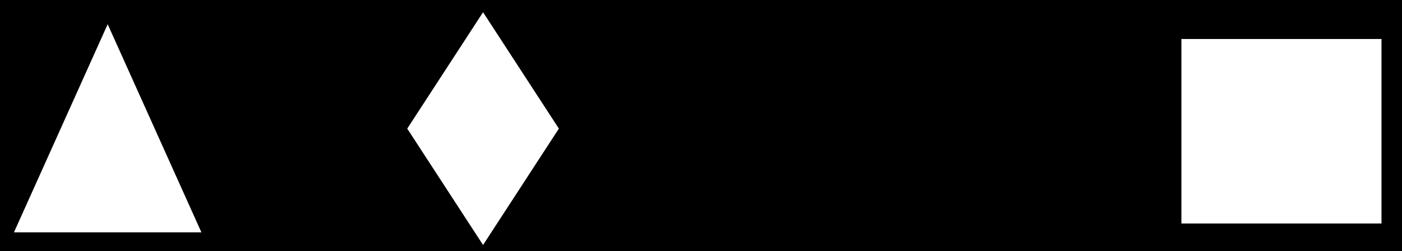
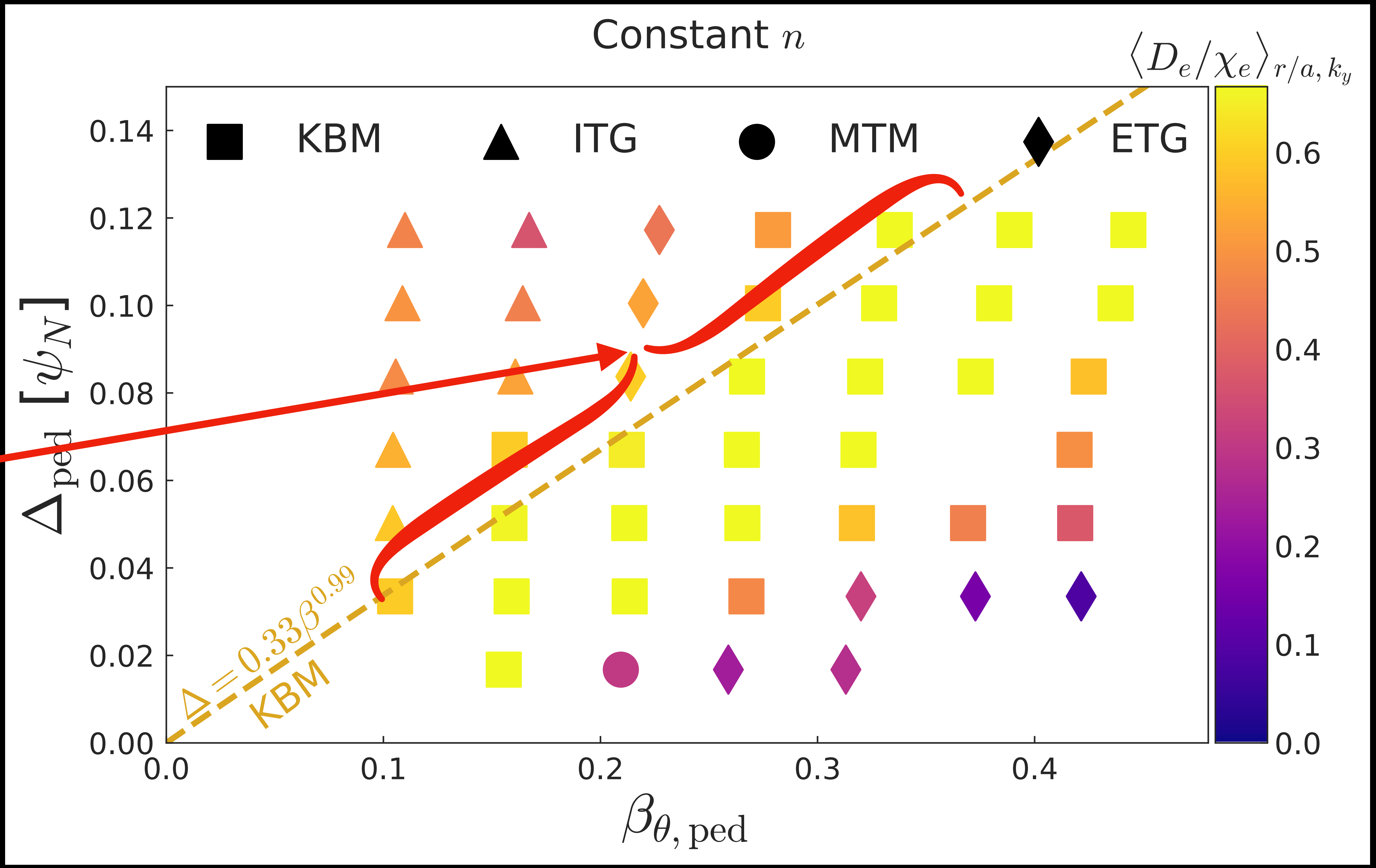
- Distinct D_e/χ_e increase at KBM stability boundary.
- Corresponds with gyrokinetic mode type change across pedestal half-width:

ITG/ETG —> KBM.





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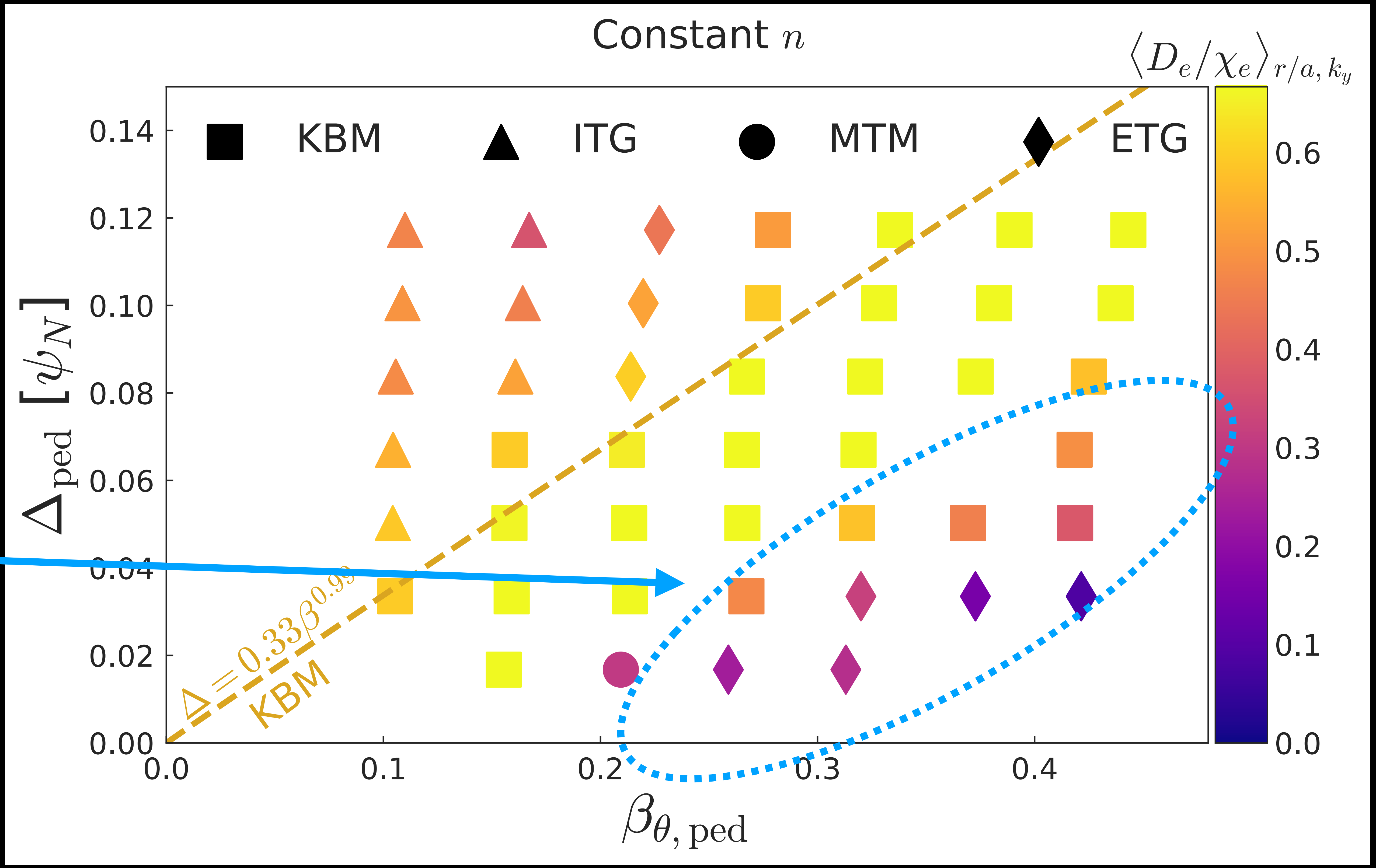

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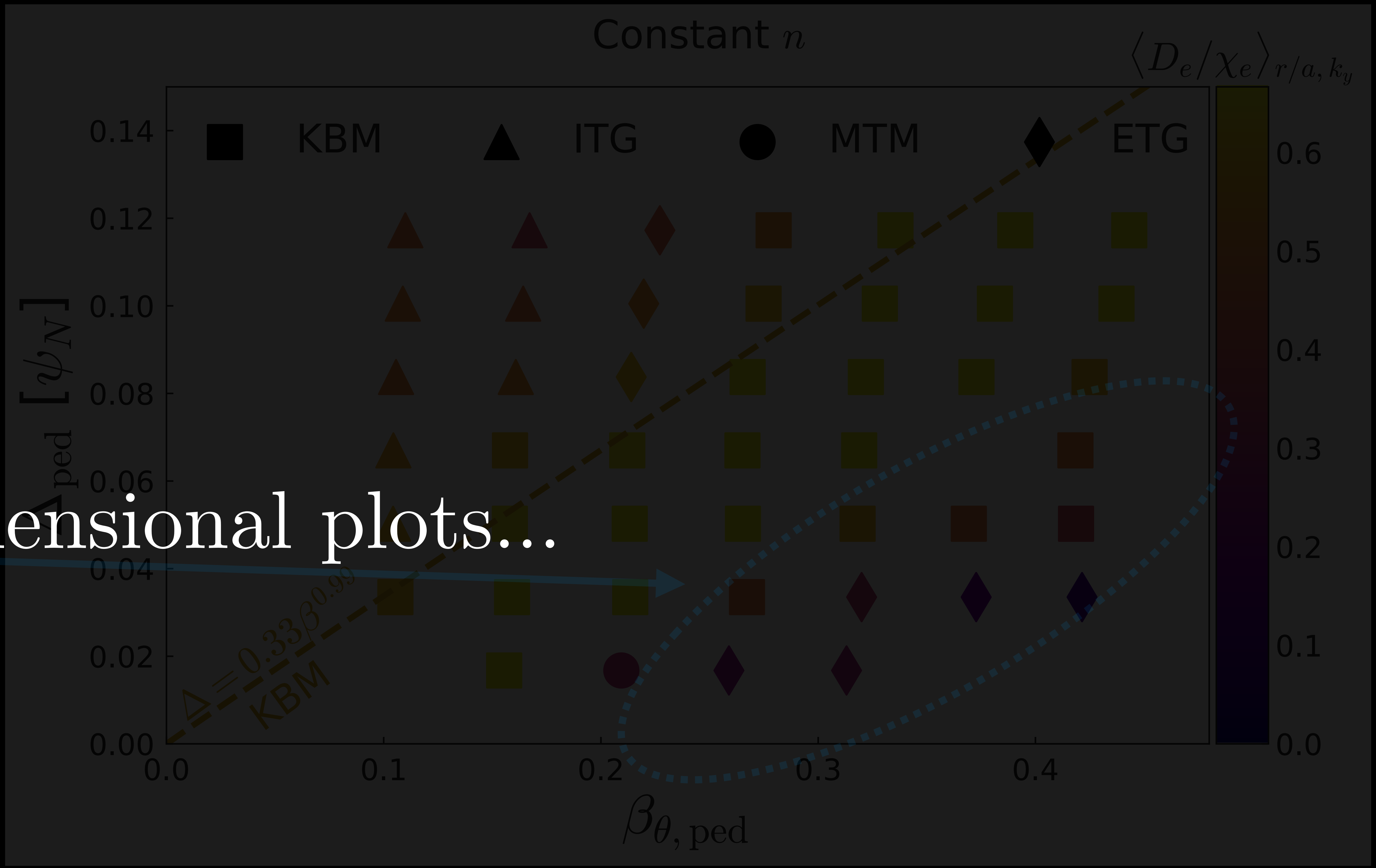
Making 1-dimensional plots...



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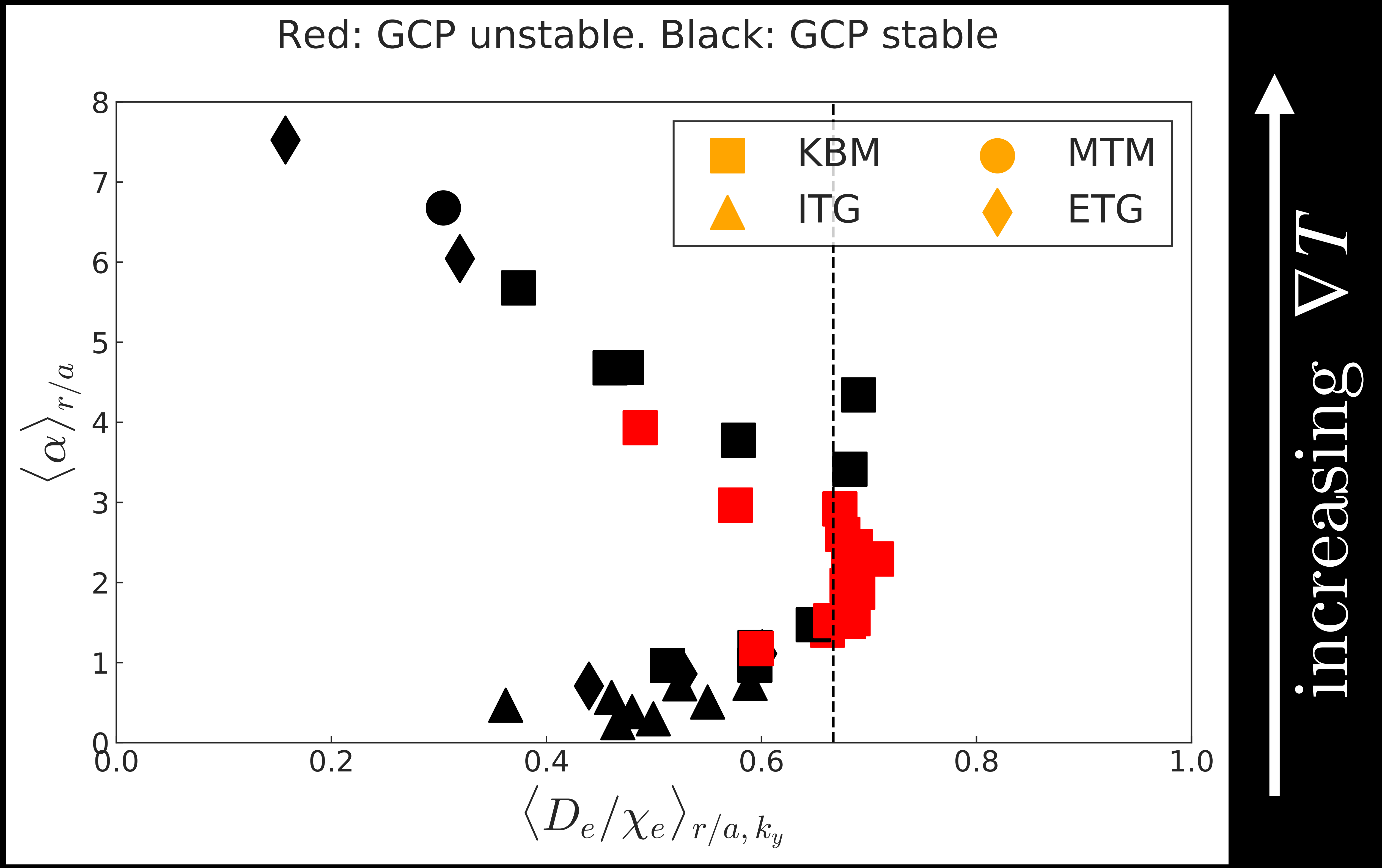

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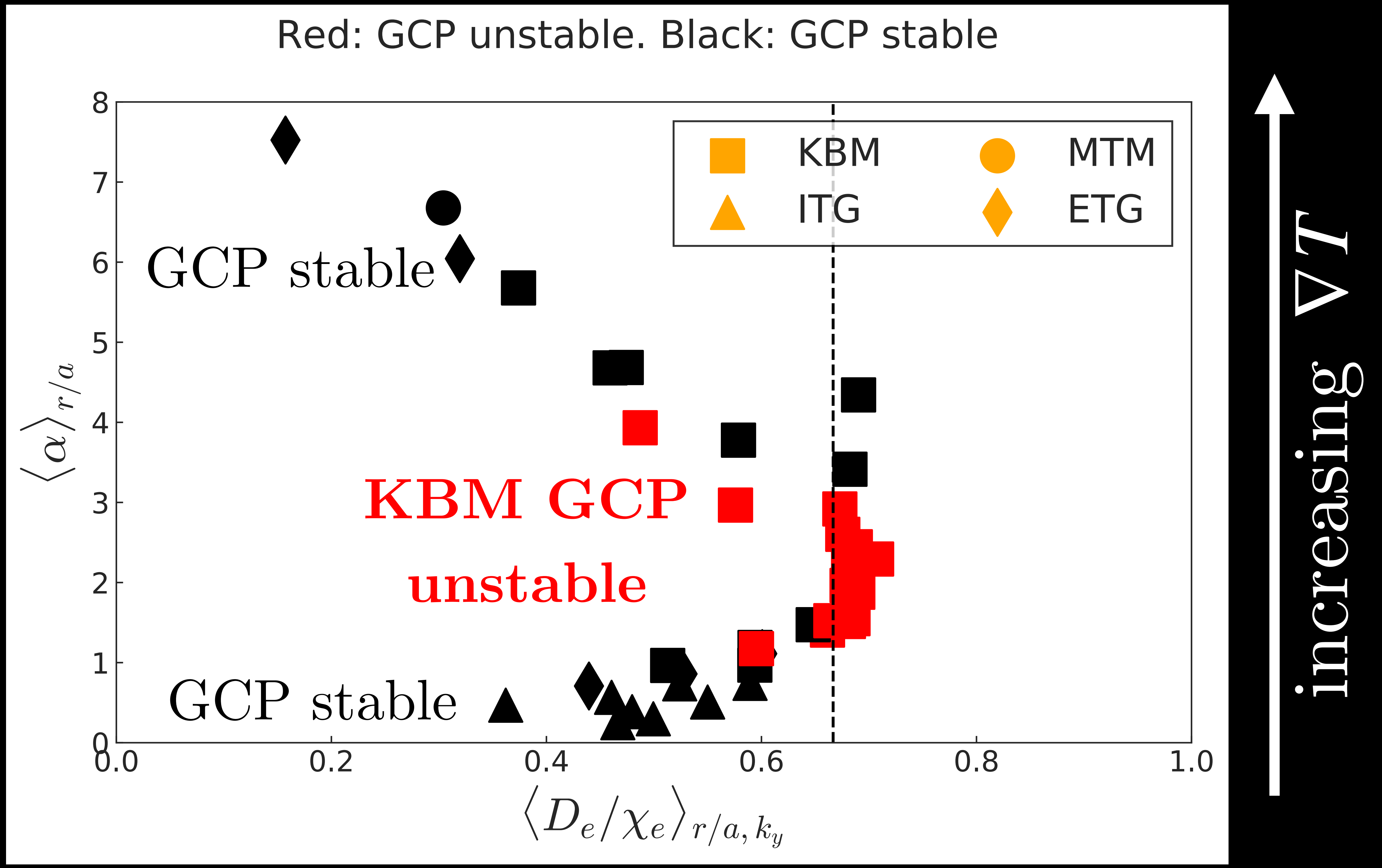
Constant n

- α important parameter for D_e/χ_e.
- **Red regions** GCP unstable to KBM.
- **Black regions** GCP stable to KBM.



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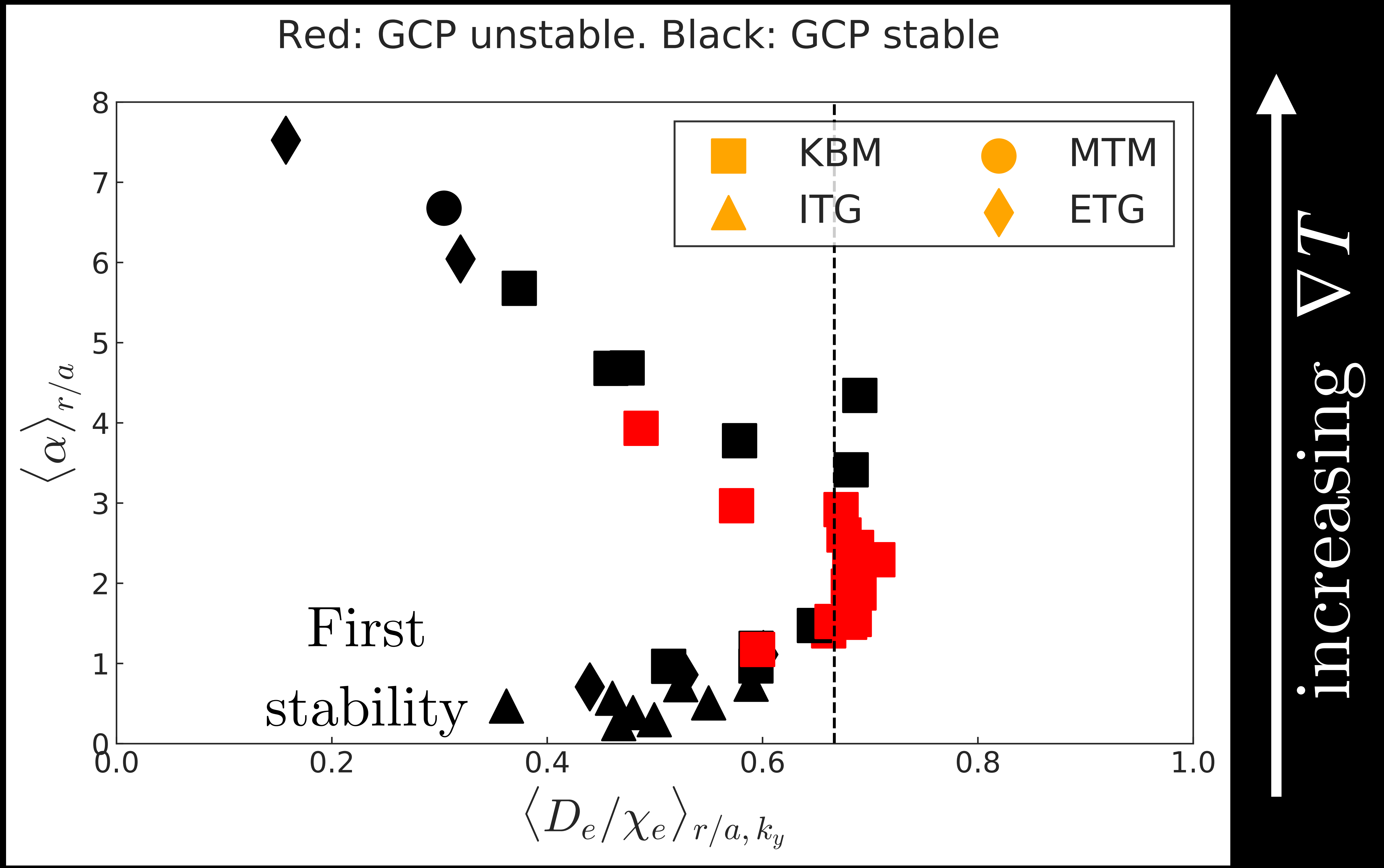

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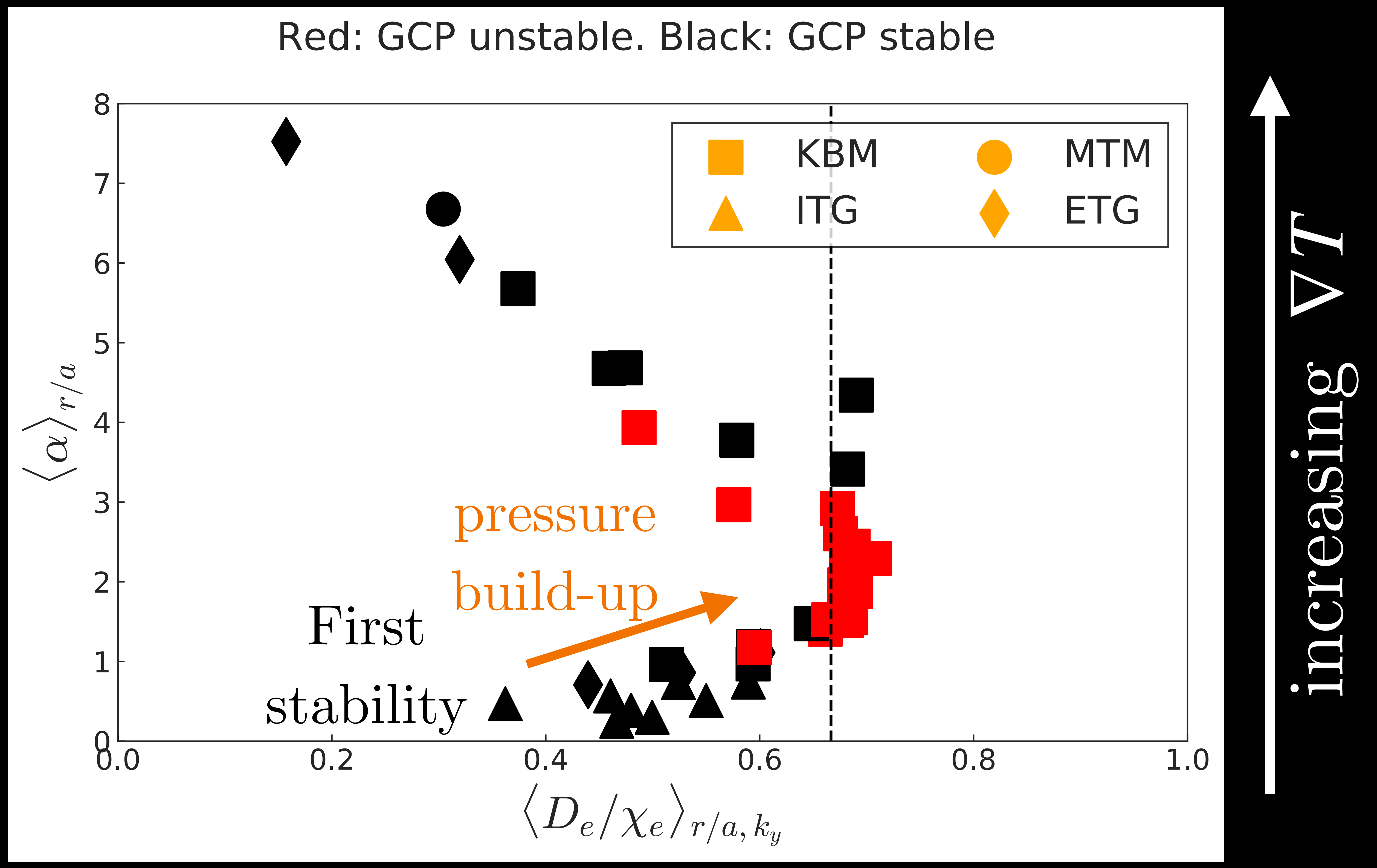

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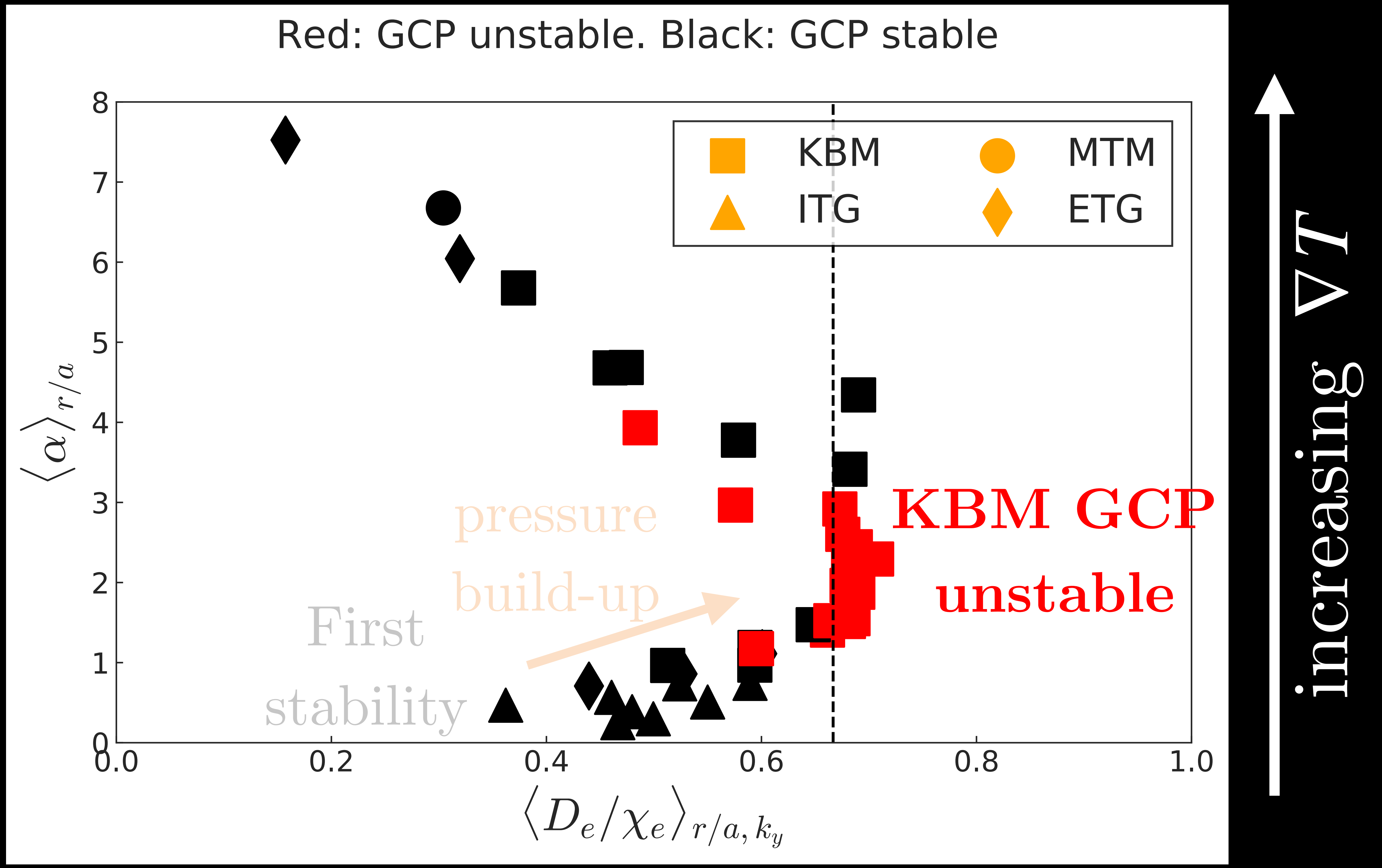

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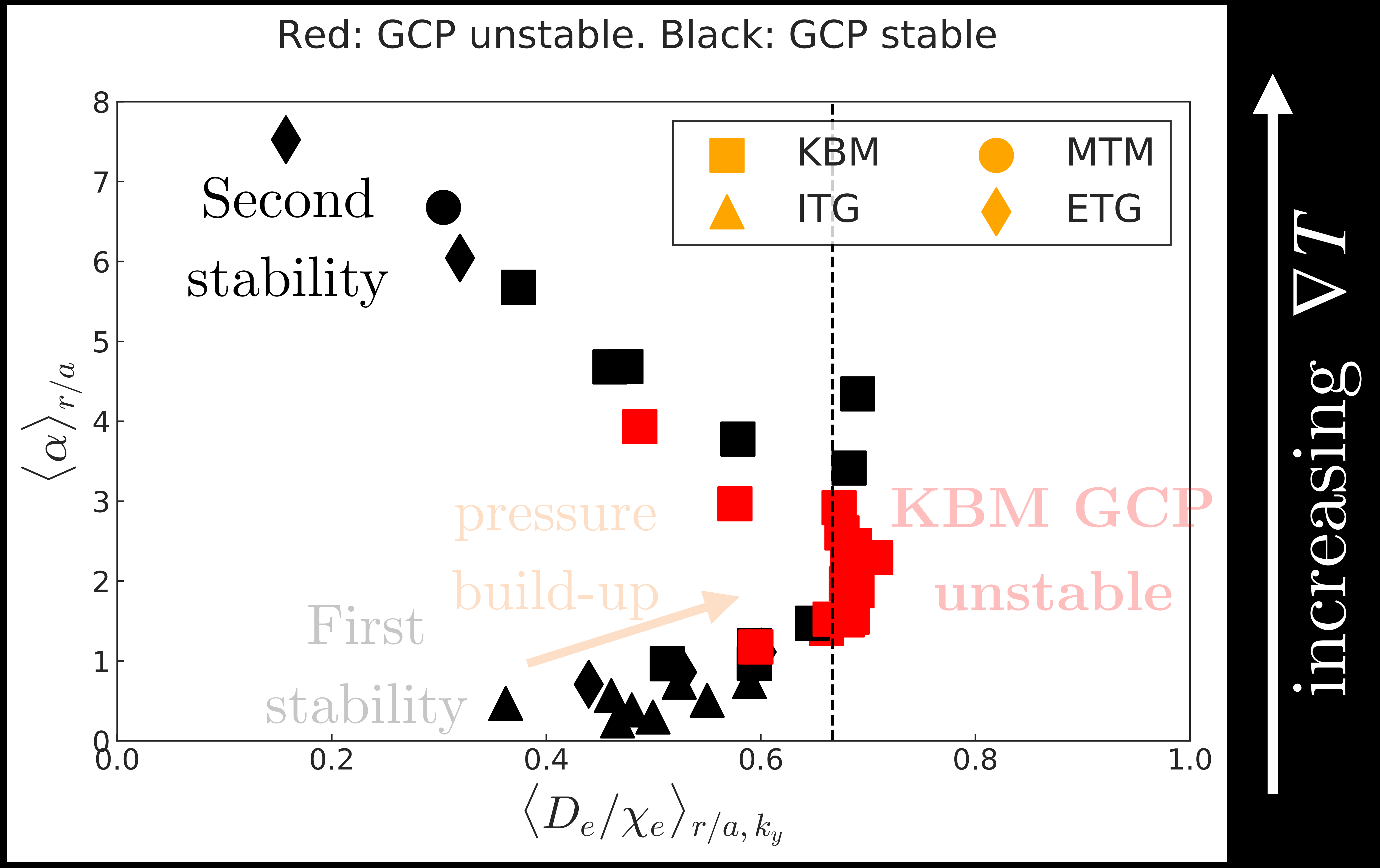

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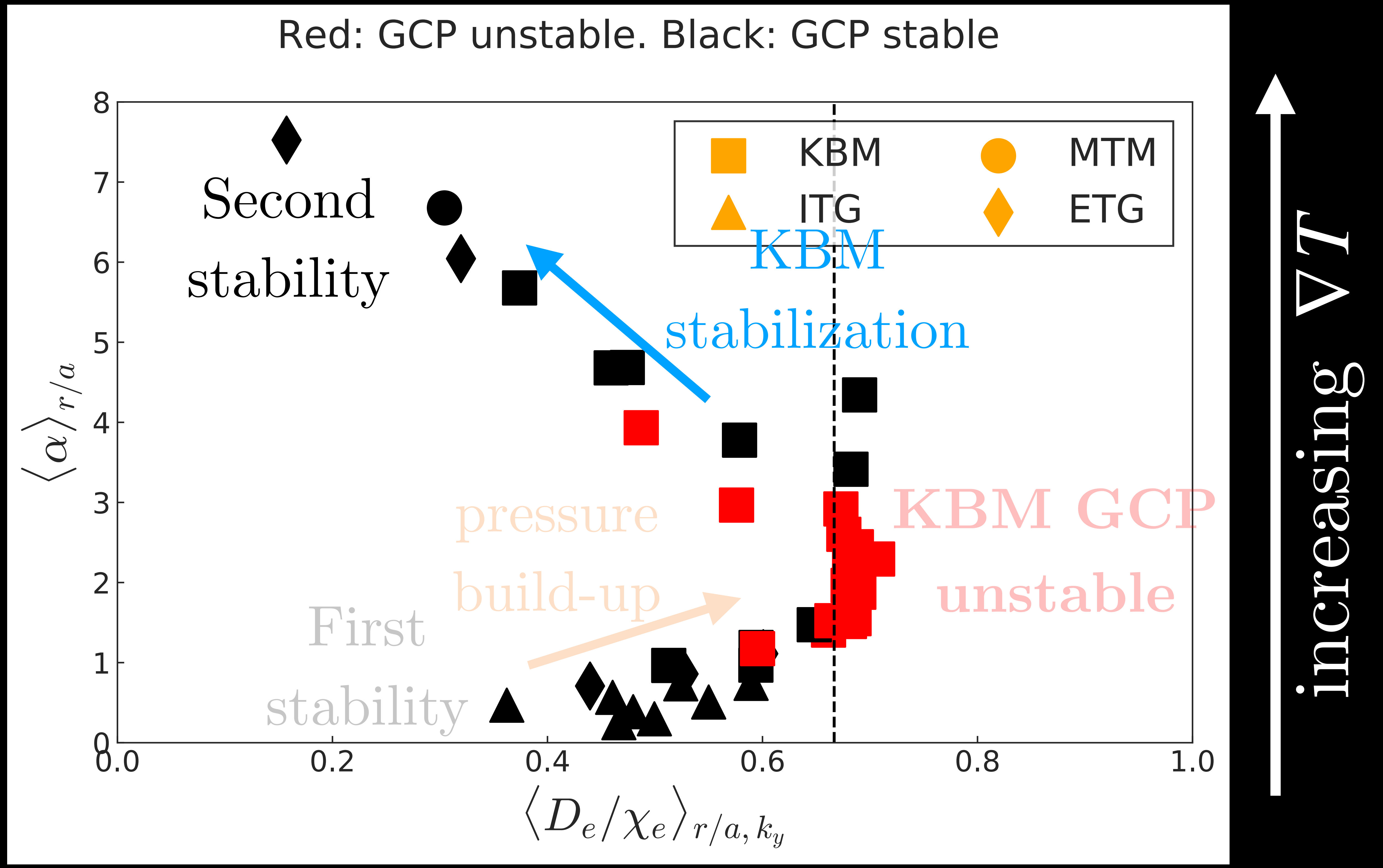

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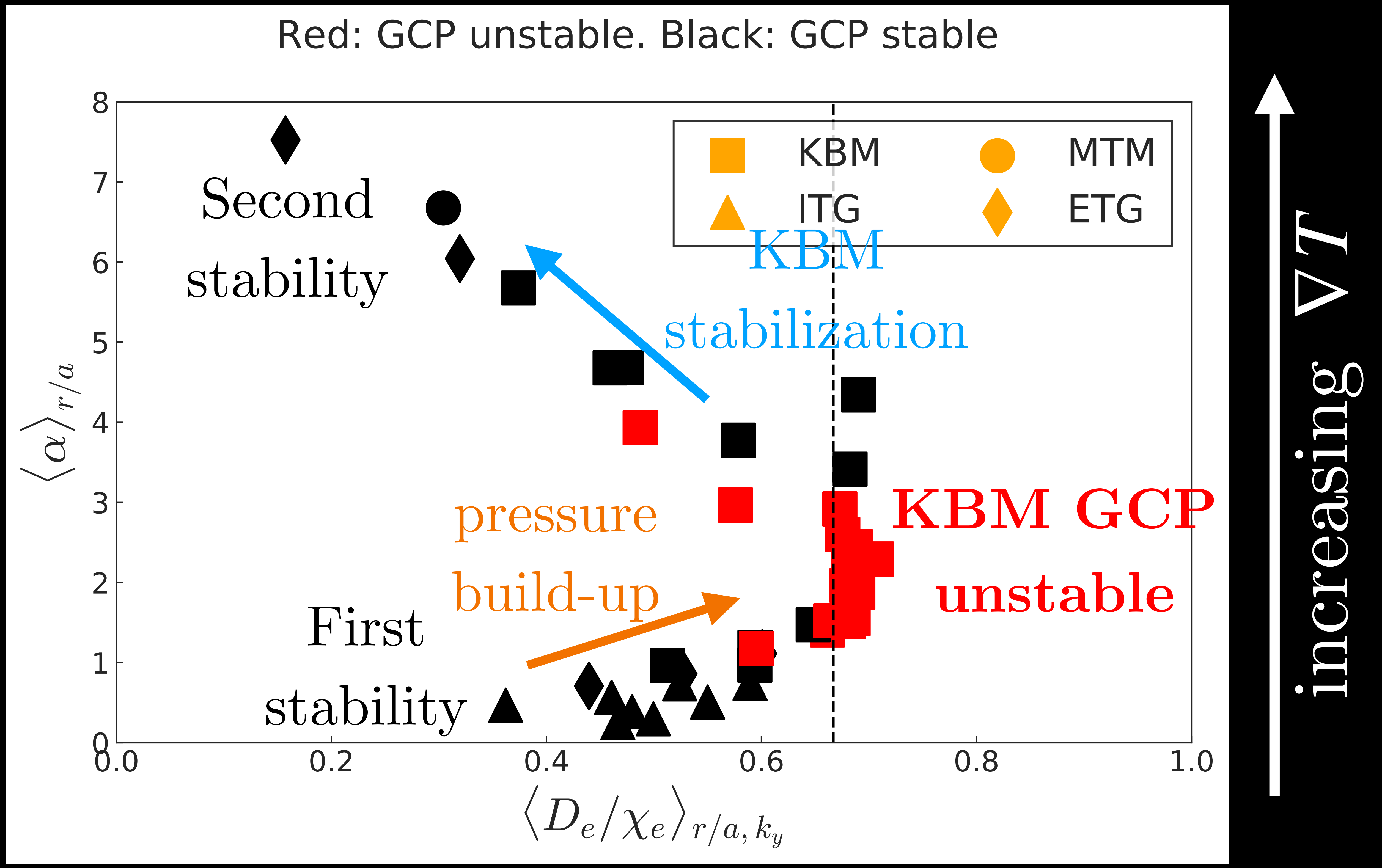

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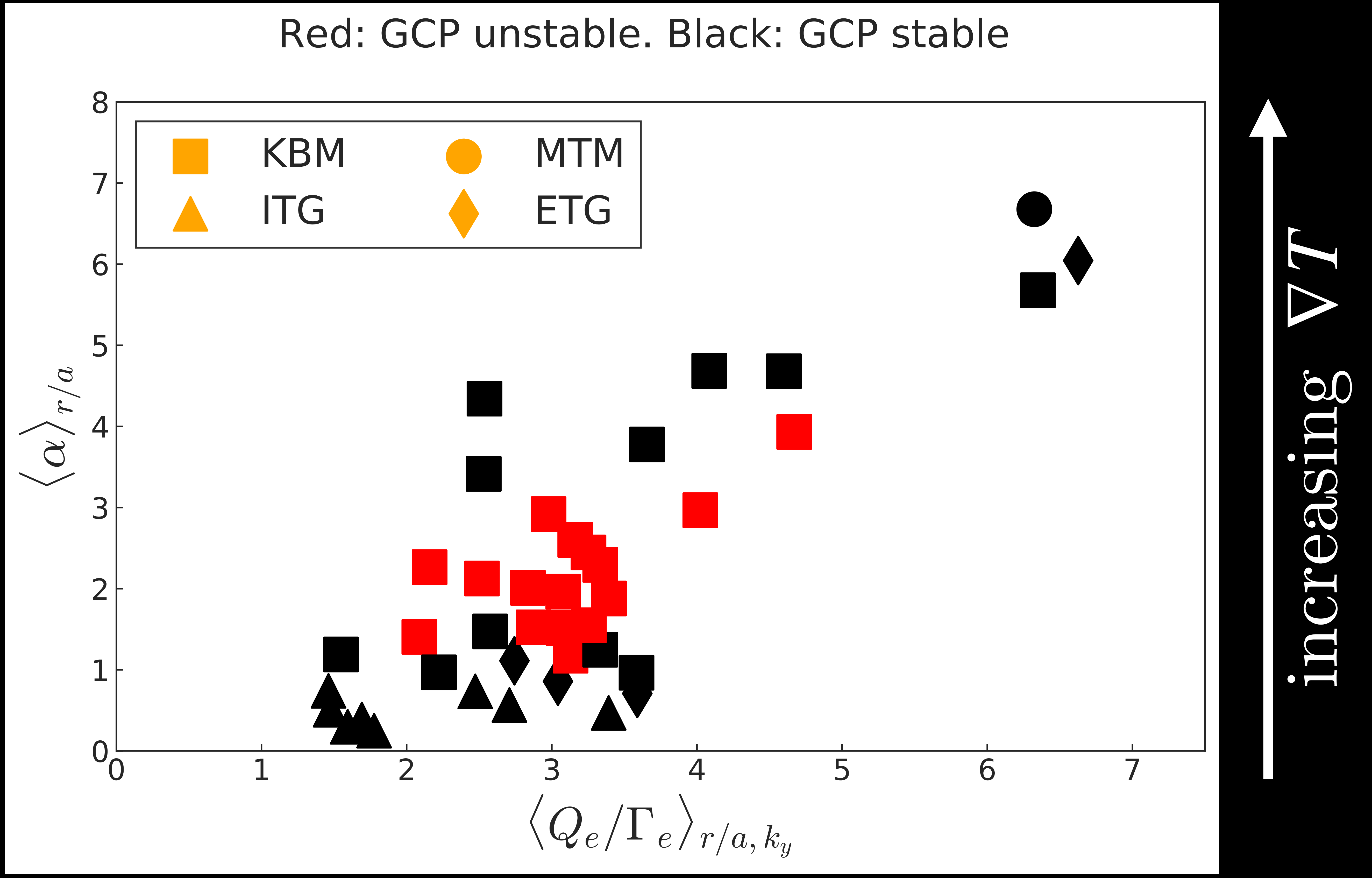
Constant n

- Plotting $\Gamma_e = D_e \nabla n_e$, $Q_e = \chi_e \nabla T_e + \frac{3}{2}\Gamma_e T_e$



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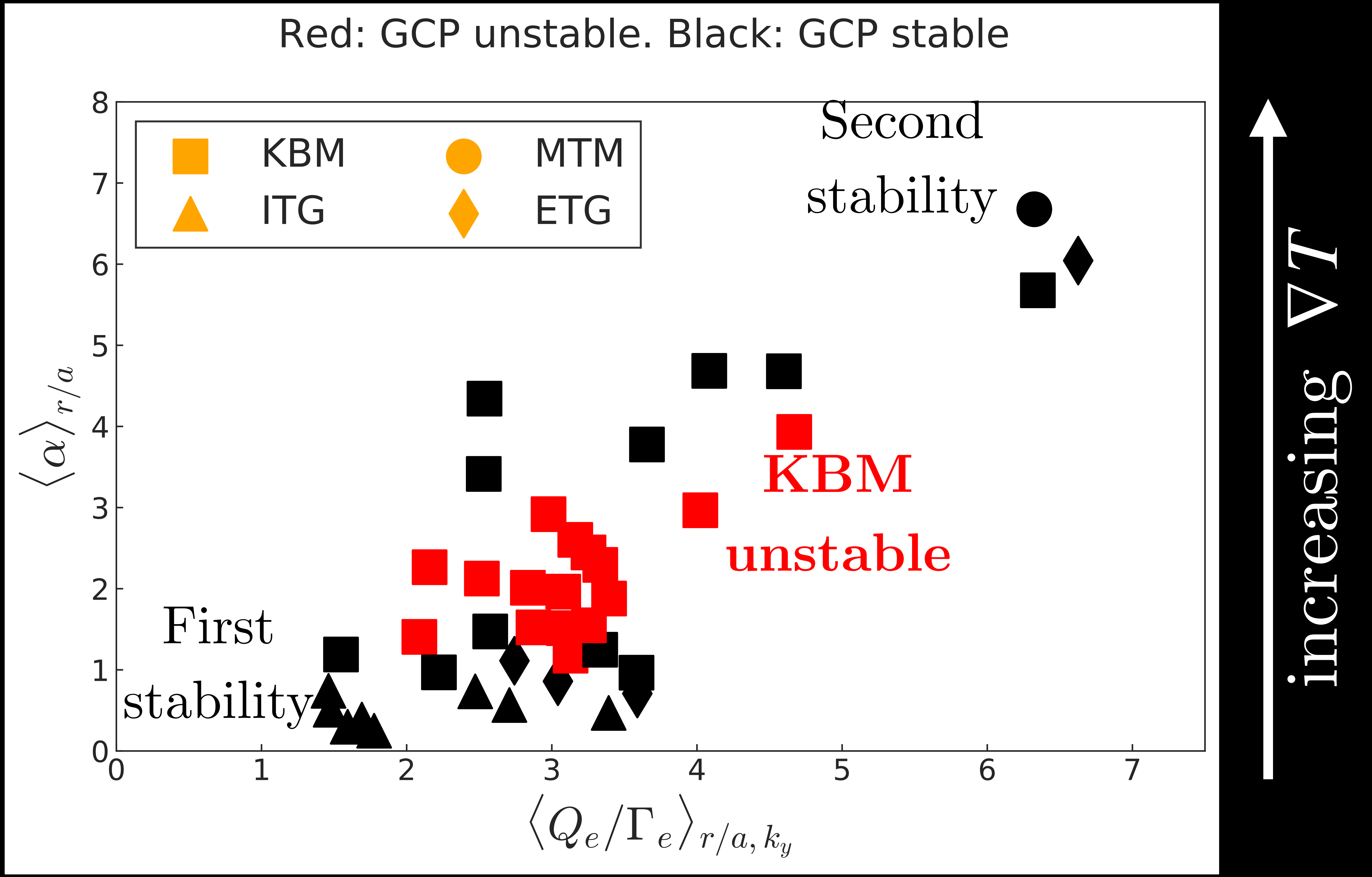
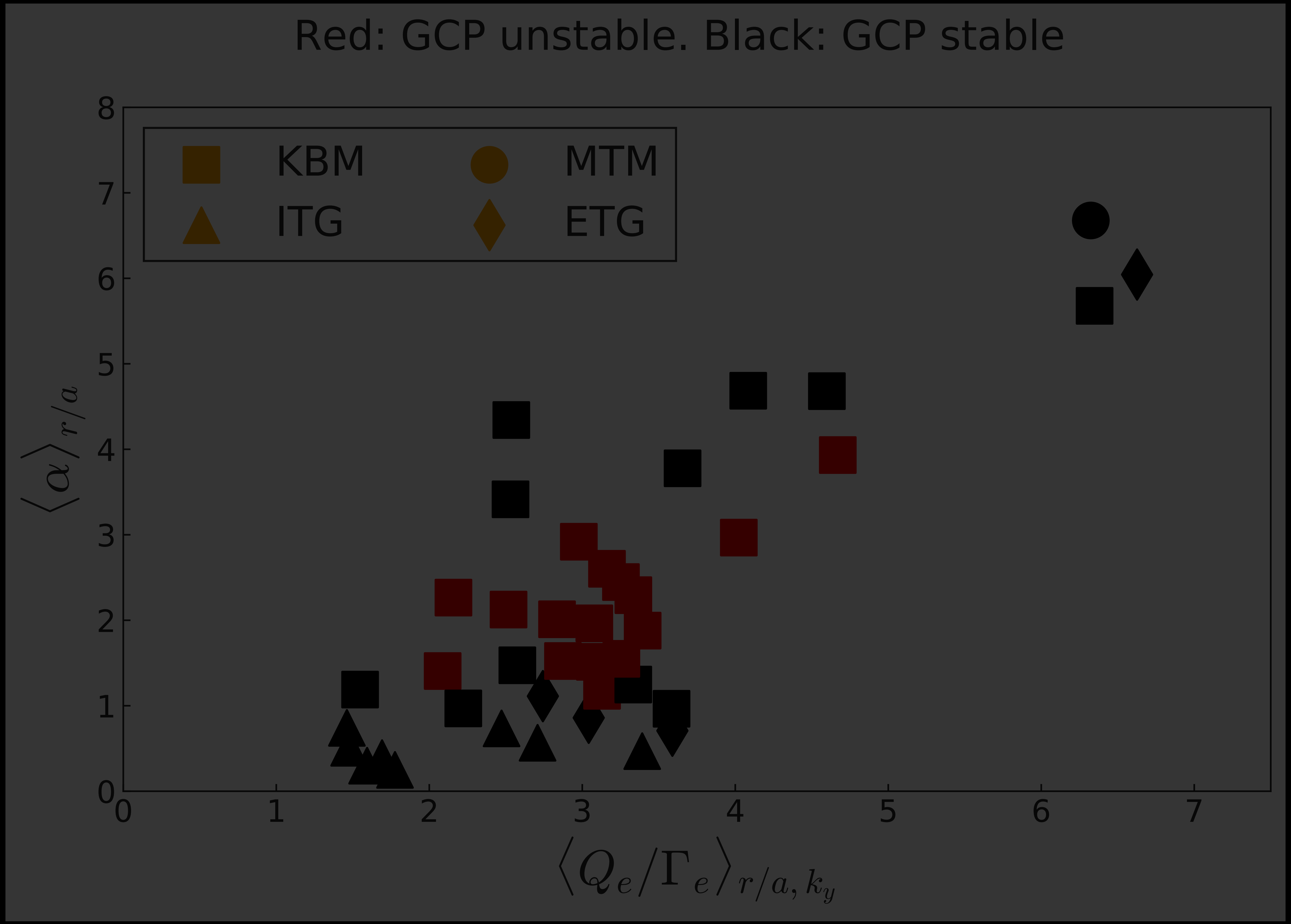
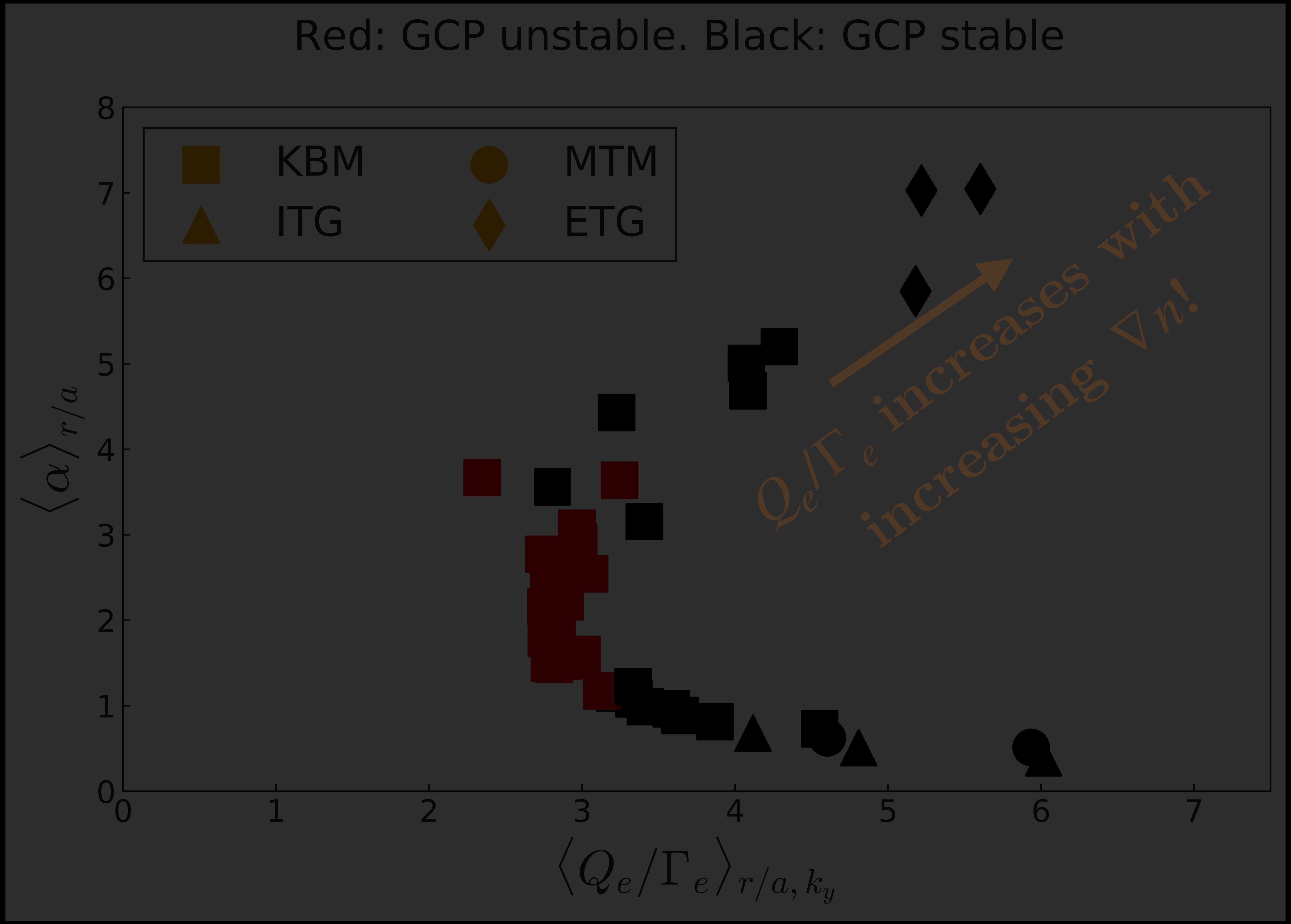
- Heat transport increases with α.



Transport Picture: Particle Vs. Heat

Constant n *Compare with constant T:* Constant T





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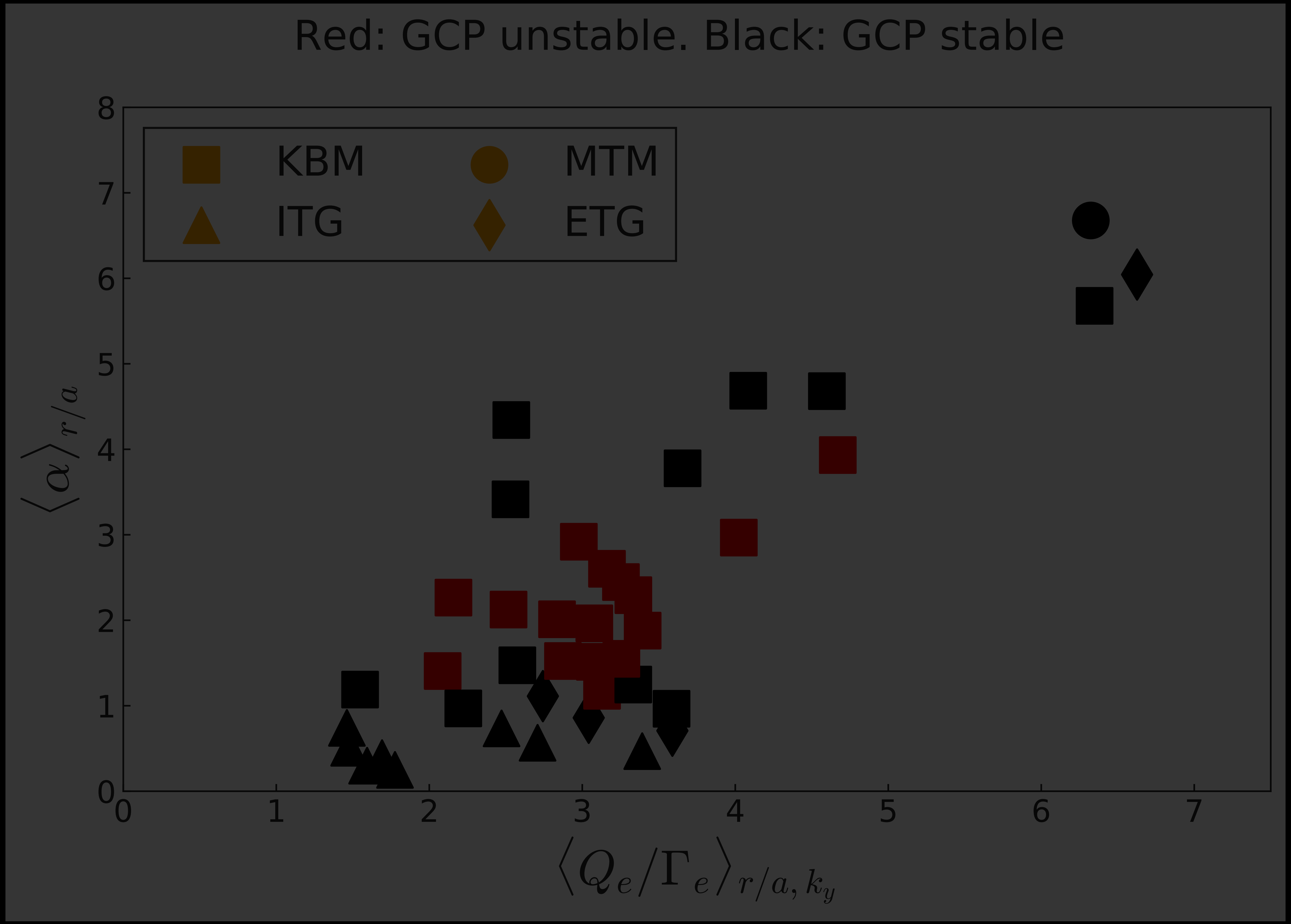

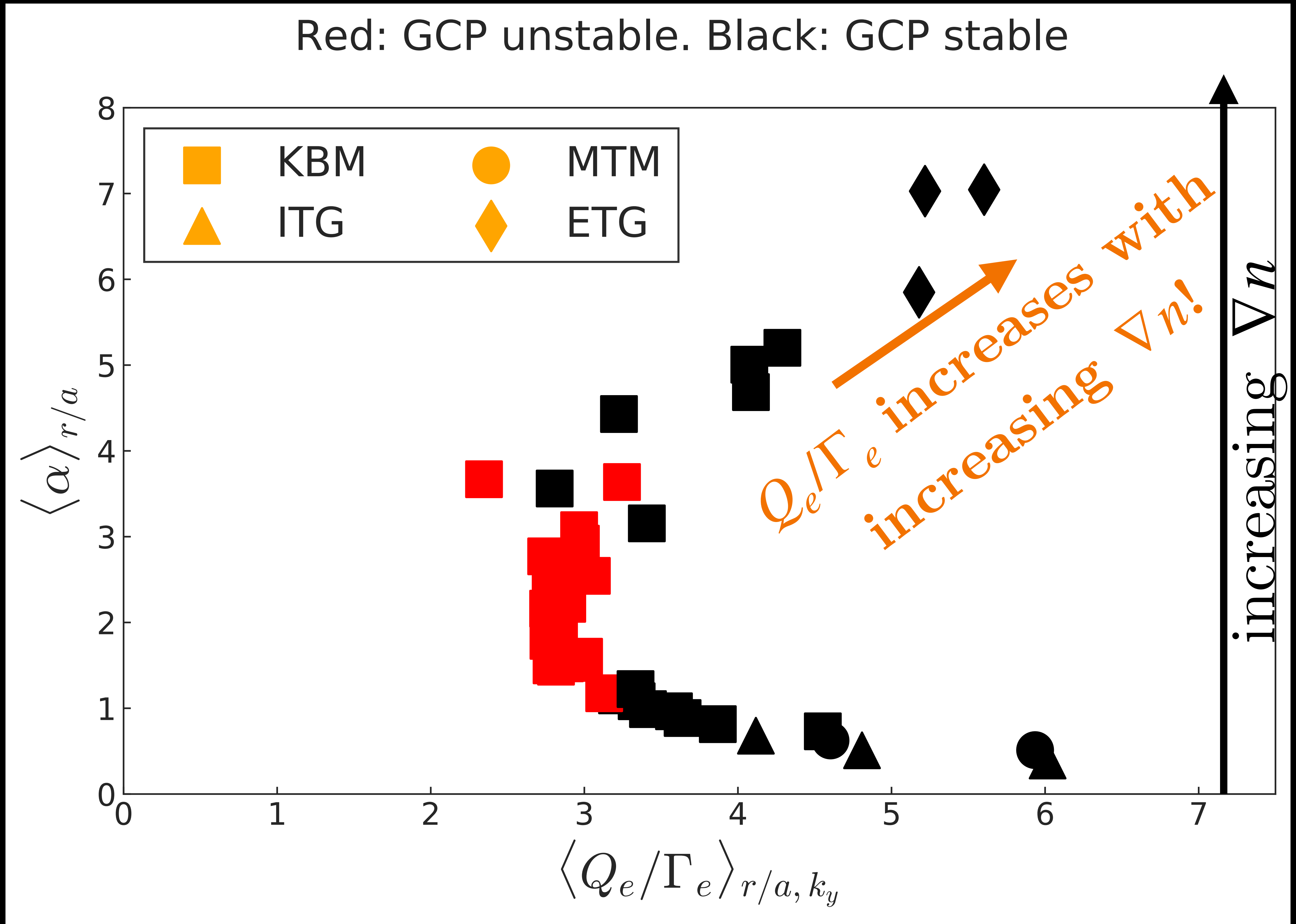

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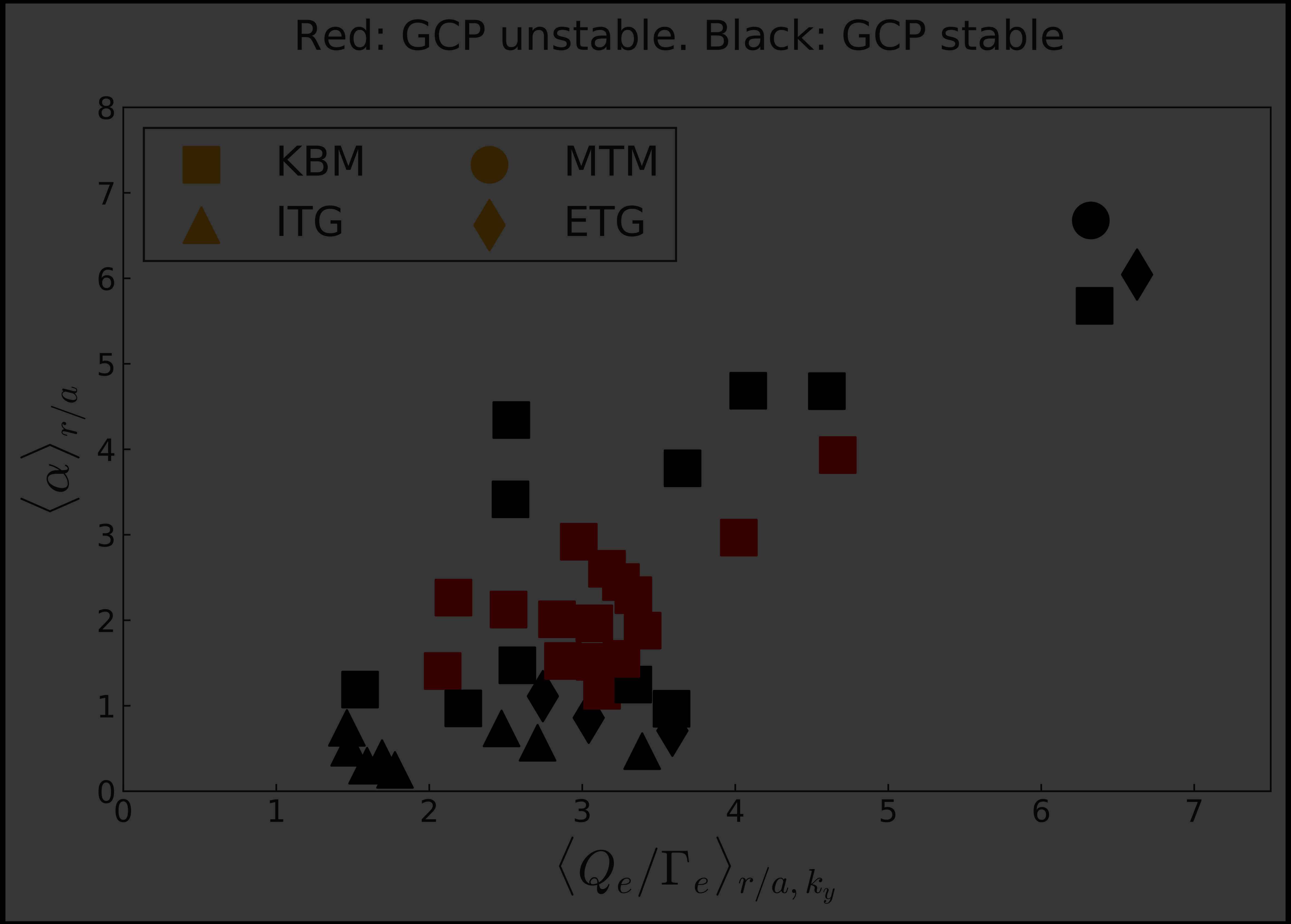
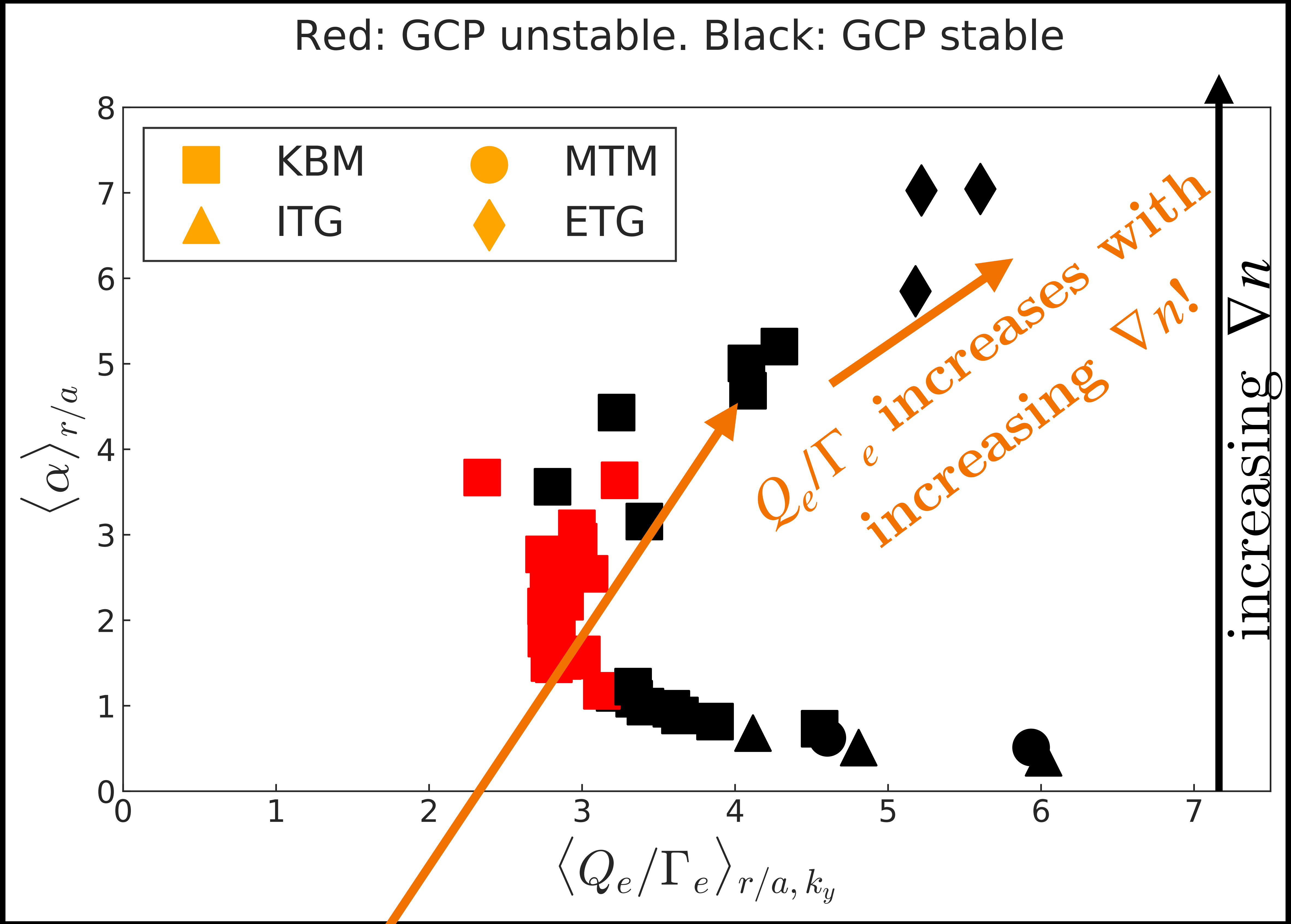
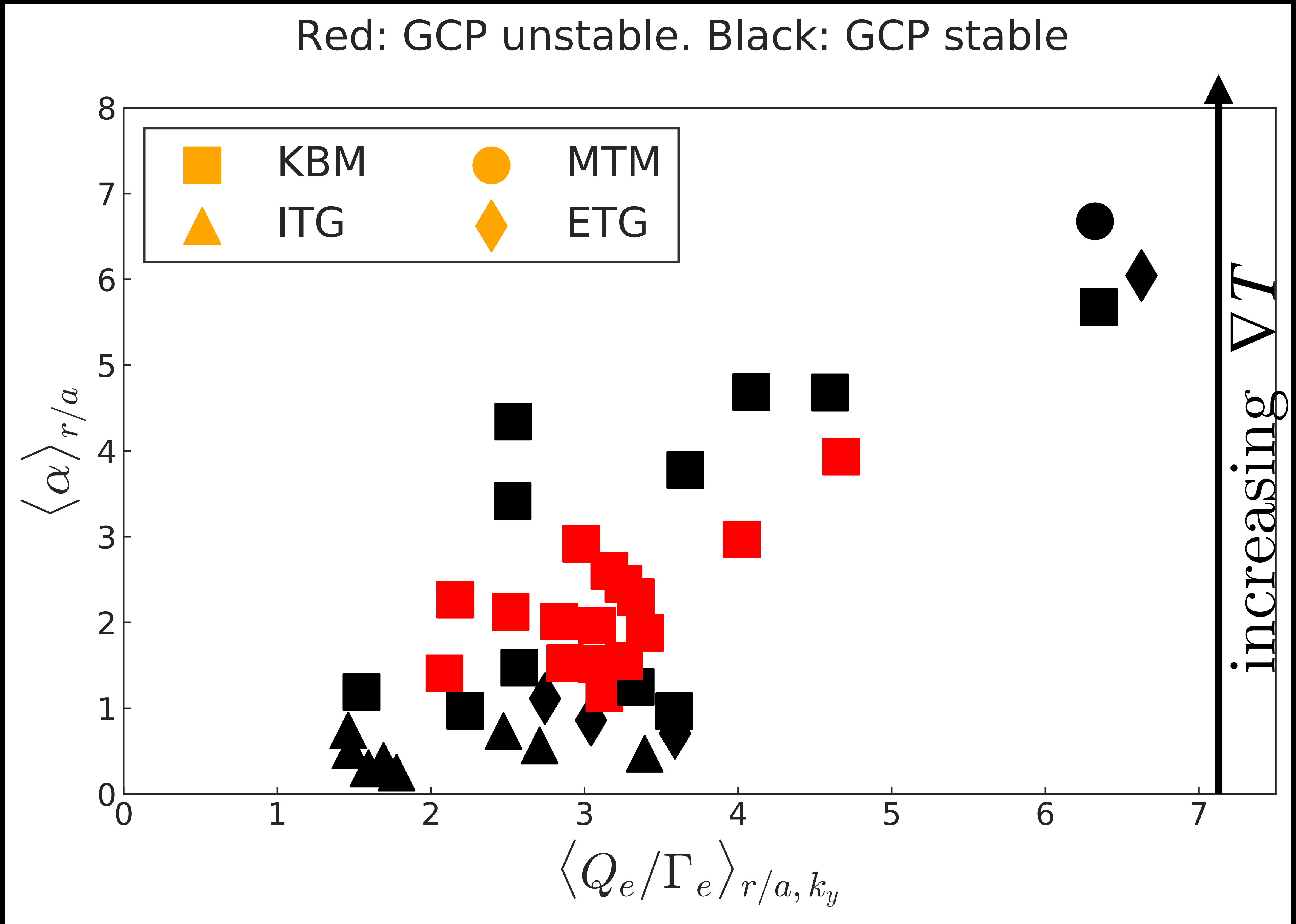




Unexpected $Q_e/\Gamma_e \sim \nabla n_e$

Transport Picture: Particle Vs. Heat

Constant n



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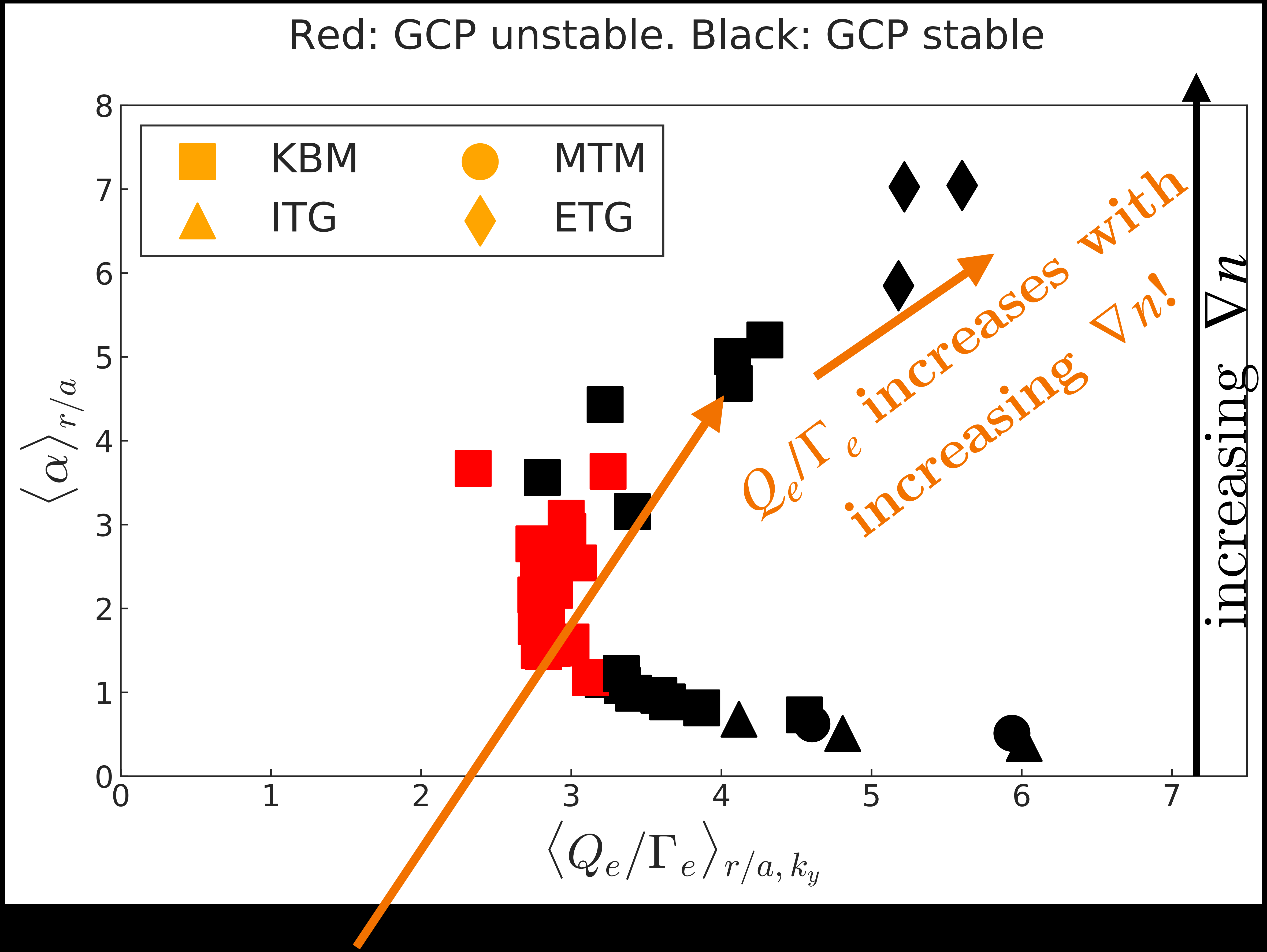

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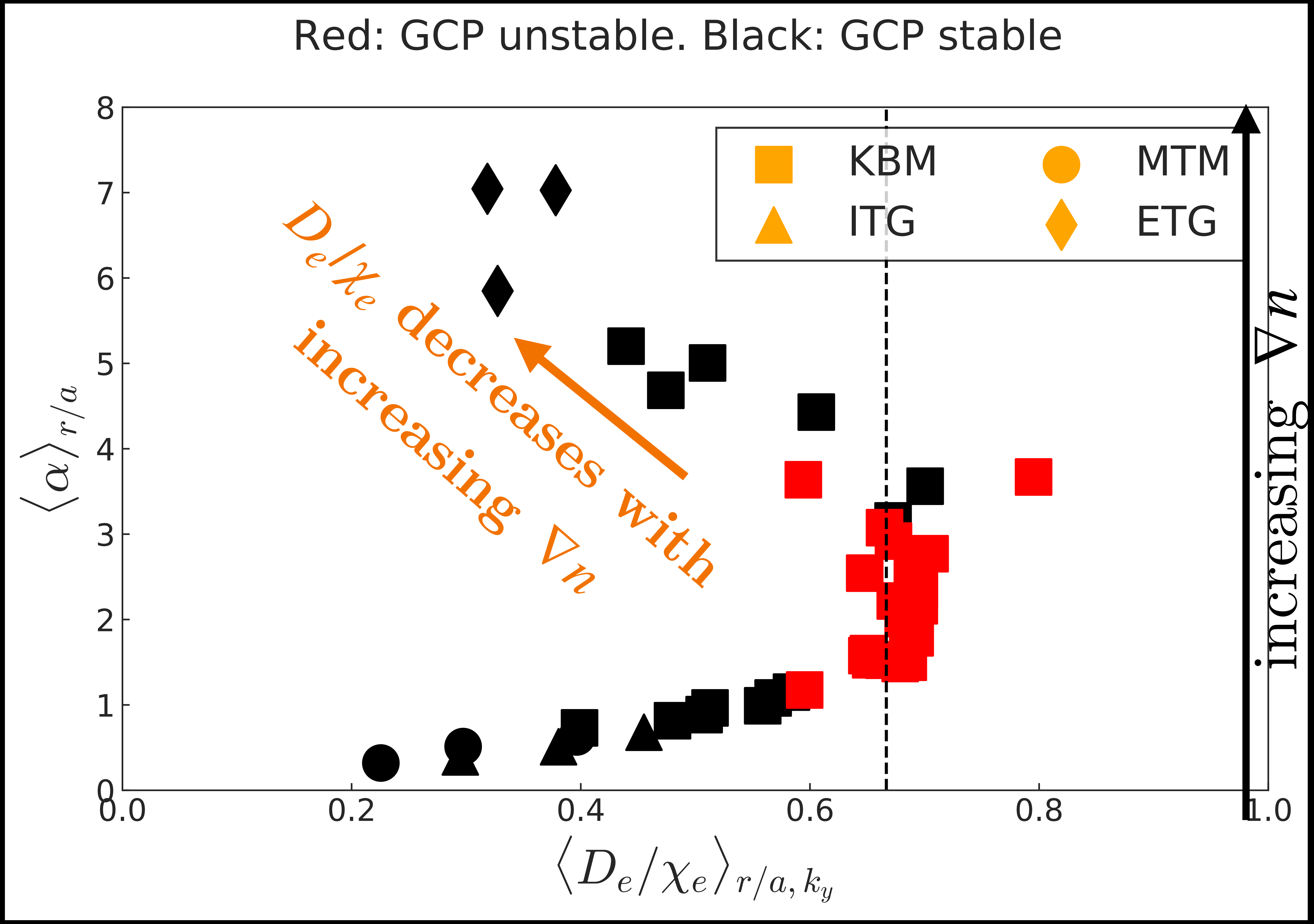
Transport Picture: Particle Vs. Heat

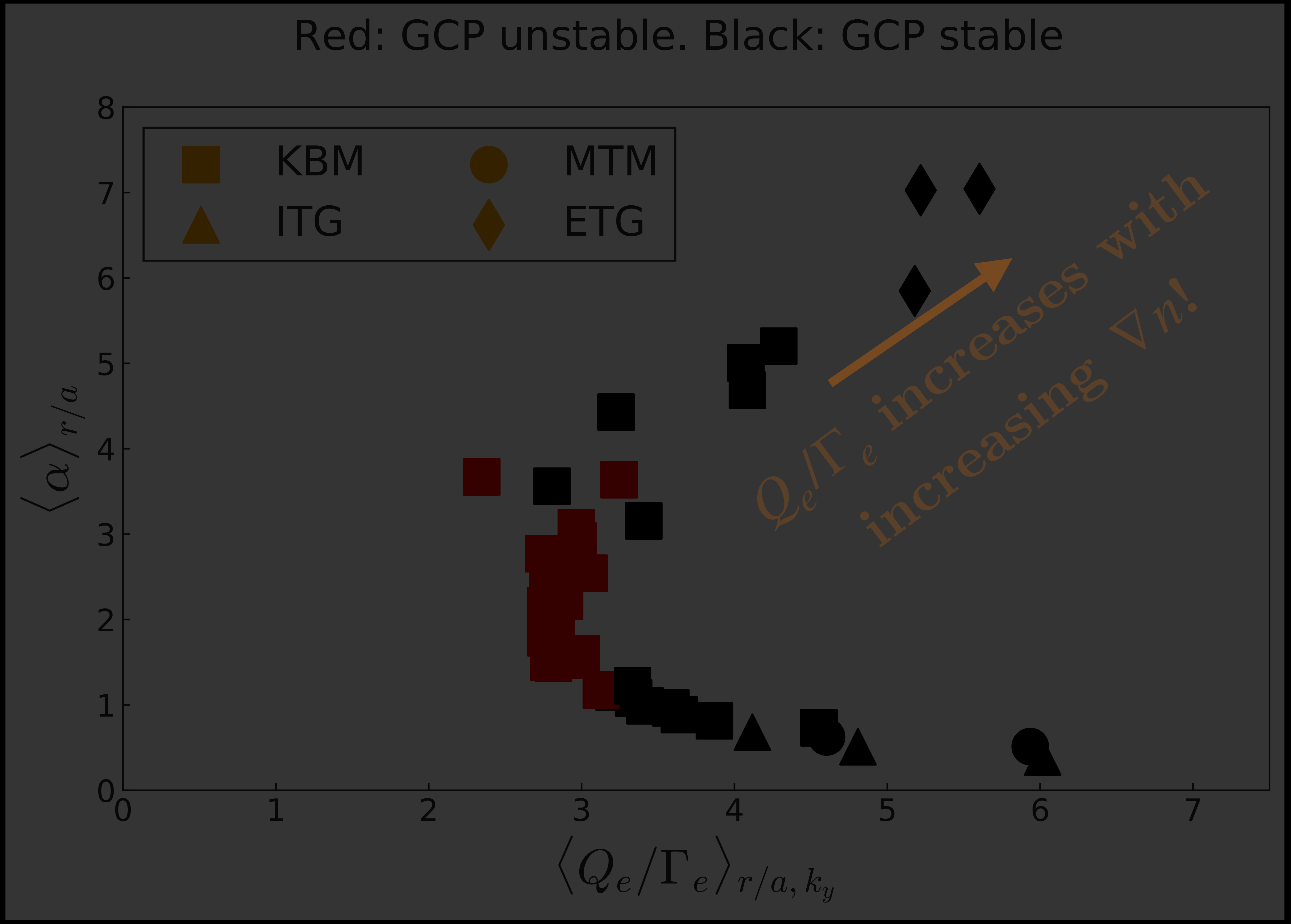
Constant T

D_e/χ_e



Constant T

Q_e/Γ_e



Transport Picture: Particle Vs. Heat

Constant T

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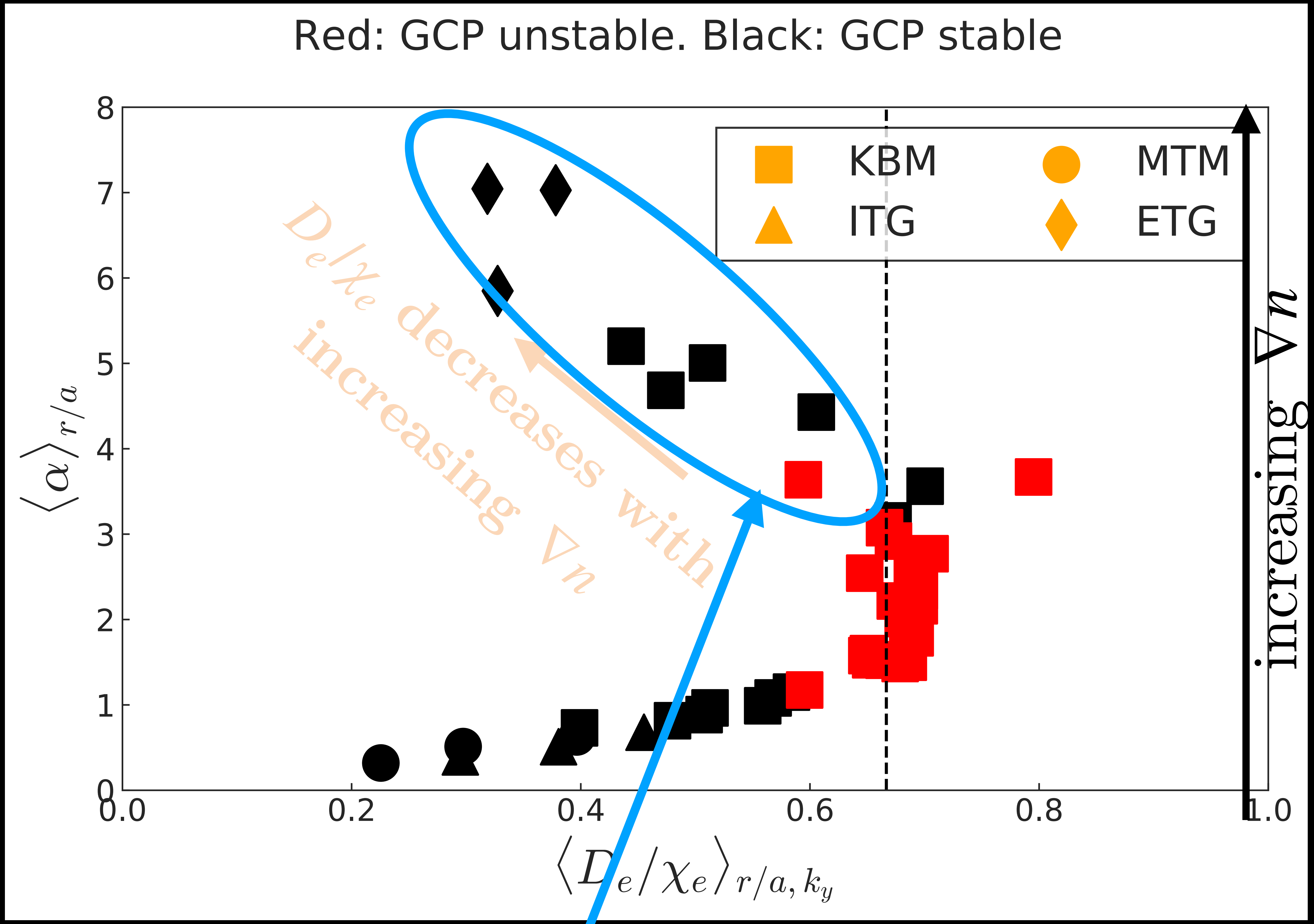
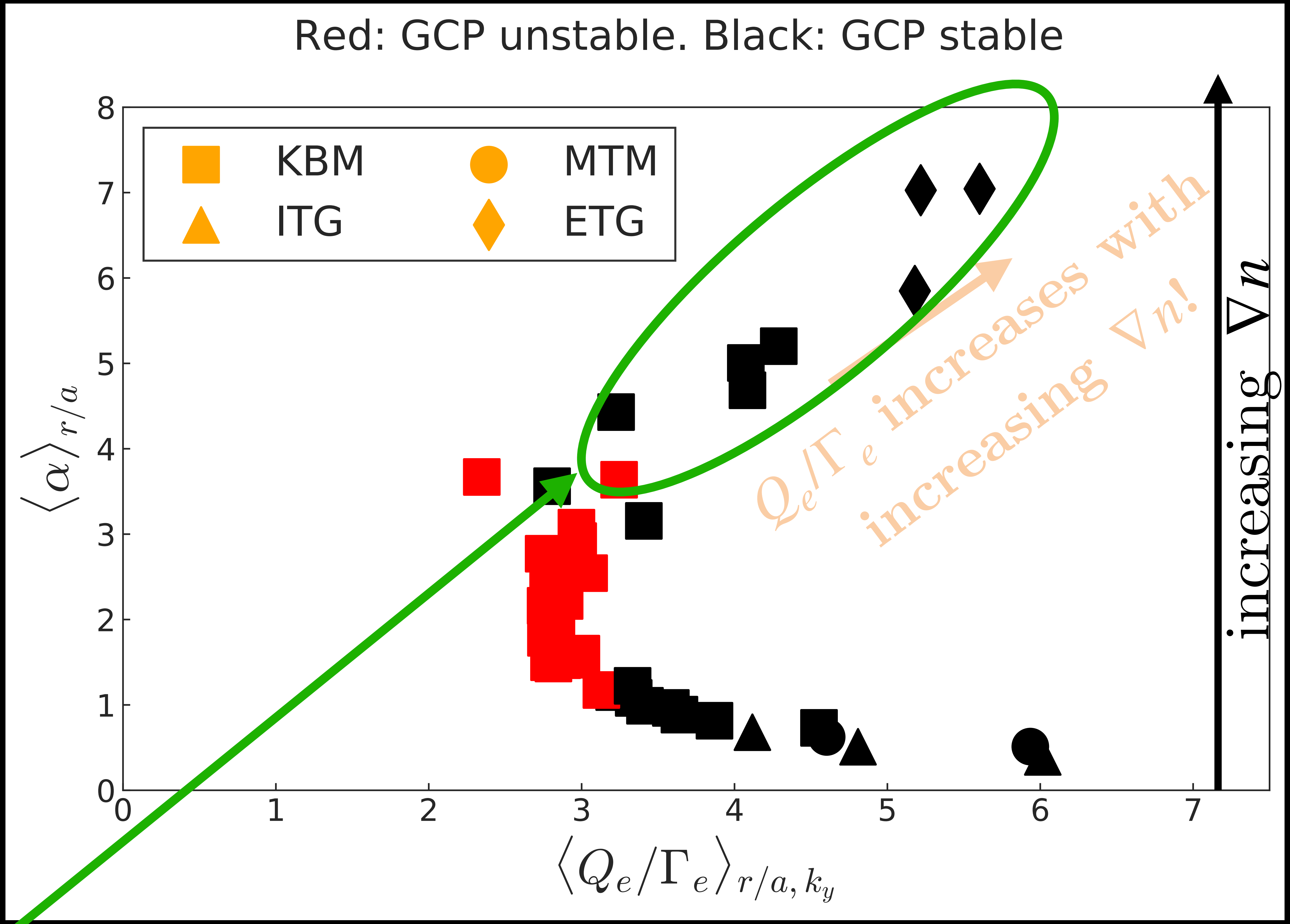


Constant T

Q_e/Γ_e



Explains how Q_e/Γ_e increases with increasing ∇n_e.

Transport Picture: Particle and Heat

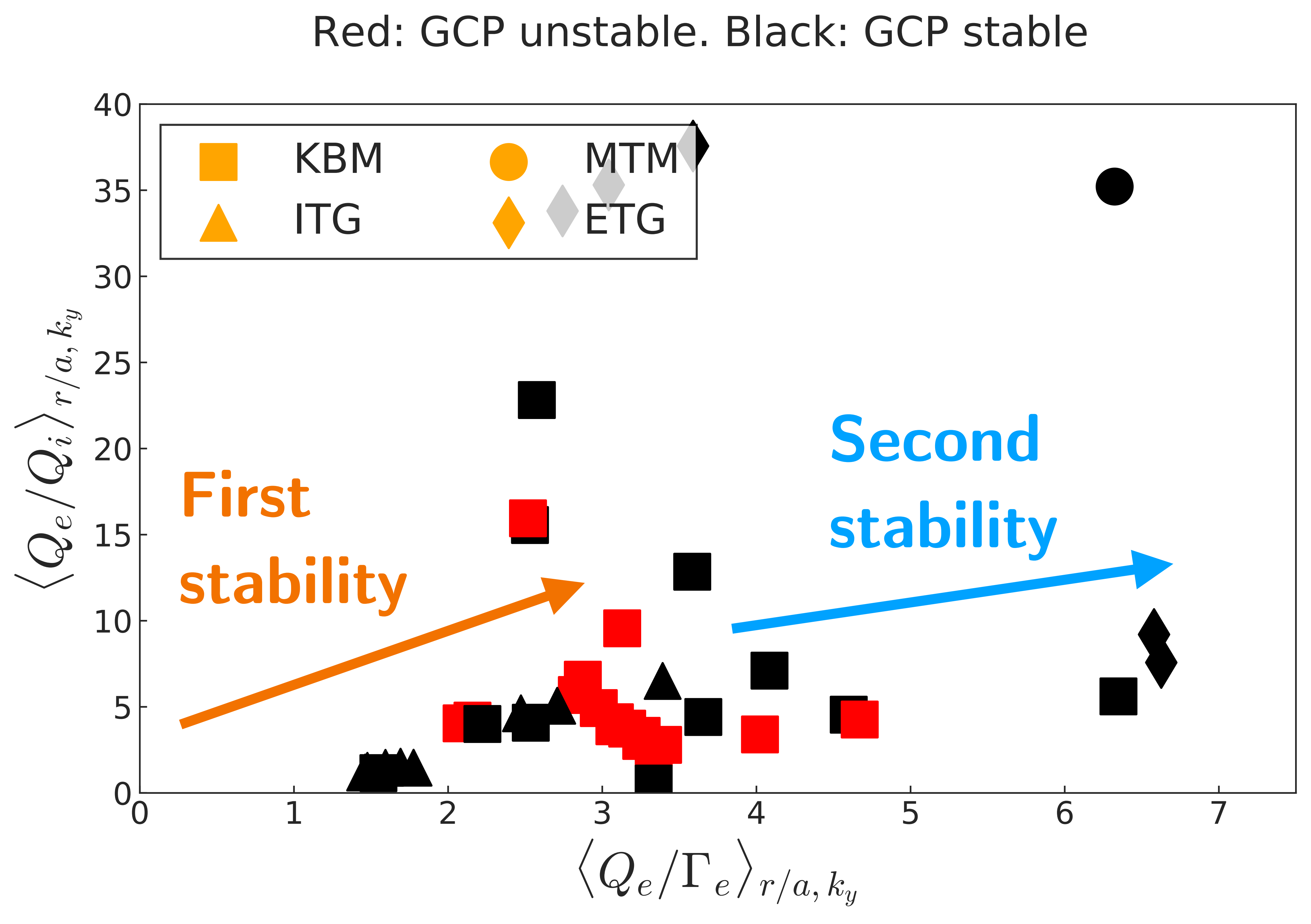
Combine Q_e/Γ_e and Q_e/Q_i

Transport Picture: Particle and Heat

Combine Q_e/Γ_e and Q_e/Q_i

Constant n

ITG —> KBM —> ETG



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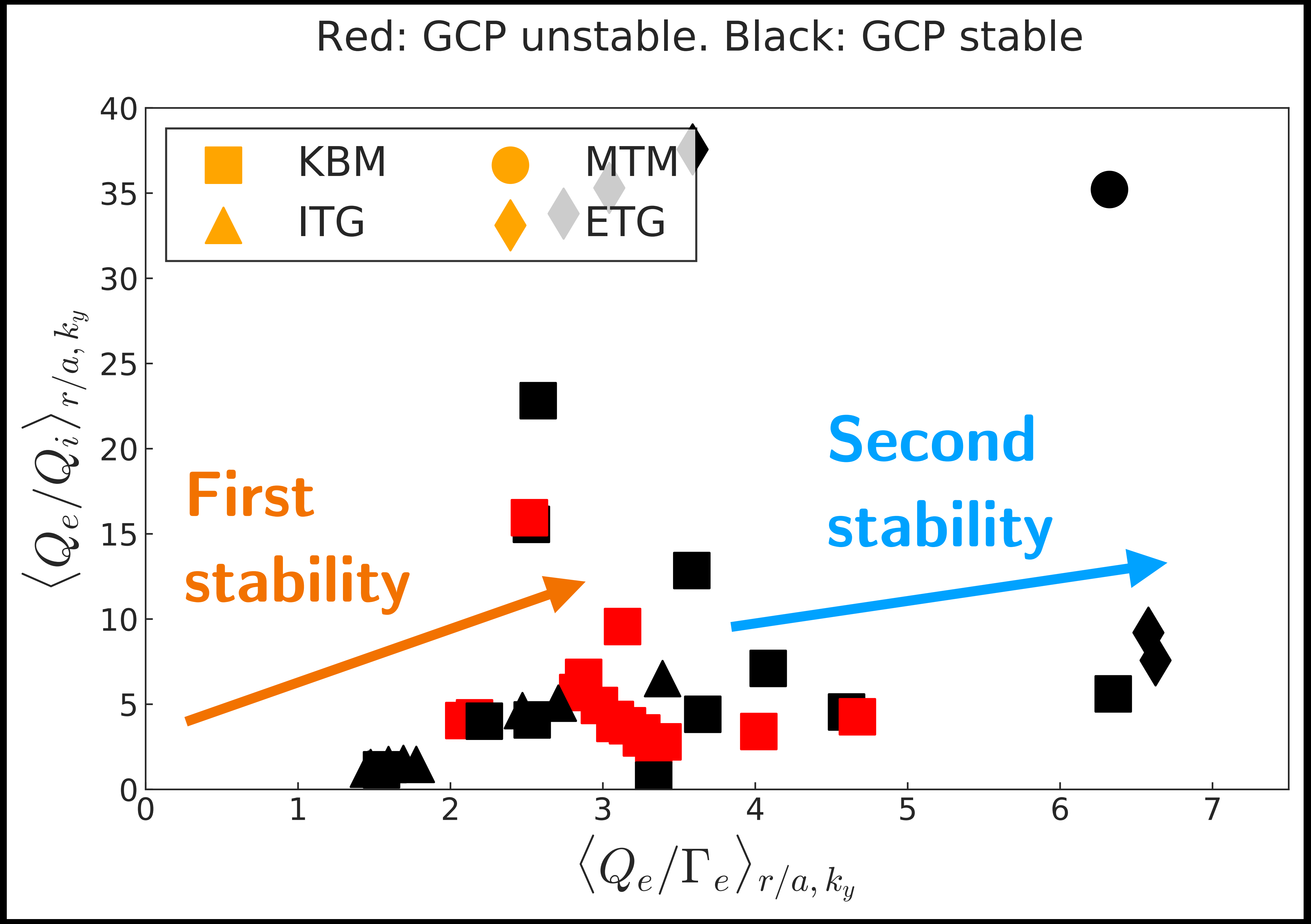
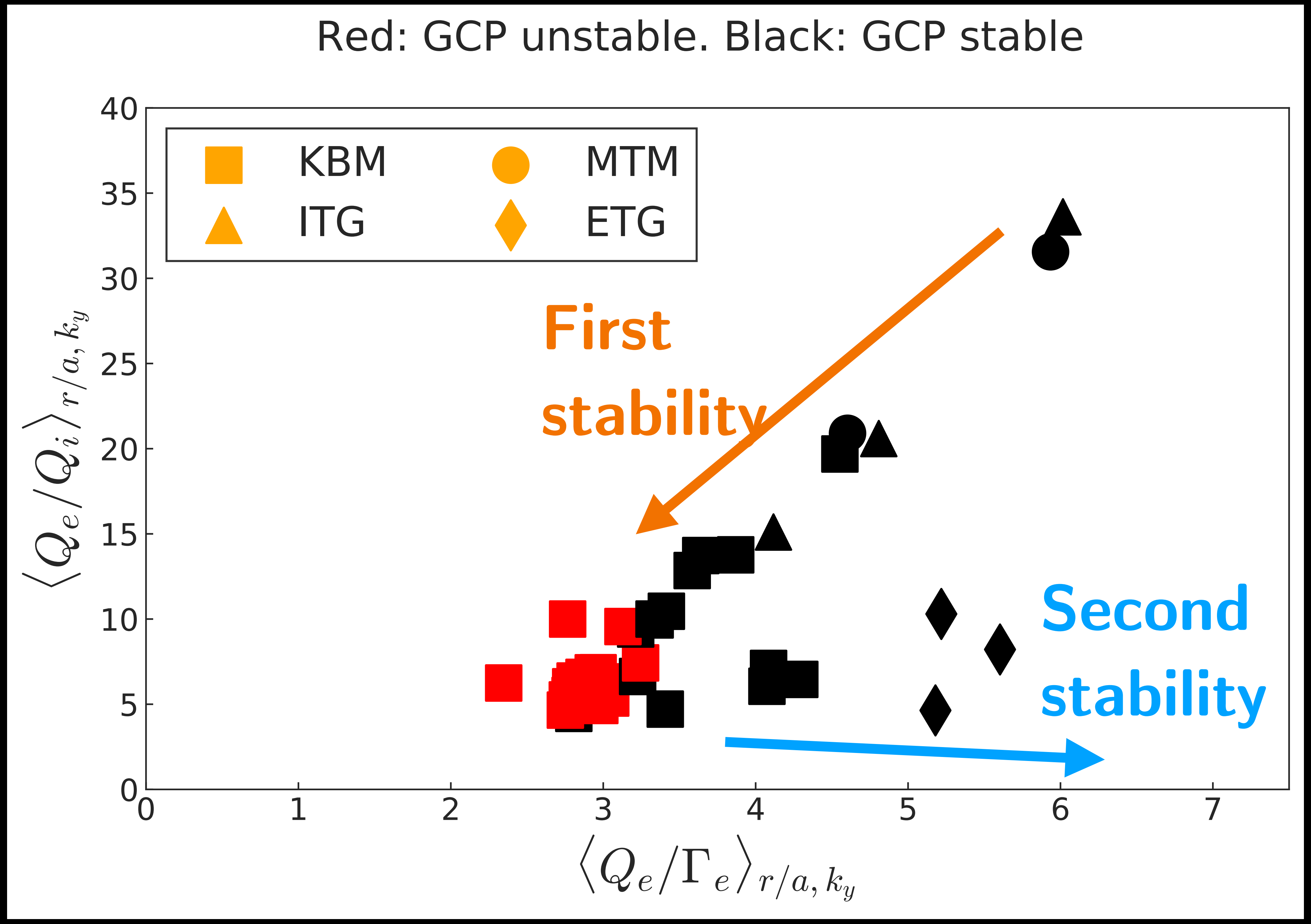


Constant T

MTM —> KBM —> MTM/ETG



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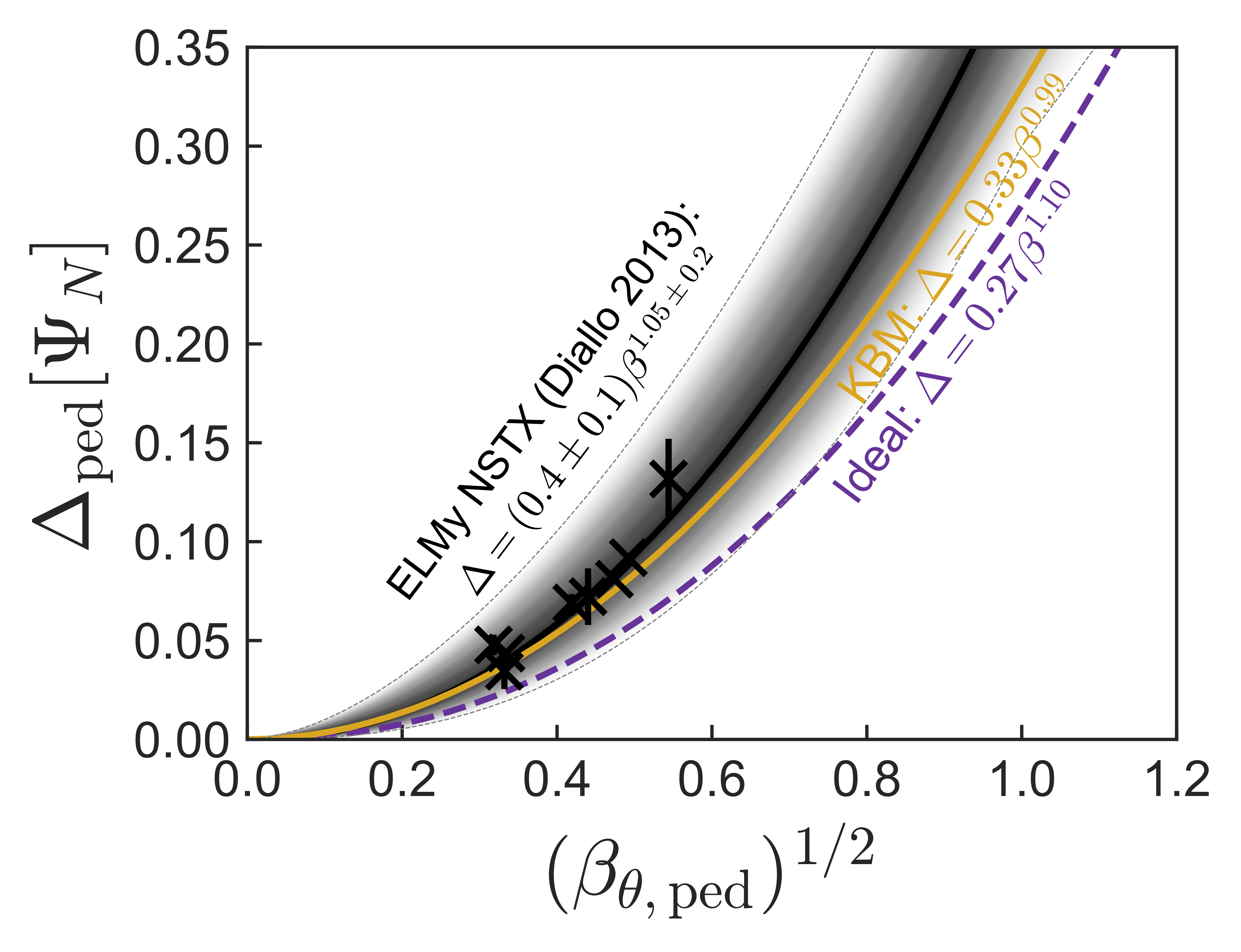

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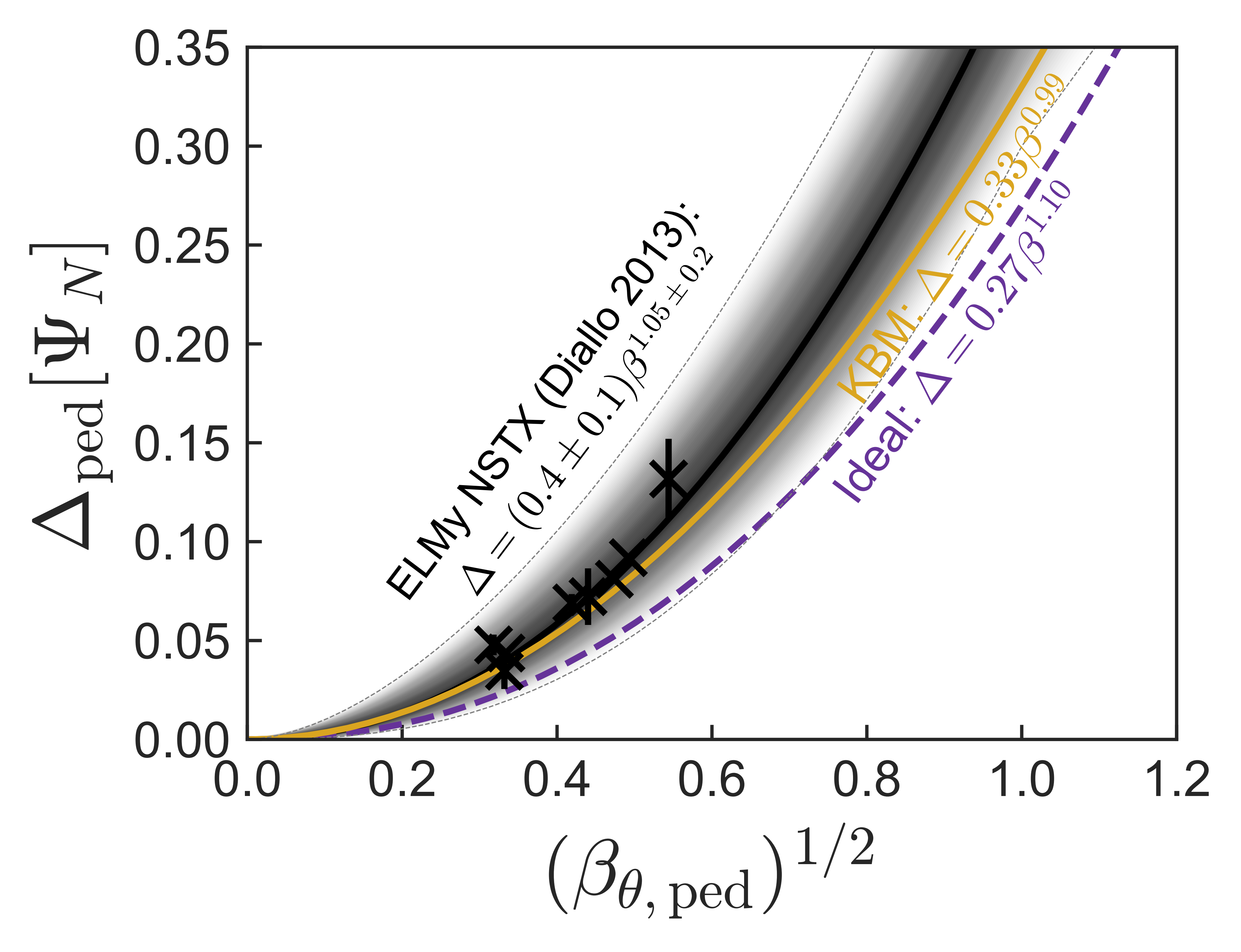

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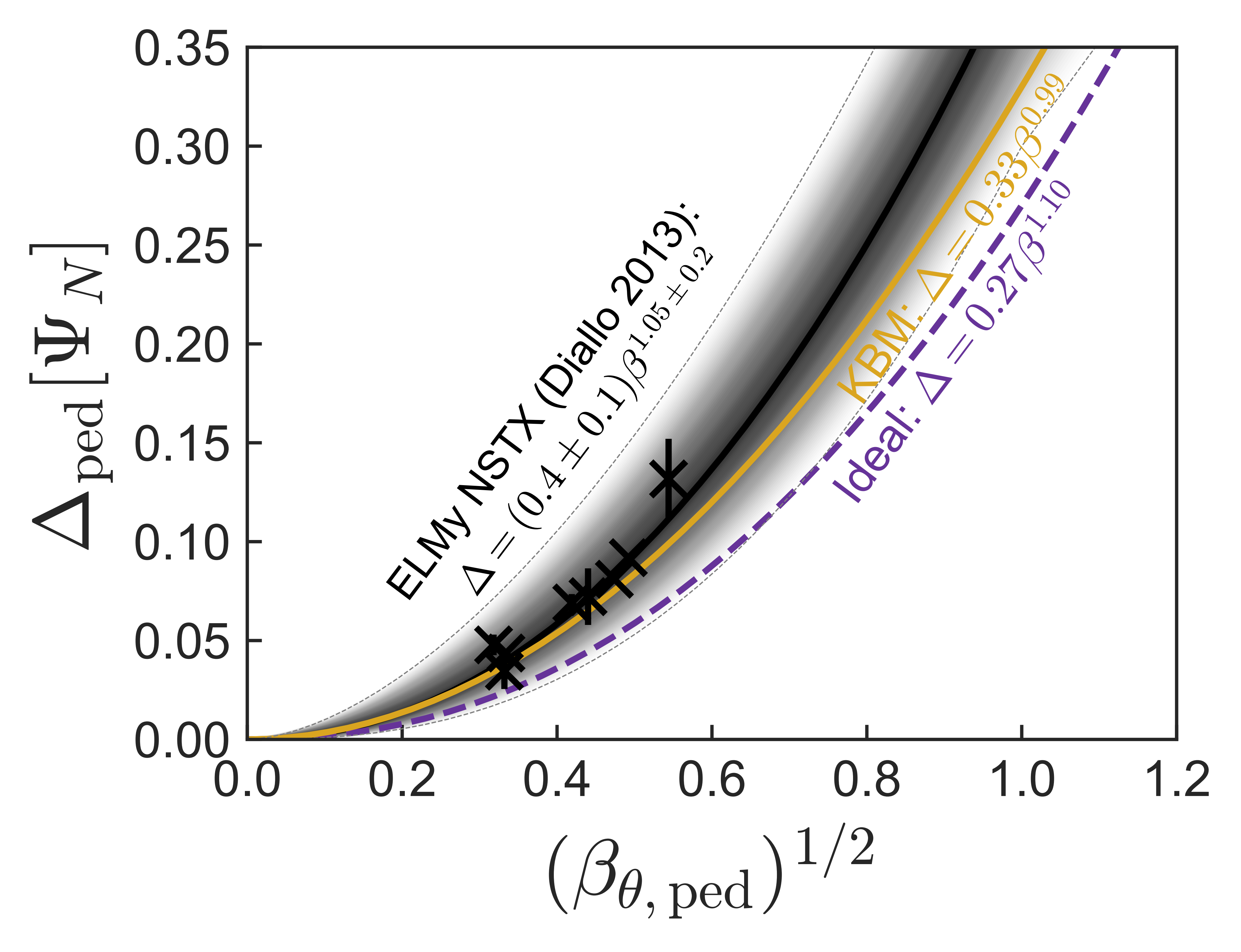

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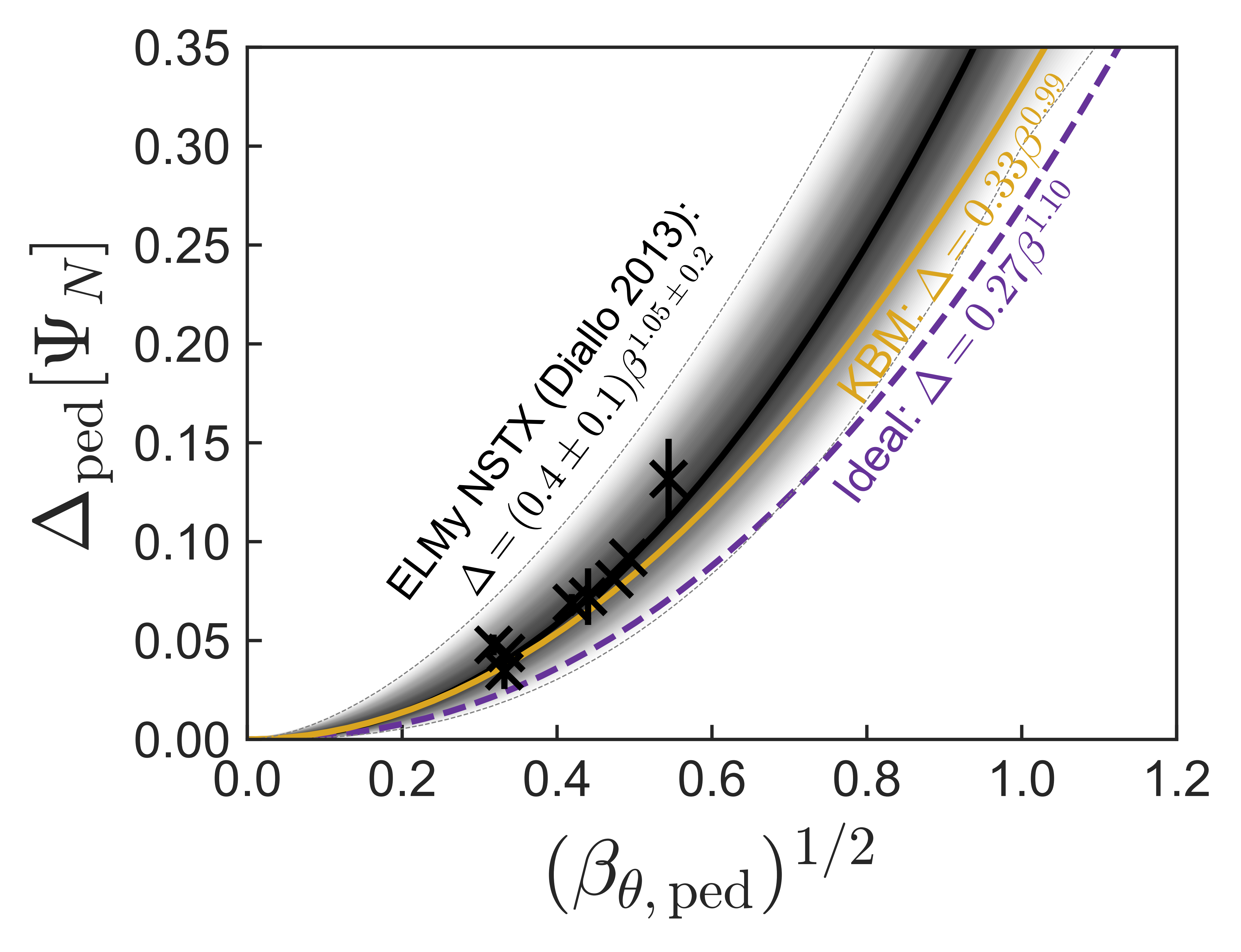
- GCP given by KBM more accurate, due to lower KBM stability threshold.

- Transport in first stability, instability, and second stability varies whether n or T kept constant during pressure buildup.



Acknowledgements

- Thanks to P. Snyder, A. Diallo, J. Candy, E. Belli, and M. Lampert for helpful discussions.

Back Up Slides

Transport Picture: Ions Vs. Electrons

Transport Picture: Ions Vs. Electrons

- Consider χ_i/χ_e, relative heat diffusivity of ions and electrons.

Transport Picture: Ions Vs. Electrons
Constant T

- Consider χ_i/χ_e, relative heat diffusivity of ions and electrons.

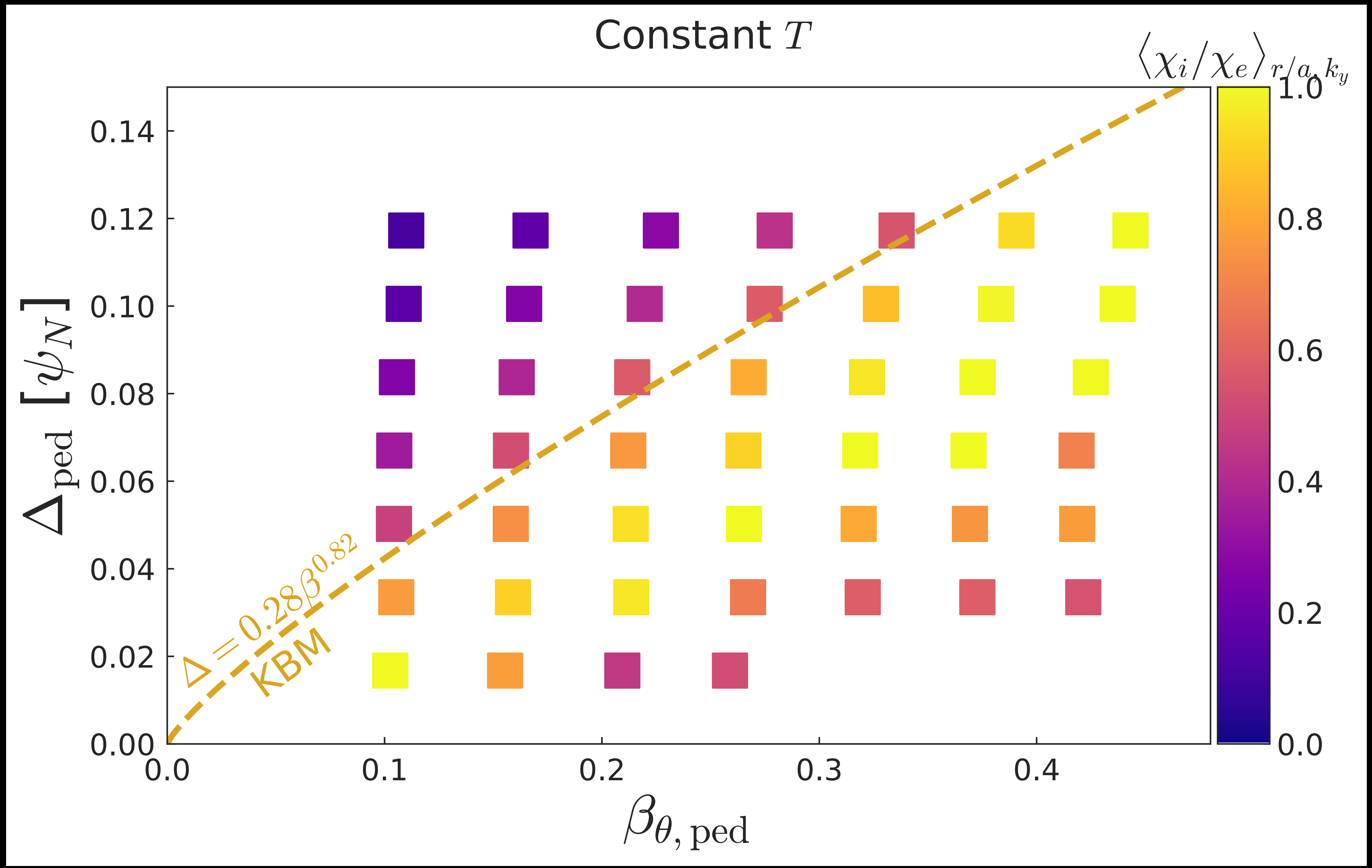


Fig 1: χ_i/χ_e versus Δ_{ped} and $\beta_{\theta,\mathrm{ped}}$ for NSTX 132543 with constant T. χ_i/χ_e averaged over half-width and all $k_y\rho_i$. Mode type is most common in half-width.

Transport Picture: Ions Vs. Electrons
Constant T

- Consider χ_i/χ_e, relative heat diffusivity of ions and electrons.
- Increase in χ_i/χ_e near first stability boundary.

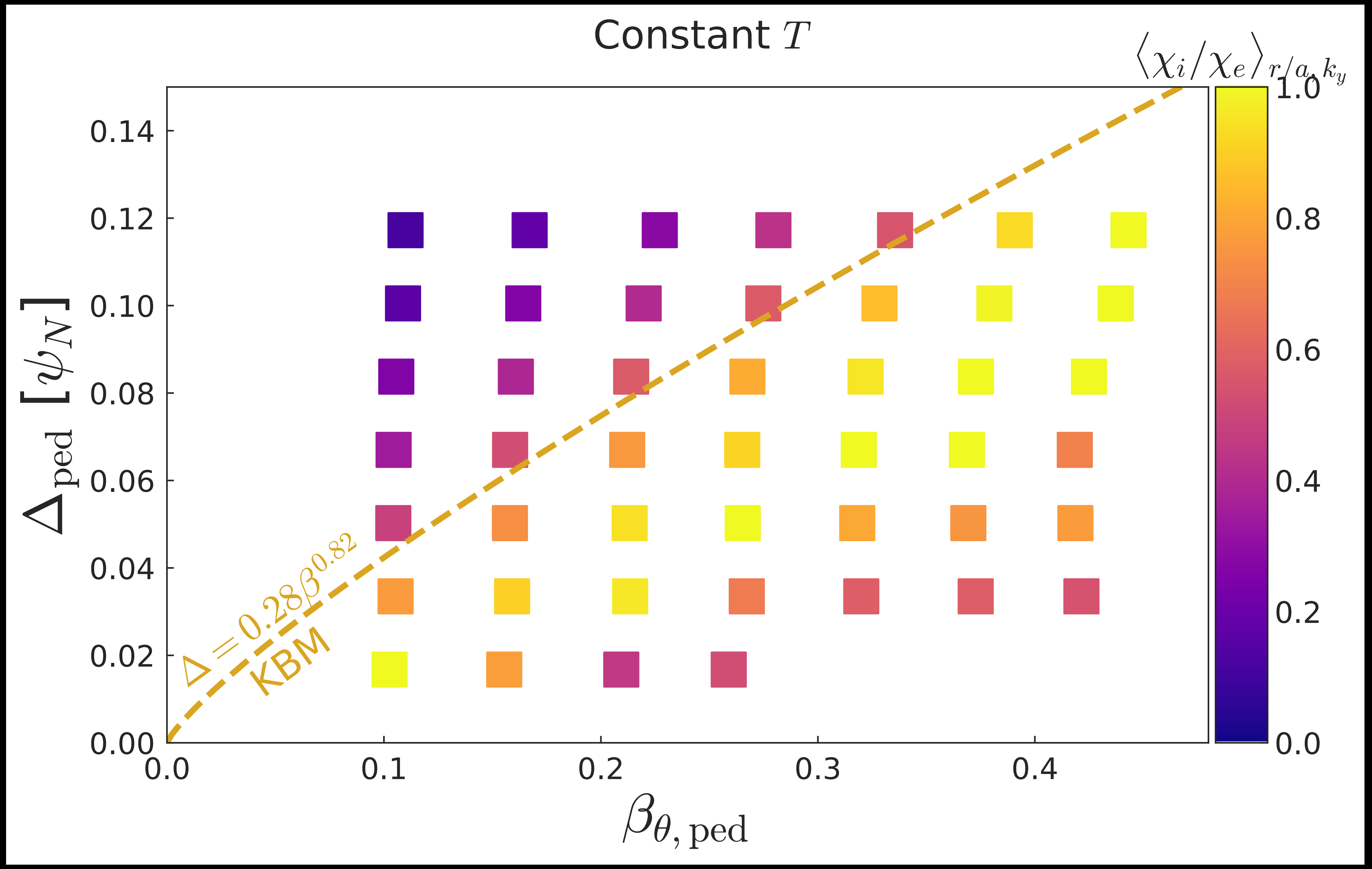


Fig 1: χ_i/χ_e versus $\Delta_{\rm ped}$ and $\beta_{\theta,\rm ped}$ for NSTX 132543 with constant T. χ_i/χ_e averaged over half-width and all $k_y\rho_i$. Mode type is most common in half-width.

Transport Picture: Ions Vs. Electrons

Constant T

- Consider χ_i/χ_e, relative heat diffusivity of ions and electrons.
- Relative ion diffusivity maximum in GCP unstable region.

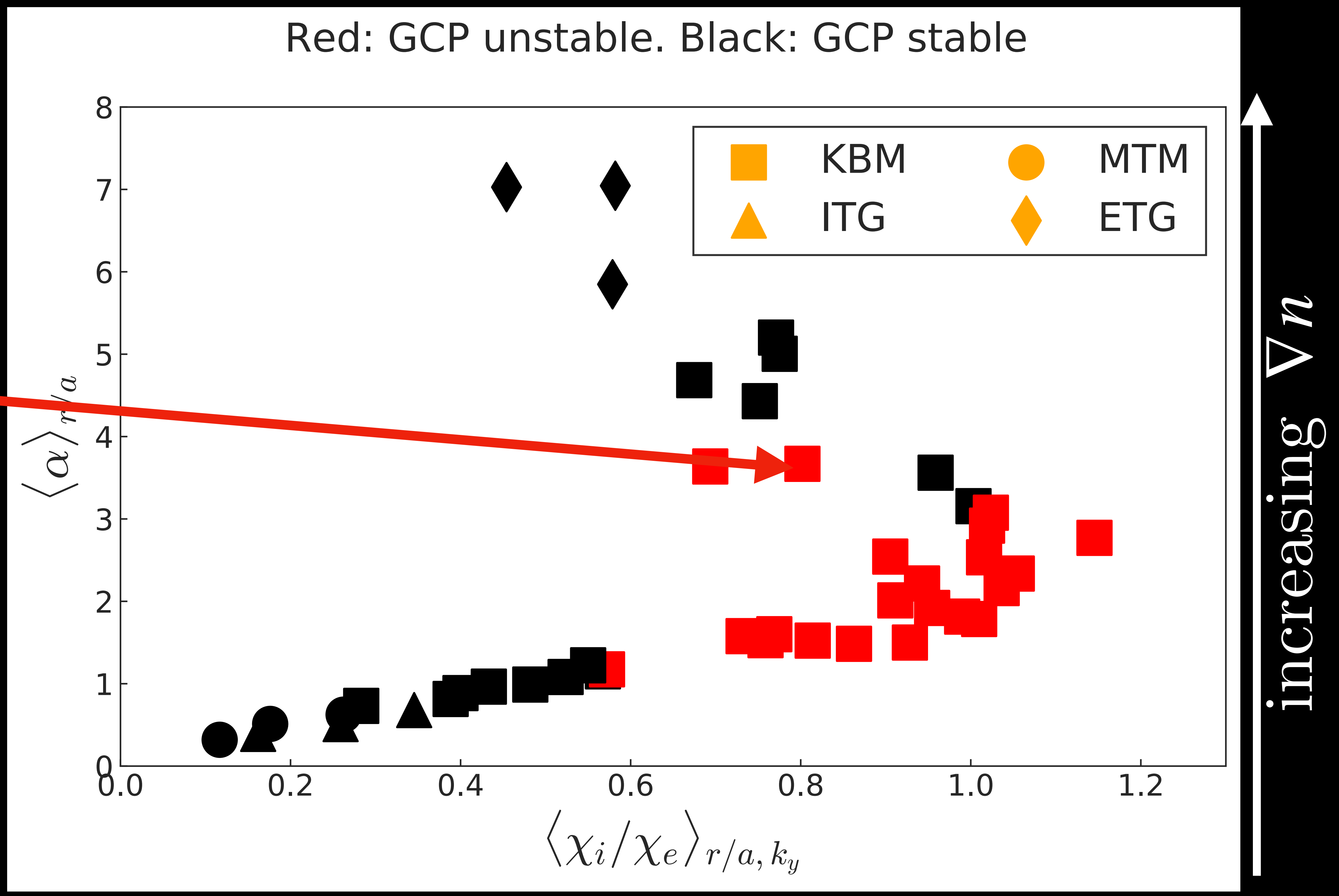
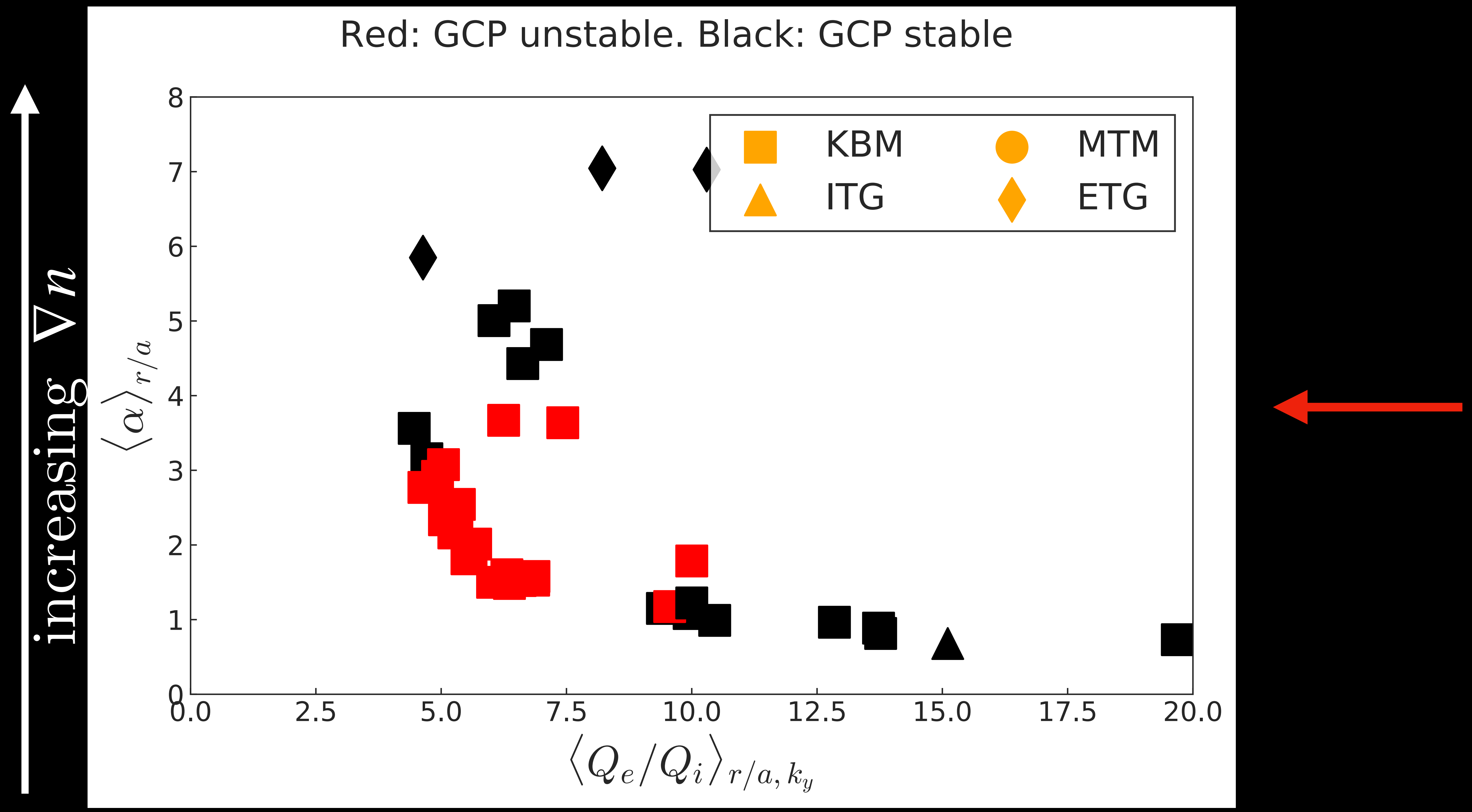


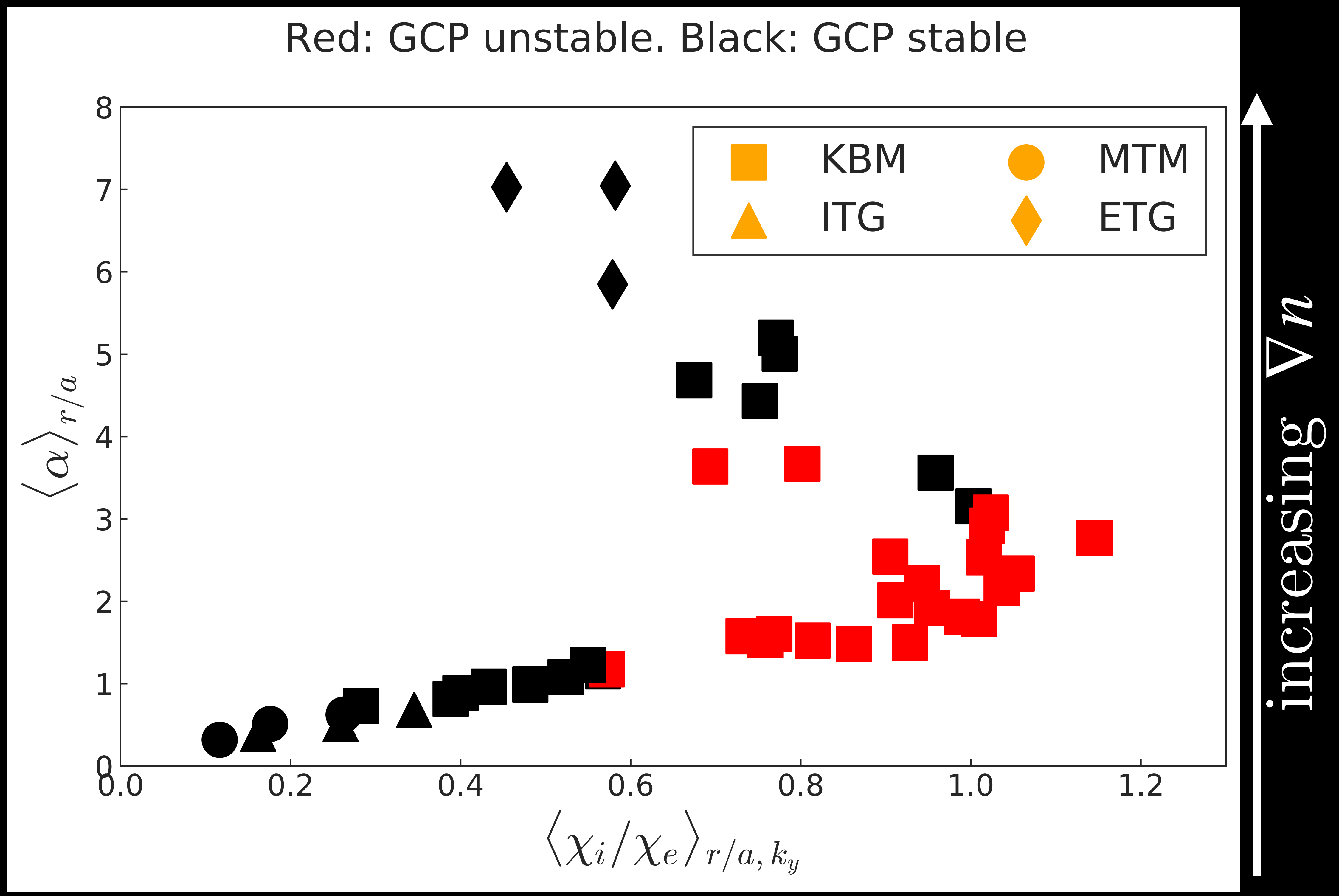
Fig 1: χ_i/χ_e versus α and χ_i/χ_e for NSTX 132543 with constant T. χ_i/χ_e averaged over half-width and all $k_y\rho_i$. Mode type is most common in half-width.

Transport Picture: Ions Vs. Electrons
Constant T

Q_e/Q_i

χ_i/χ_e

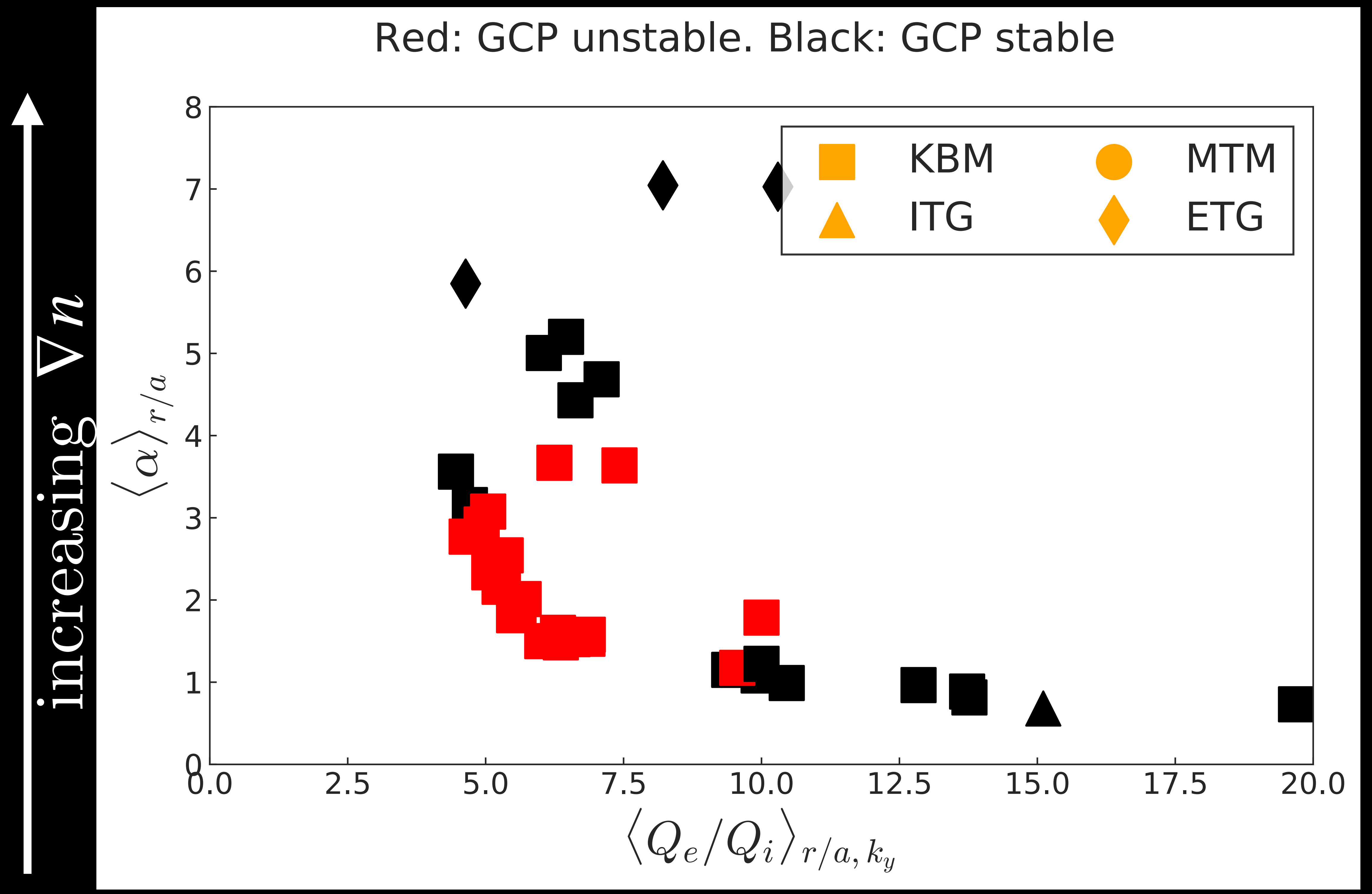




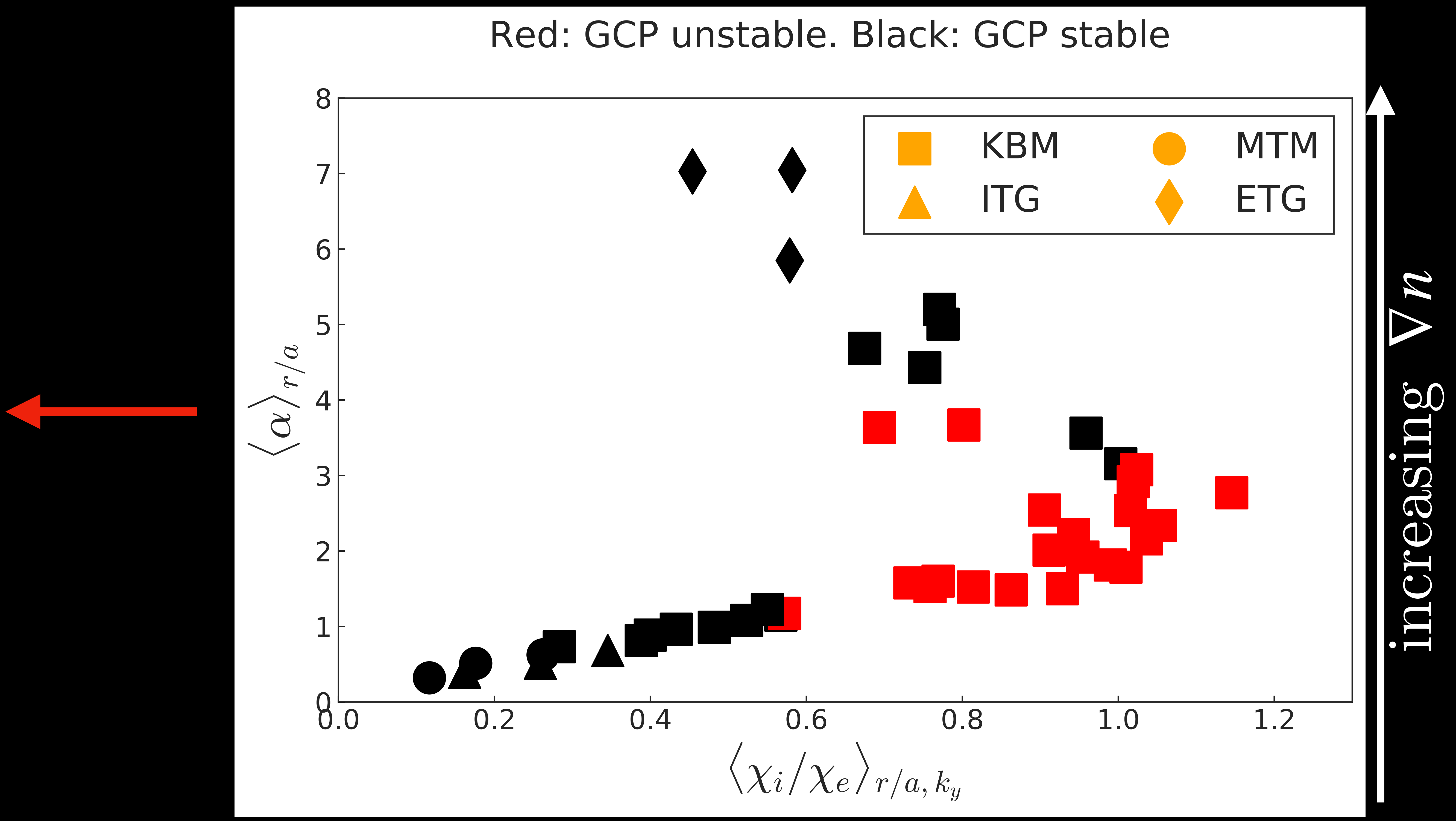
Transport Picture: Ions Vs. Electrons

Constant T

Q_e/Q_i



χ_i/χ_e



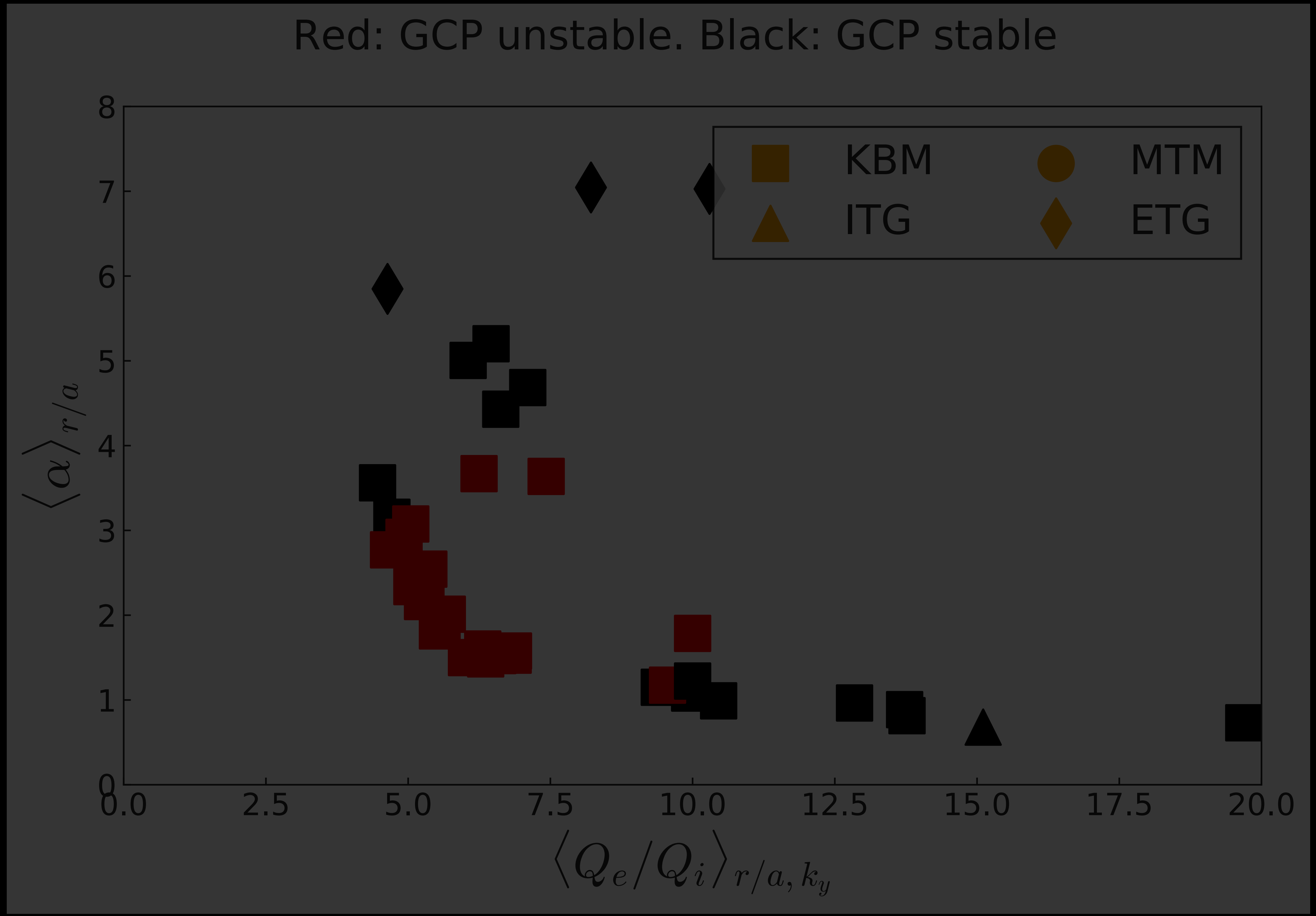
χ_i/χ_e profile explains Q_e/Q_i profile at constant T.

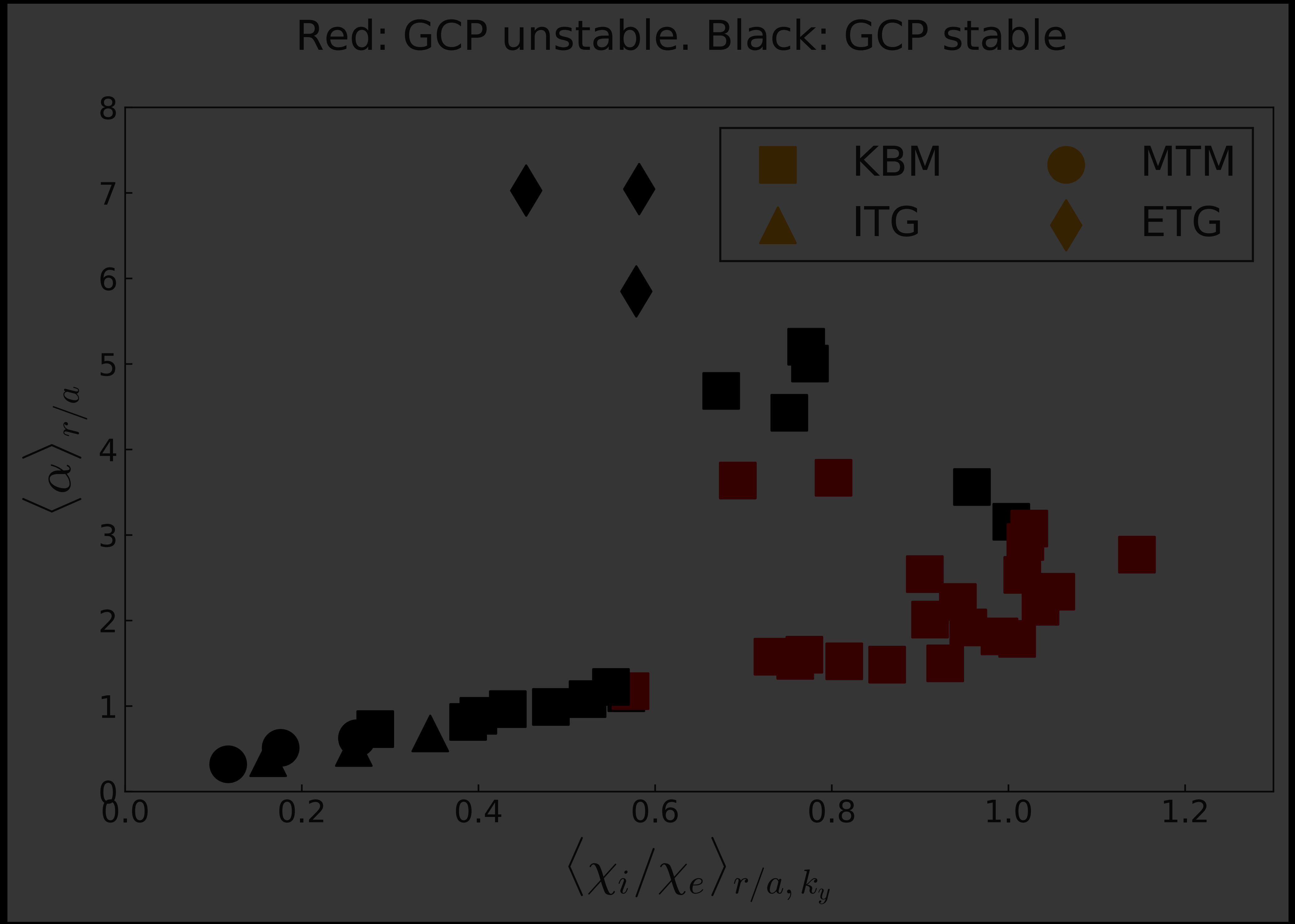
Transport Picture: Ions Vs. Electrons

Constant T

Q_e/Q_i

χ_i/χ_e





χ_i/χ_e profile explains Q_e/Q_i profile at constant T.

Consider constant n

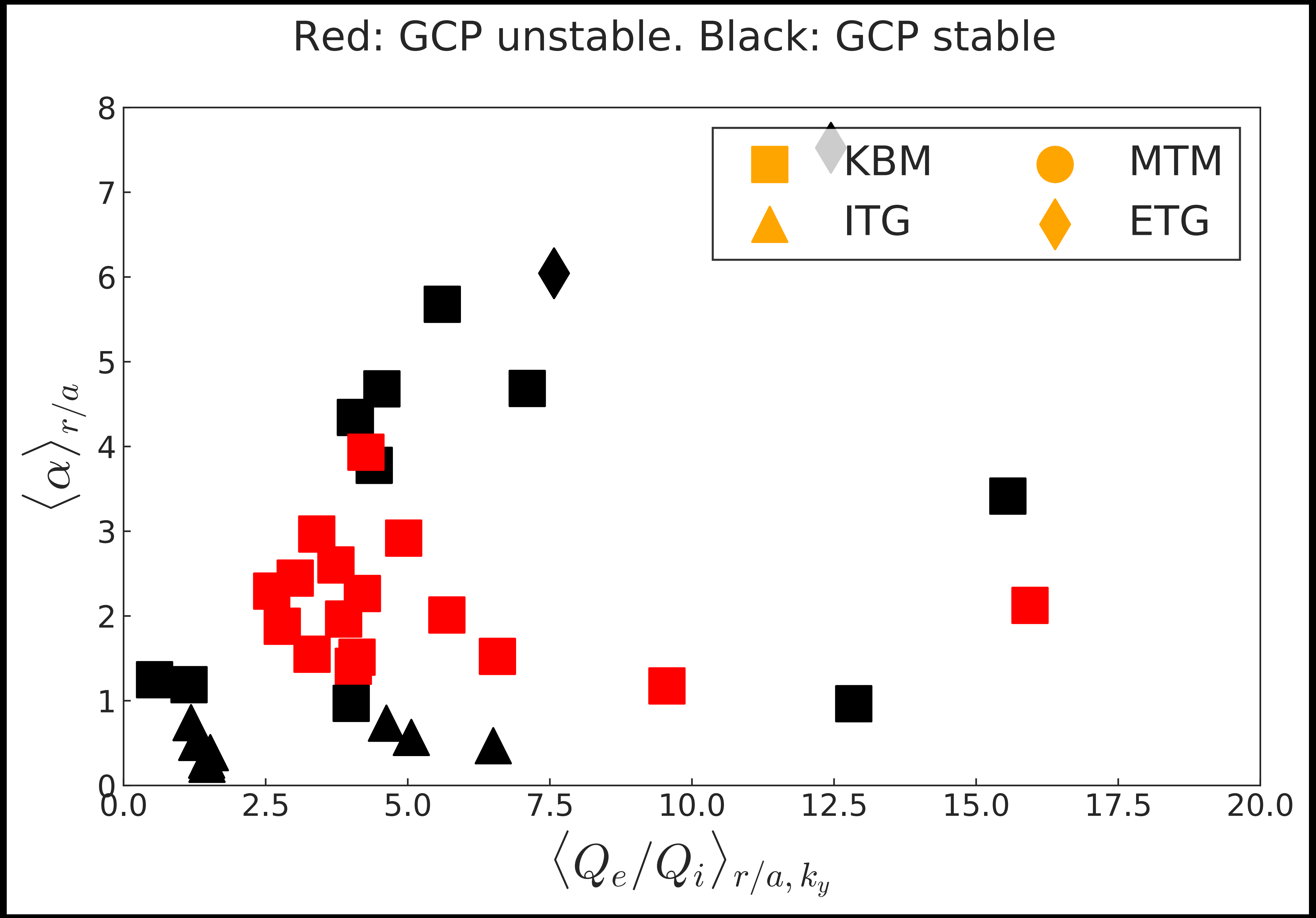
Transport Picture: Ions Vs. Electrons

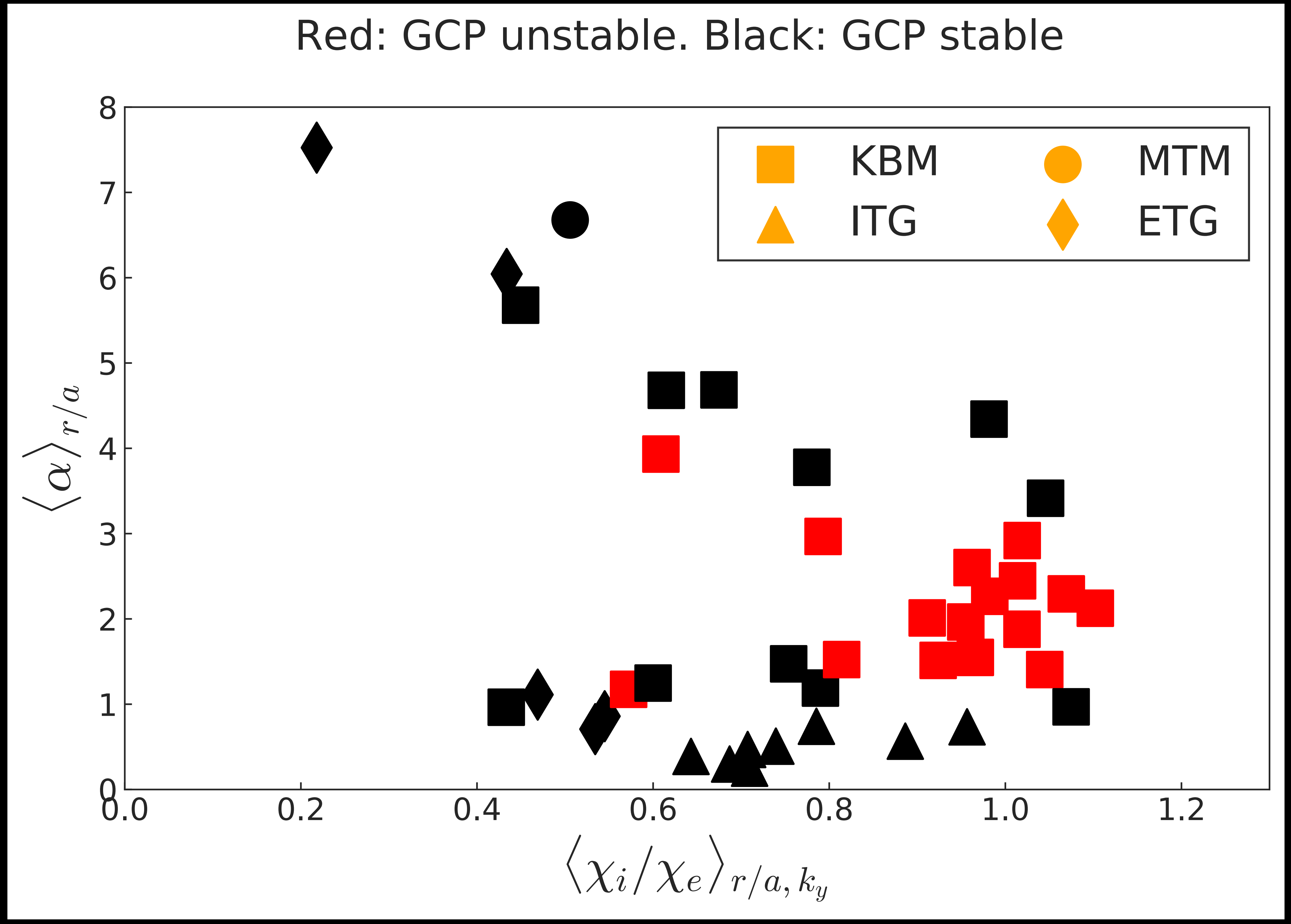
Constant n

Q_e/Q_i

χ_i/χ_e

increasing ∇T



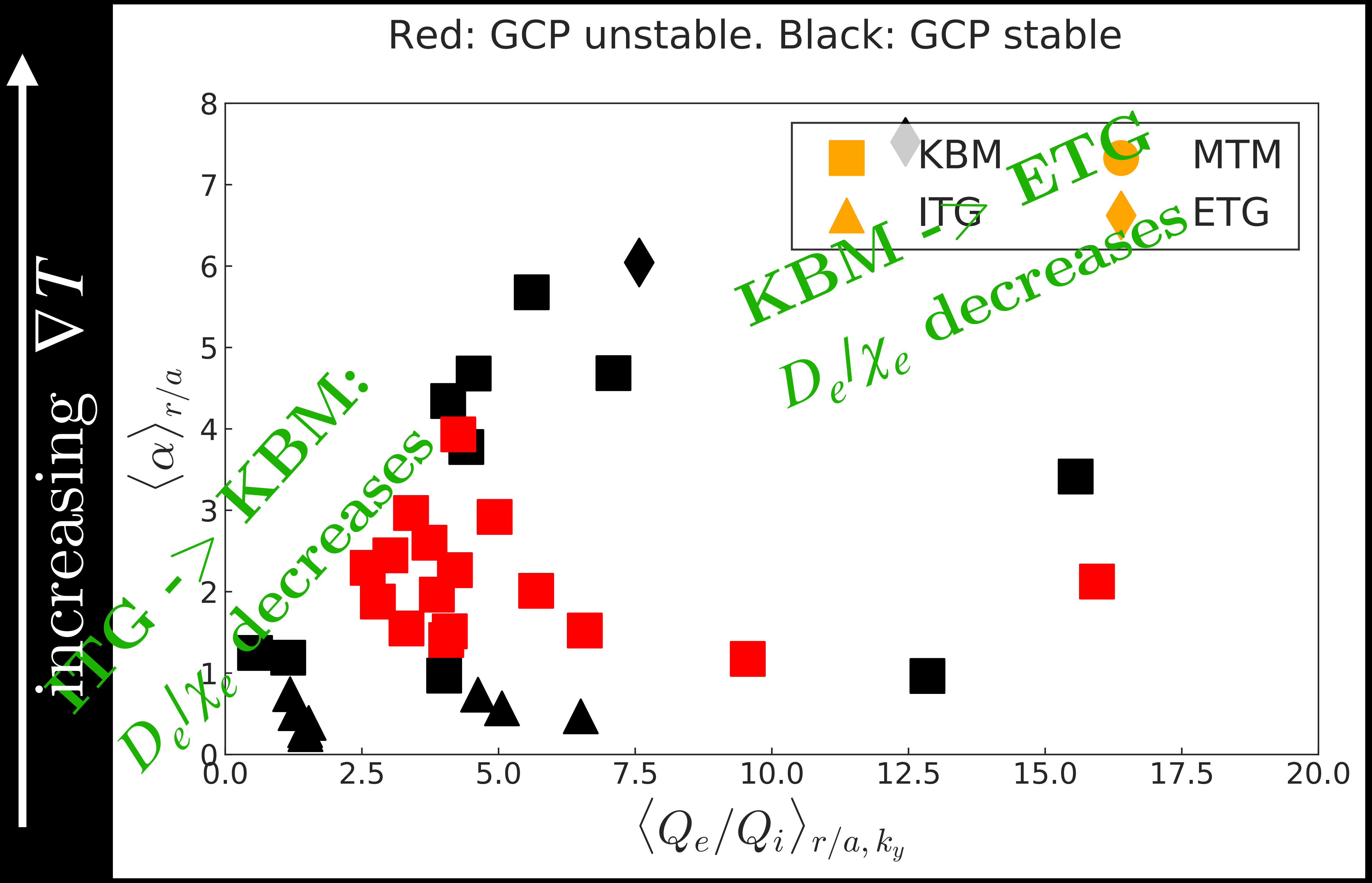


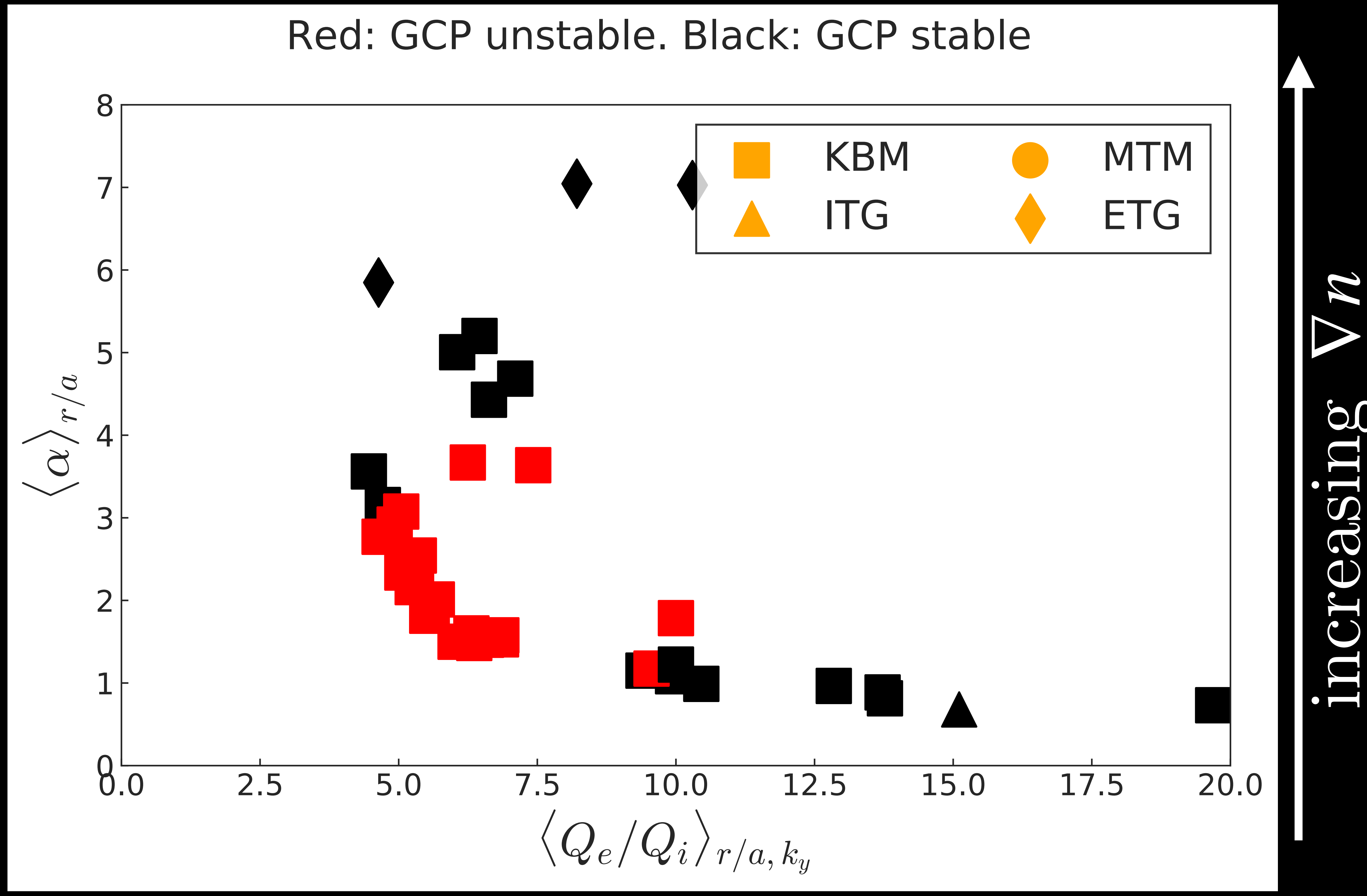
increasing ∇T

Transport Picture: Ions Vs. Electrons Q_e/Q_i

Constant n

Constant T

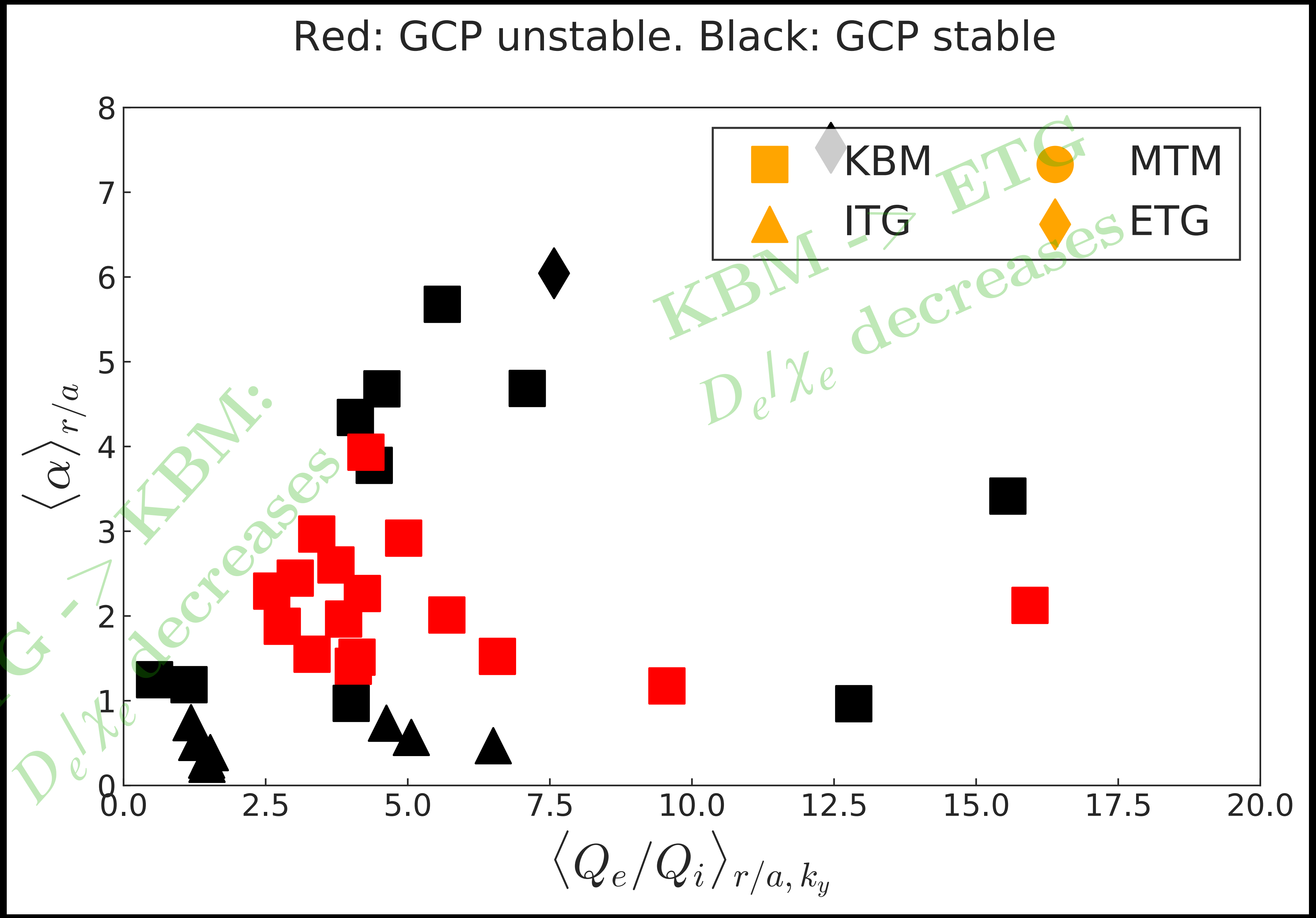




Transport Picture: Ions Vs. Electrons Q_e/Q_i

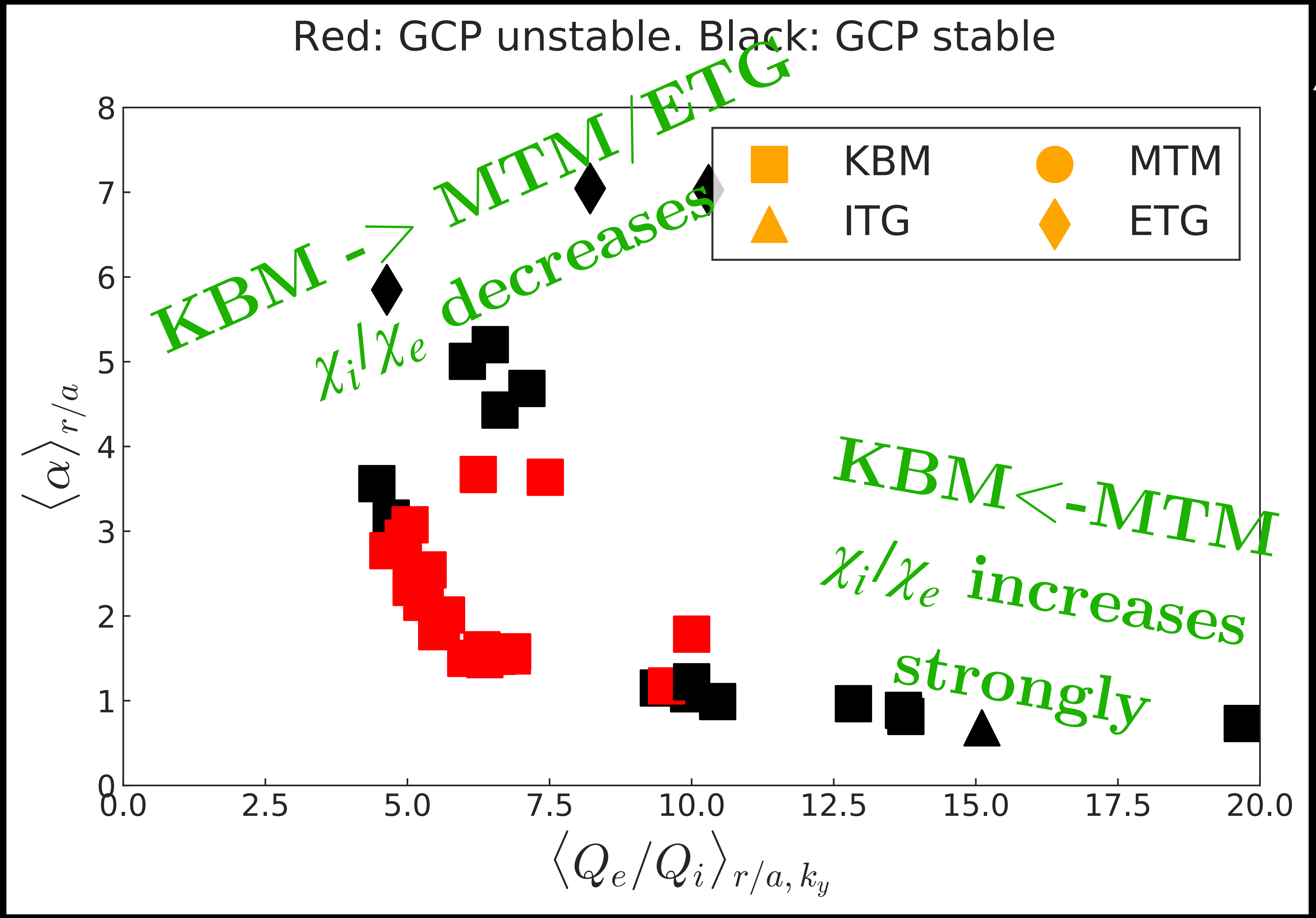
Constant n

increasing ∇T



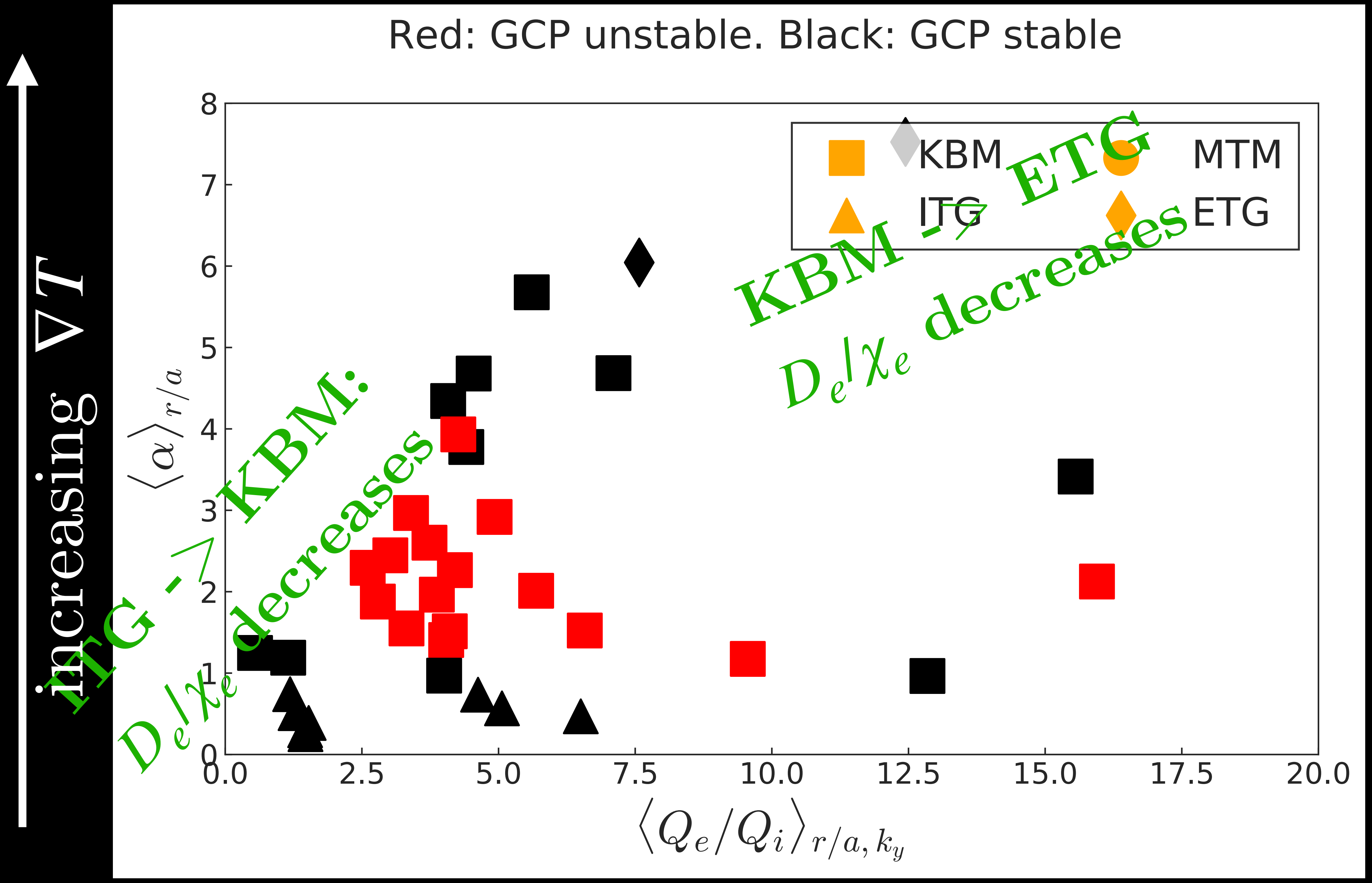
Constant T

increasing ∇n

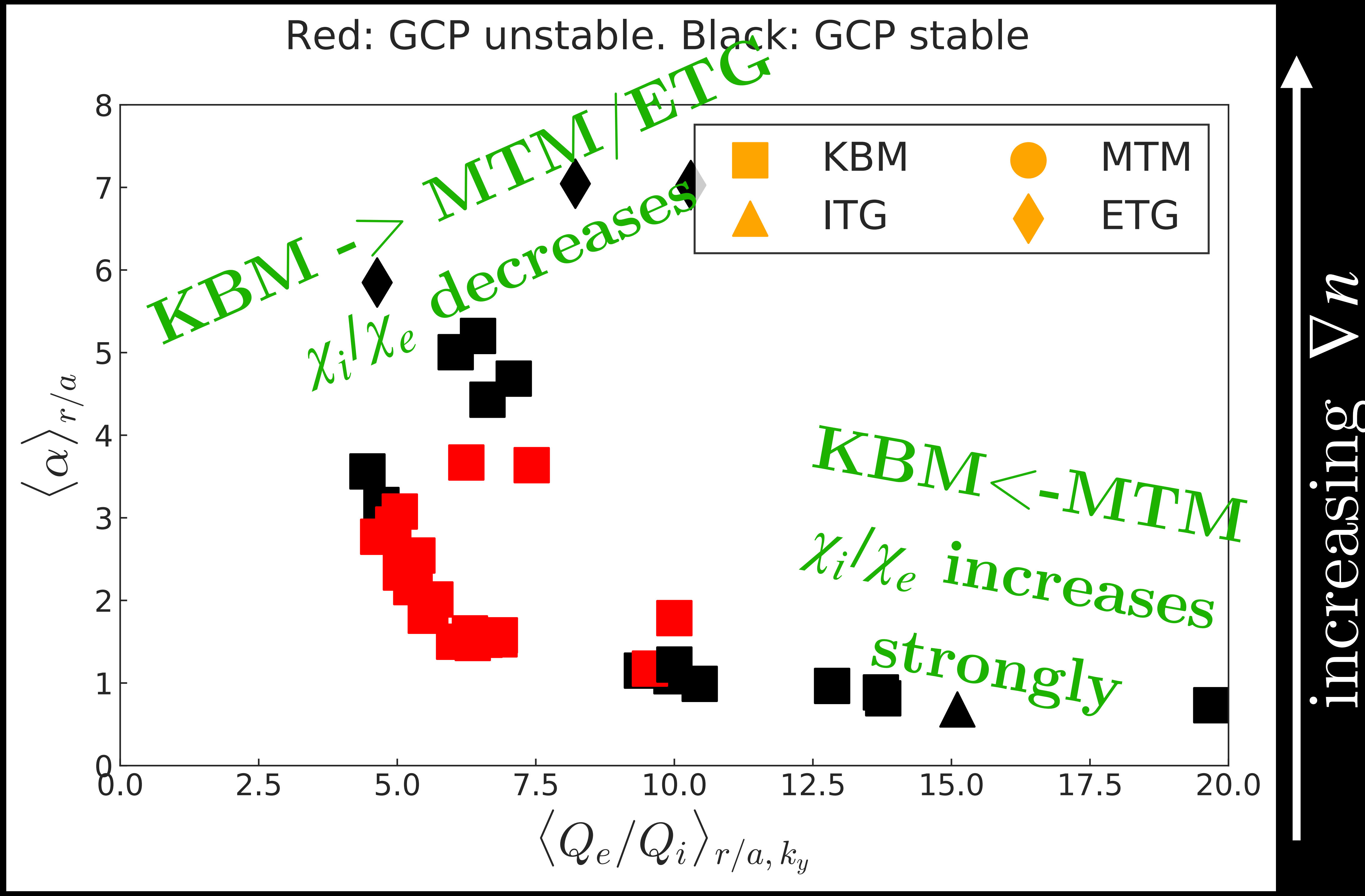


Transport Picture: Ions Vs. Electrons Q_e/Q_i

Constant n



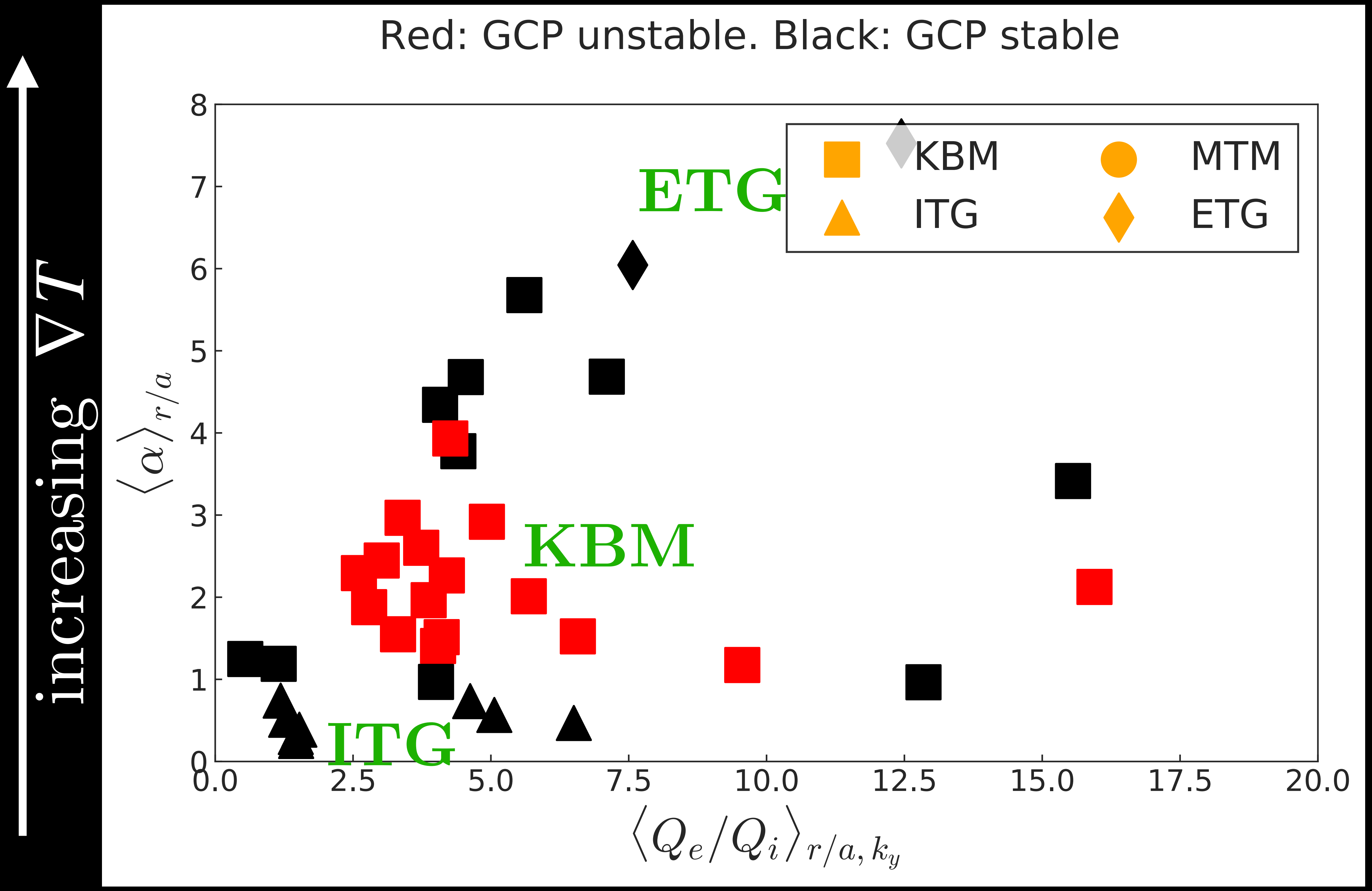
Constant T



Transport Picture: Summary

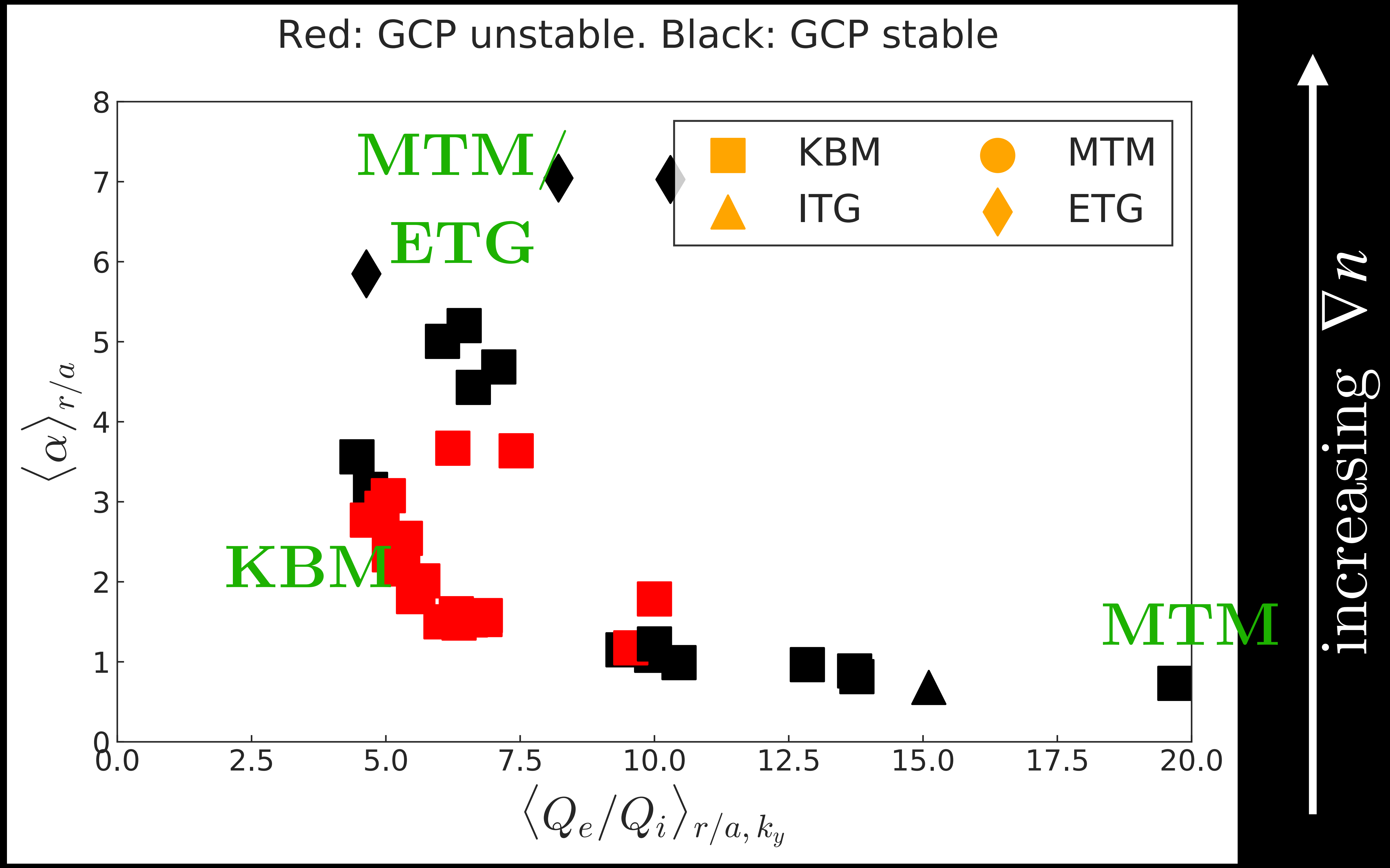
Constant n

- ITG —> KBM —> ETG
  increases Q_e/Q_i



Constant T

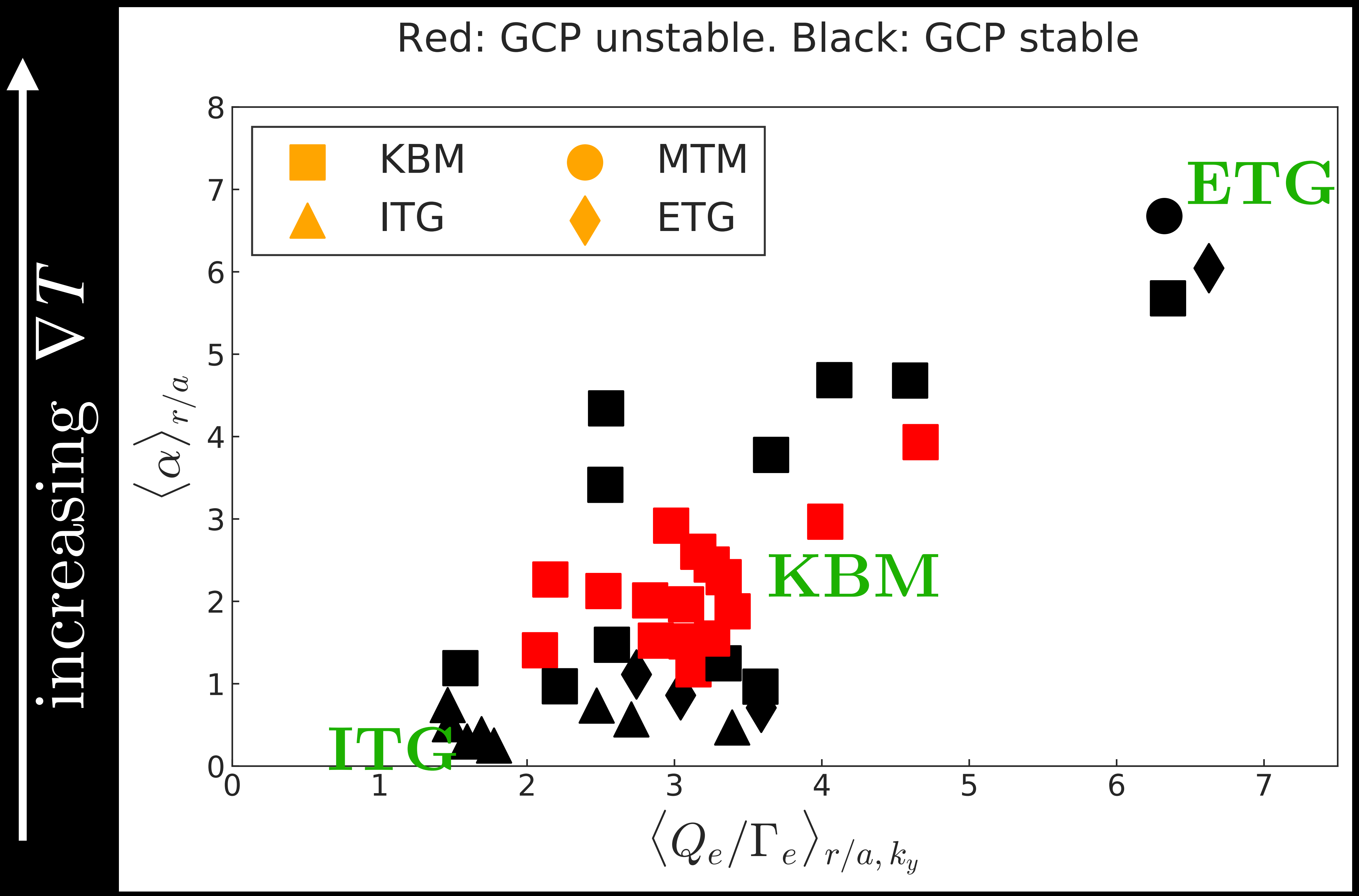
- MTM —> KBM —> MTM/ETG
  decreases Q_e/Q_i



Transport Picture: Summary

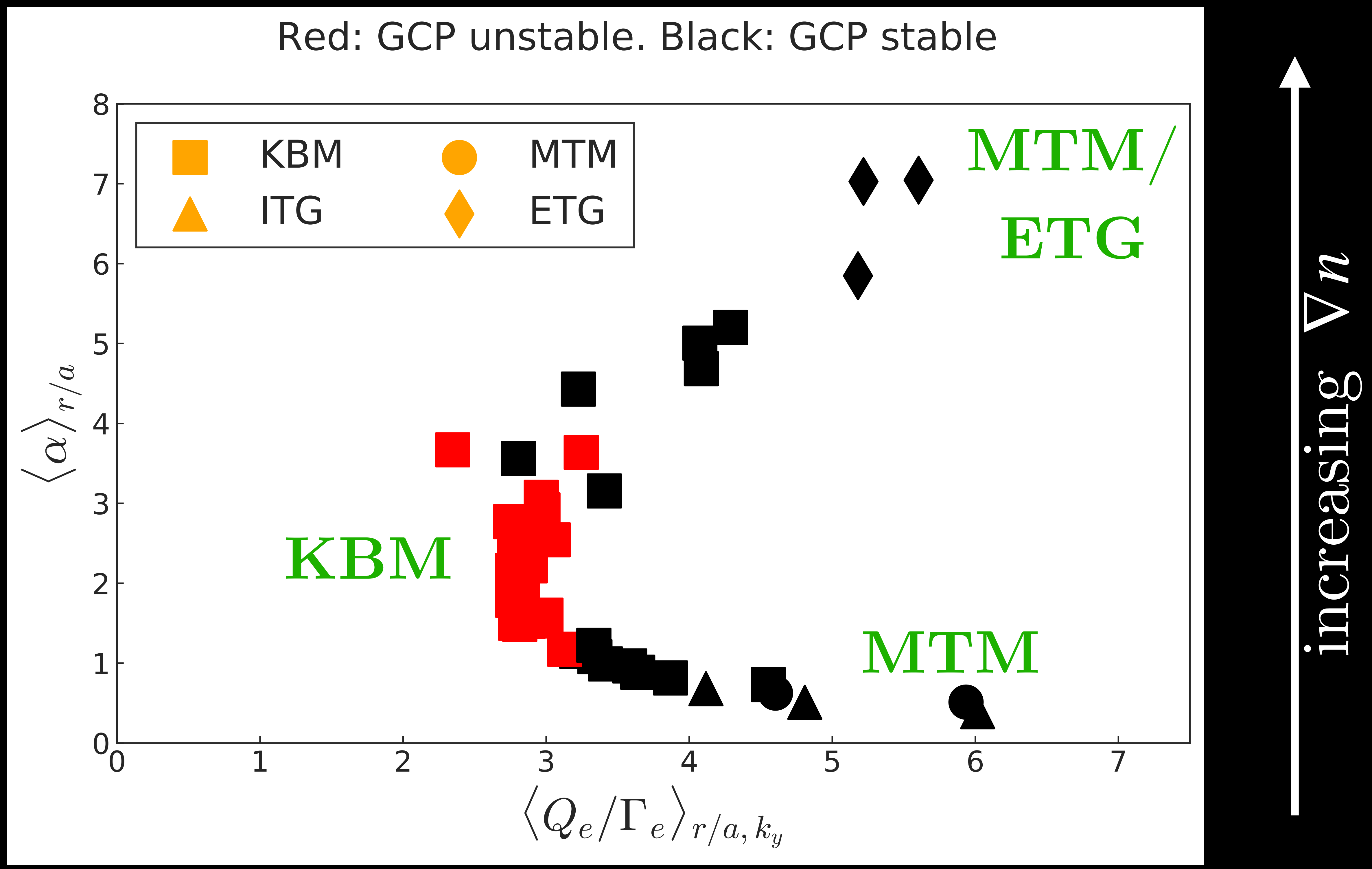
Constant n

- ITG —> KBM —> ETG
  increases Q_e/Γ_e



Constant T

- MTM —> KBM —> MTM/ETG
  complicated Q_e/Γ_e

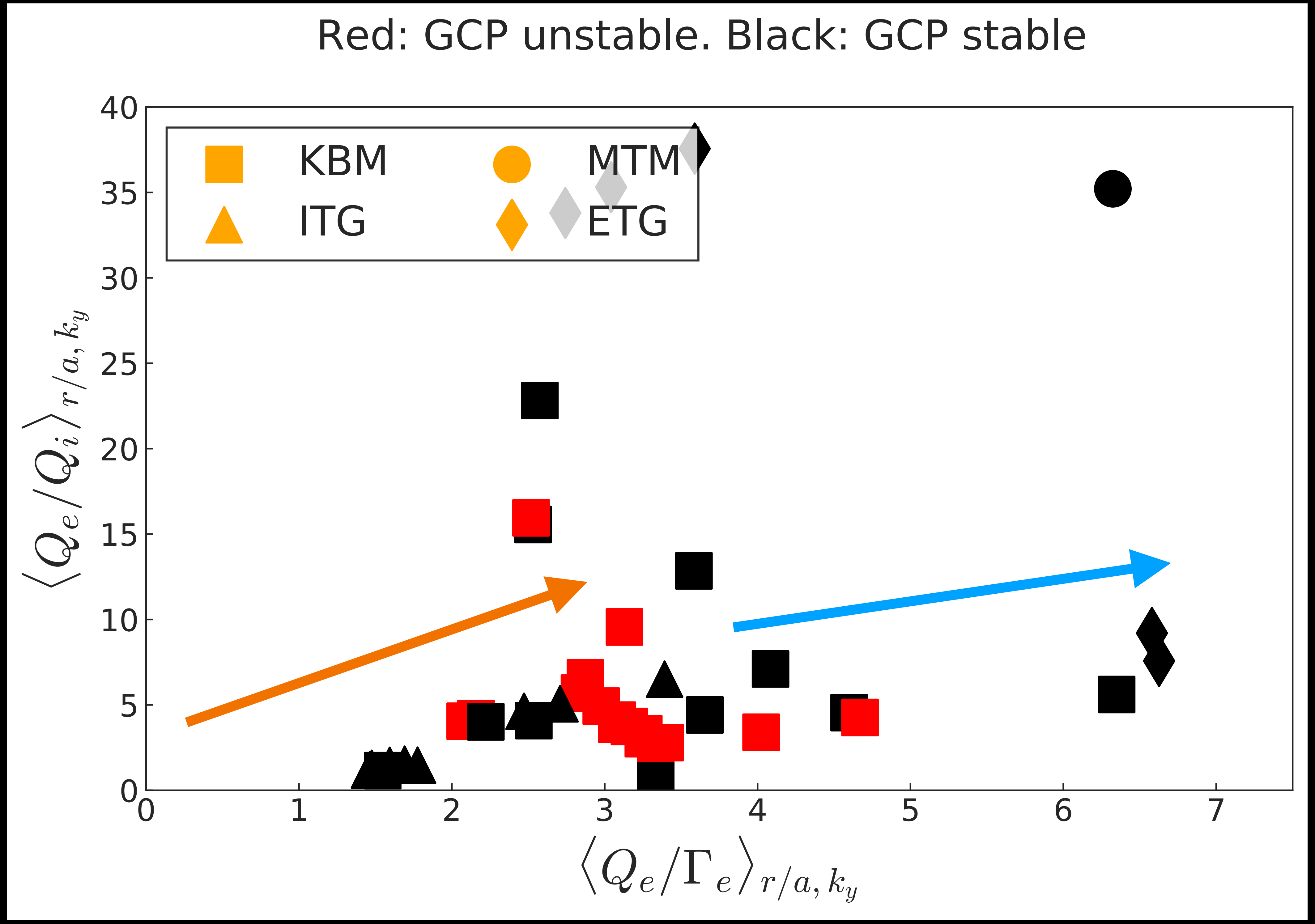


Transport Picture: Summary

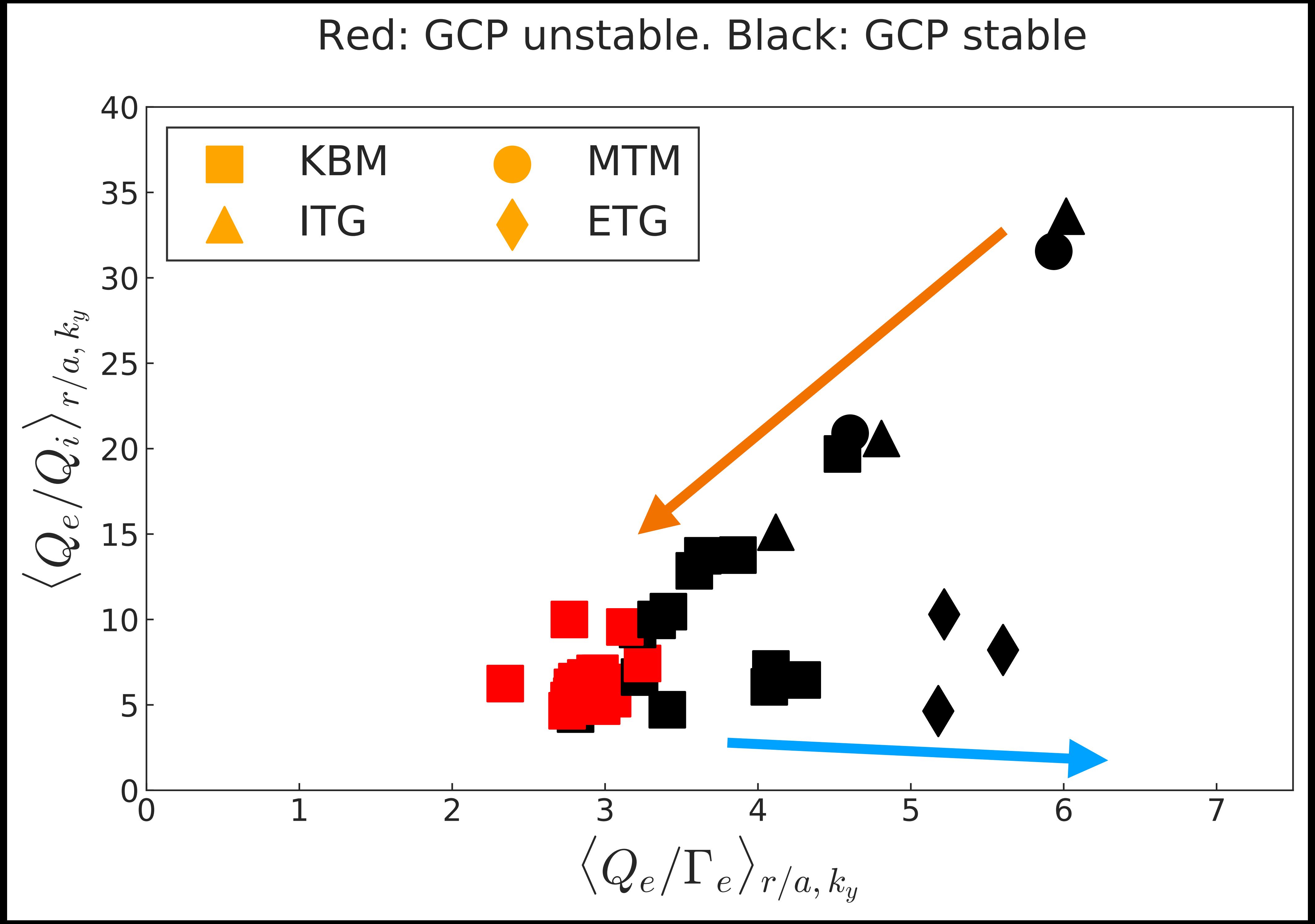
- ITG —> KBM —> ETG
- MTM —> KBM —> MTM/ETG

complicated Q_e/Γ_e

Constant n



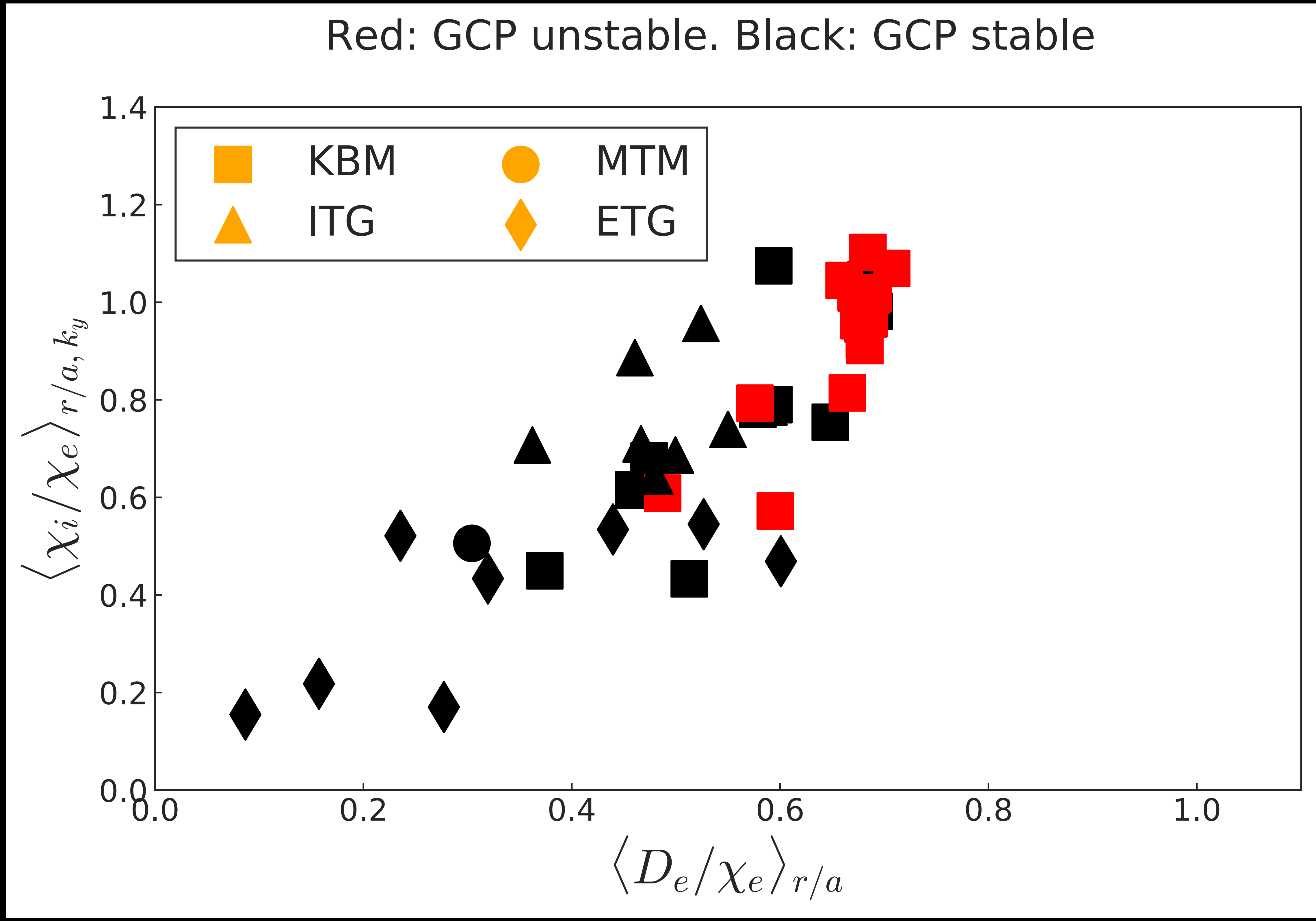
Constant T



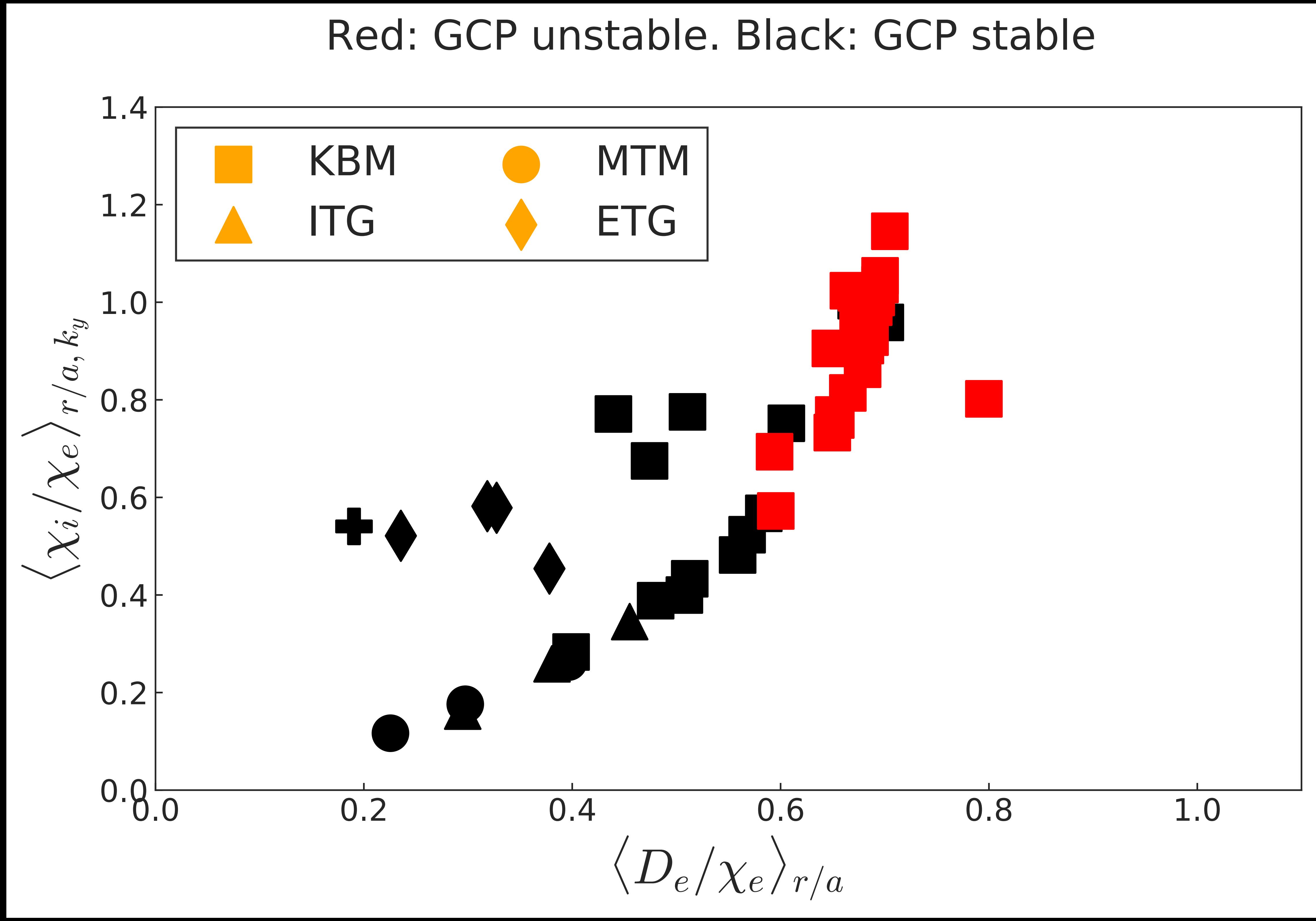
Backup Slides

Unstable pedestals sit at maximum electron diffusivity points.

Constant n



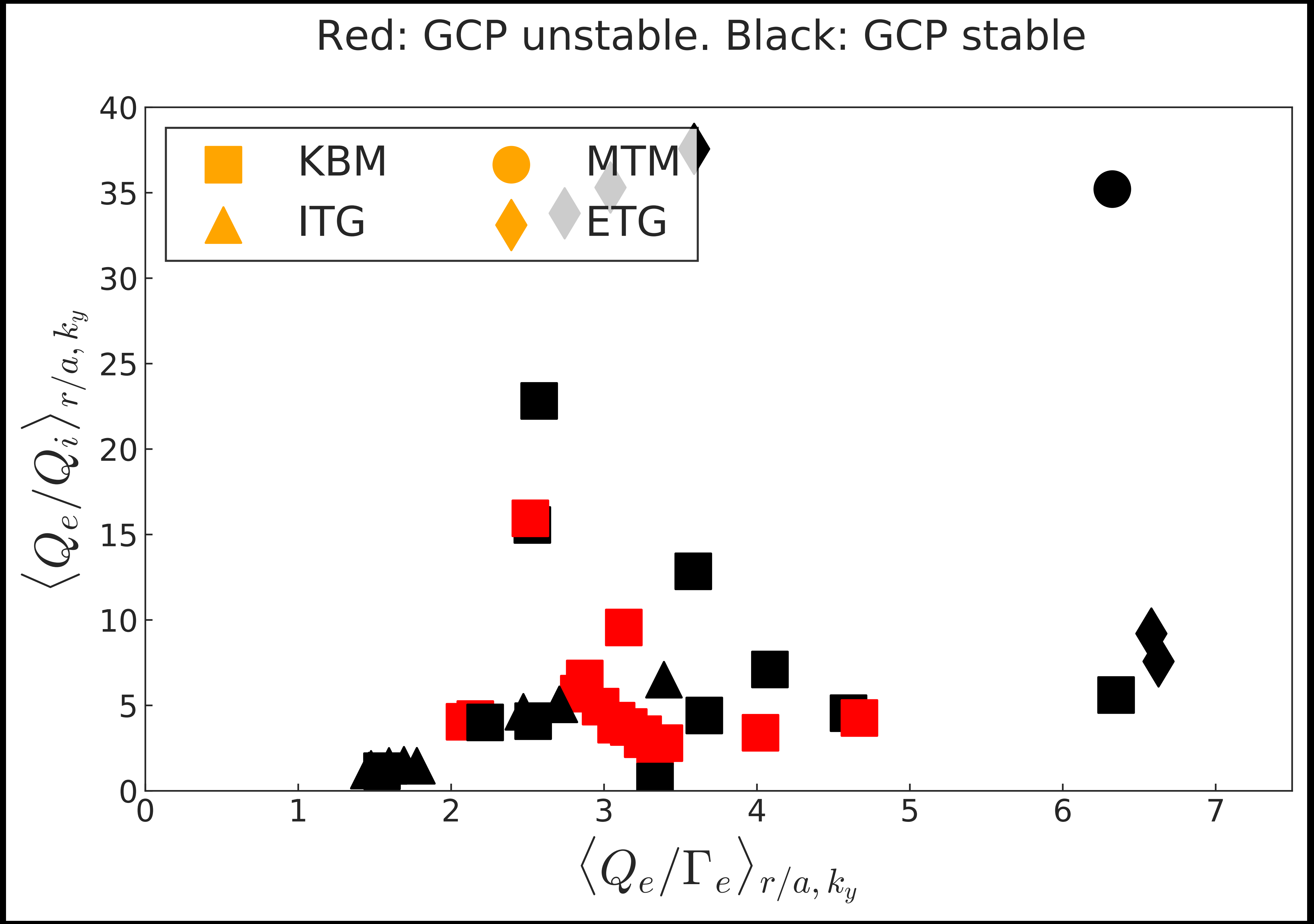
Constant T



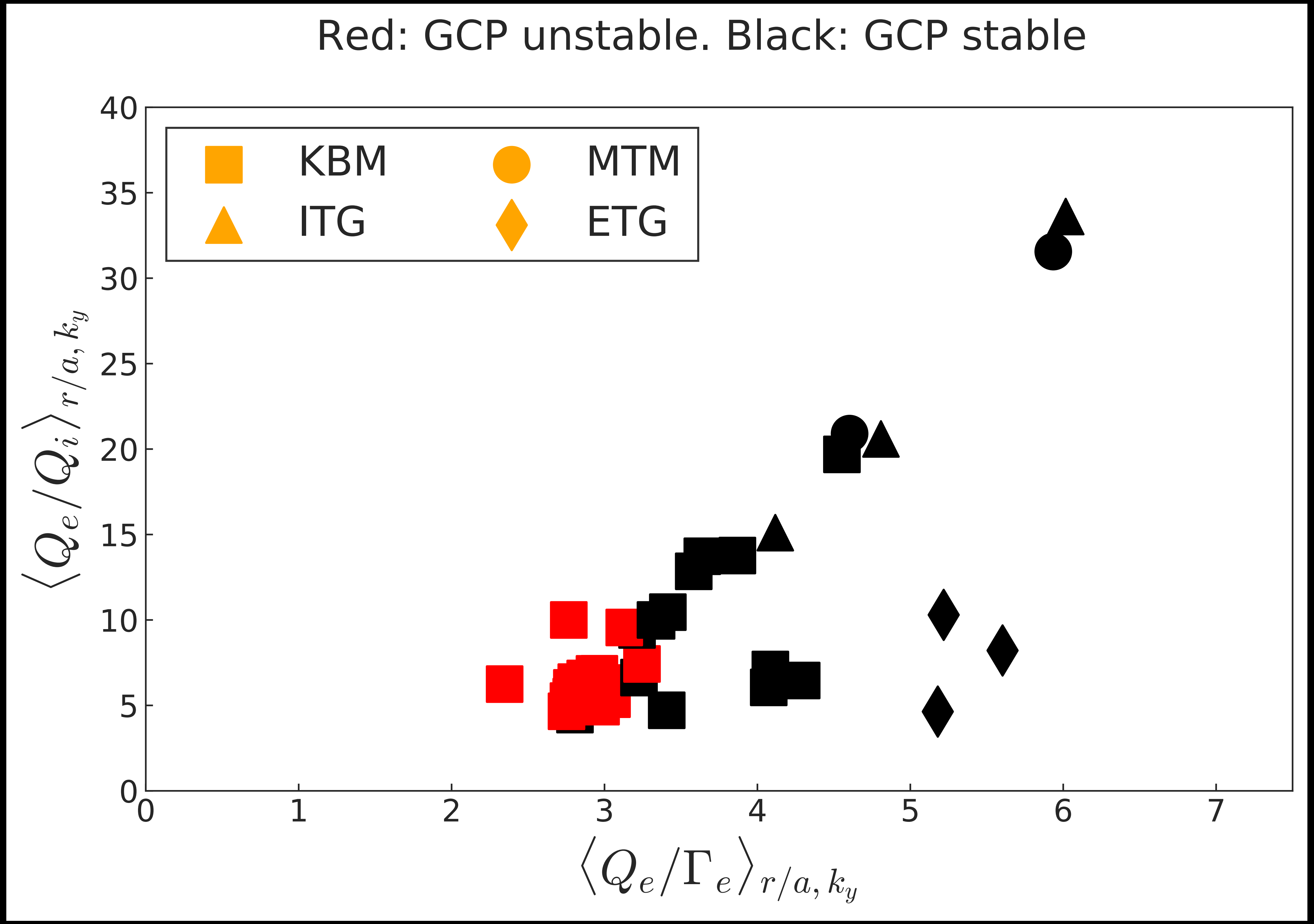
Backup Slides

Constant T pedestal sits at a minimum Q_e state. Presence of ITG in constant n gives very low Q_e for constant n.

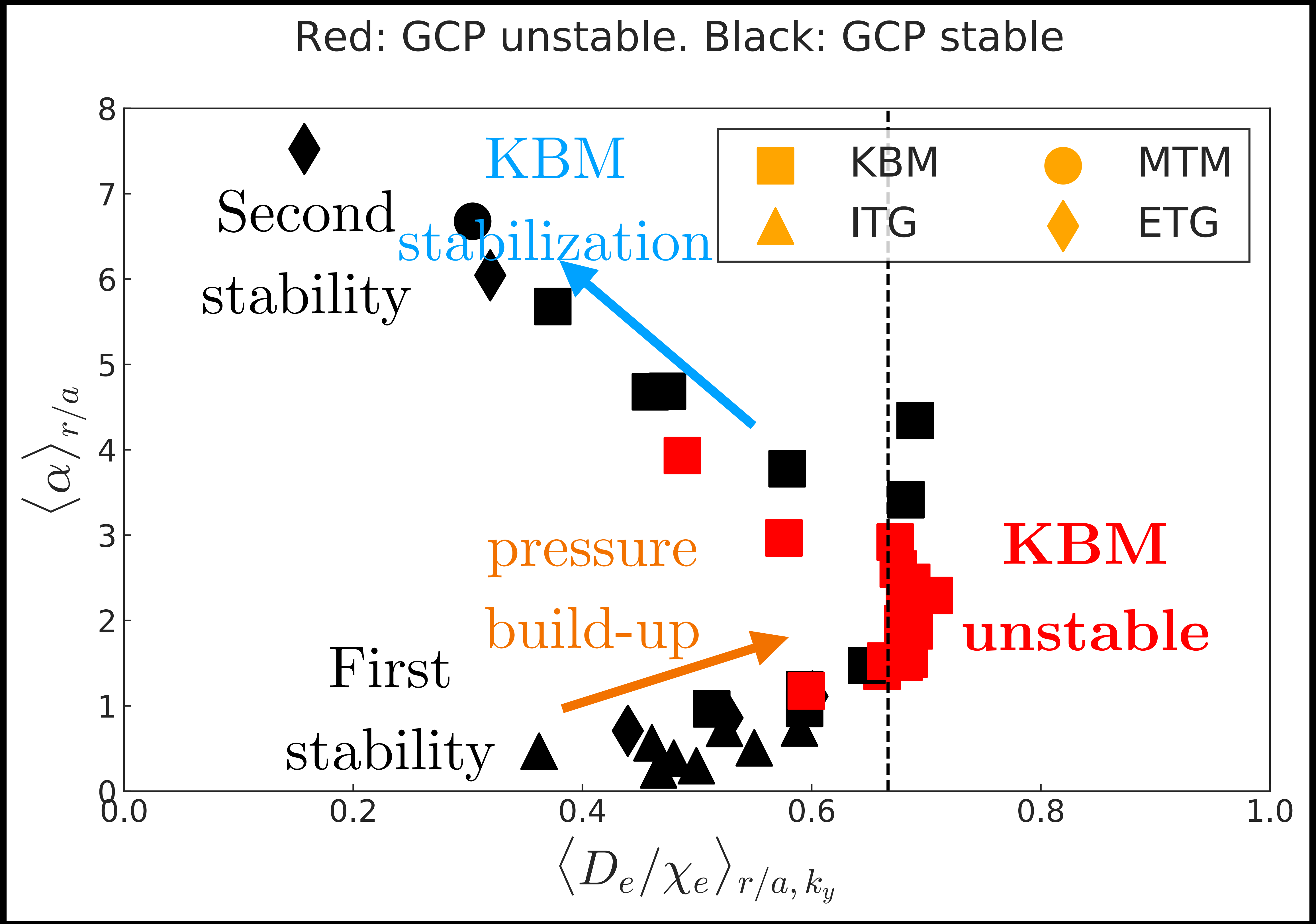
Constant n

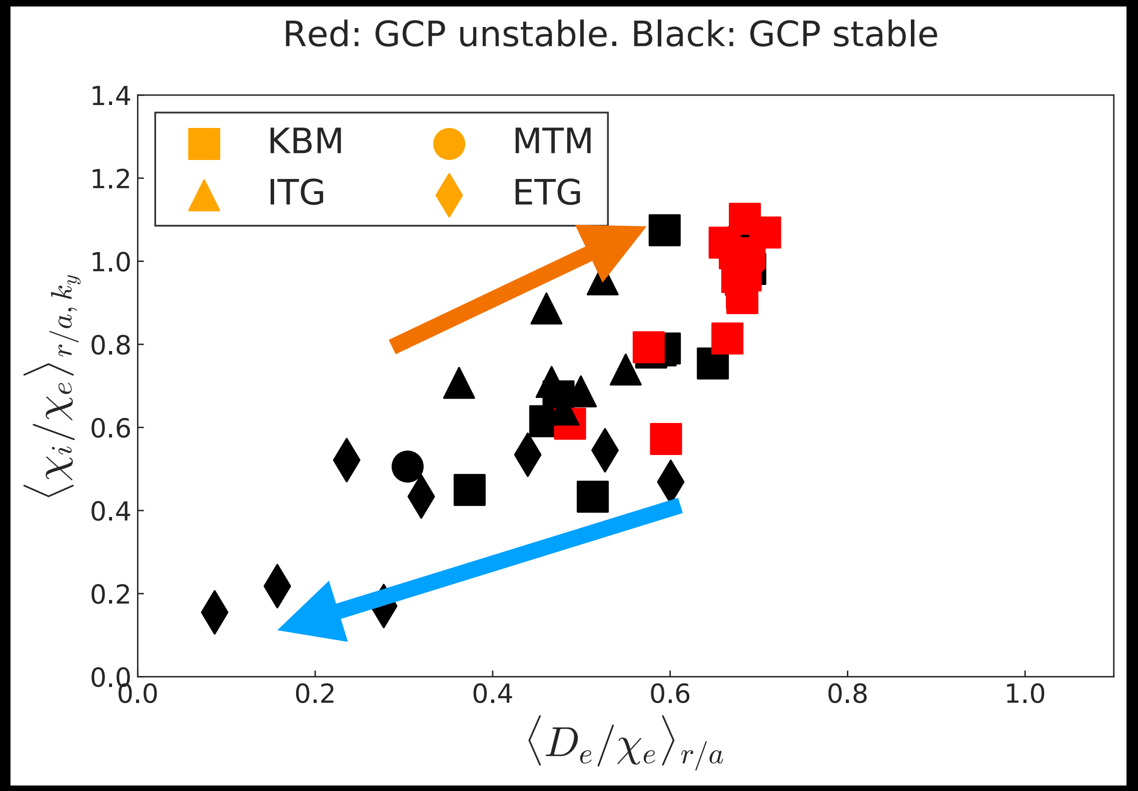


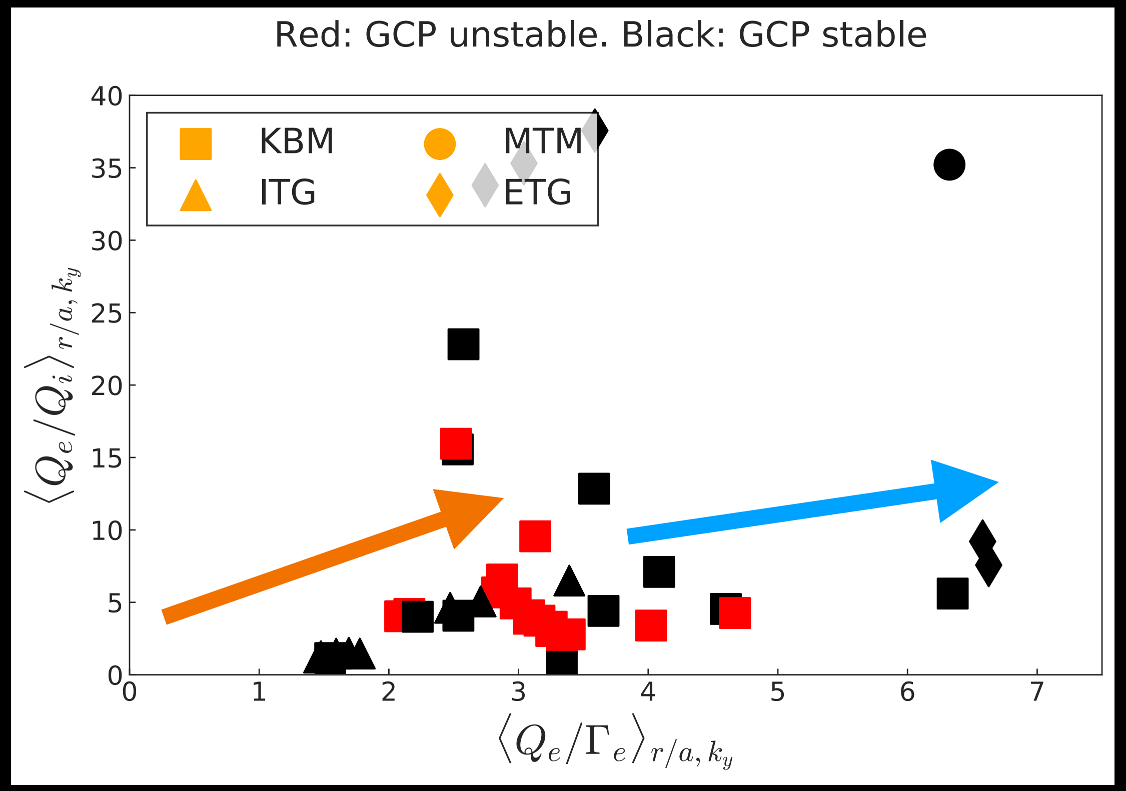
Constant T



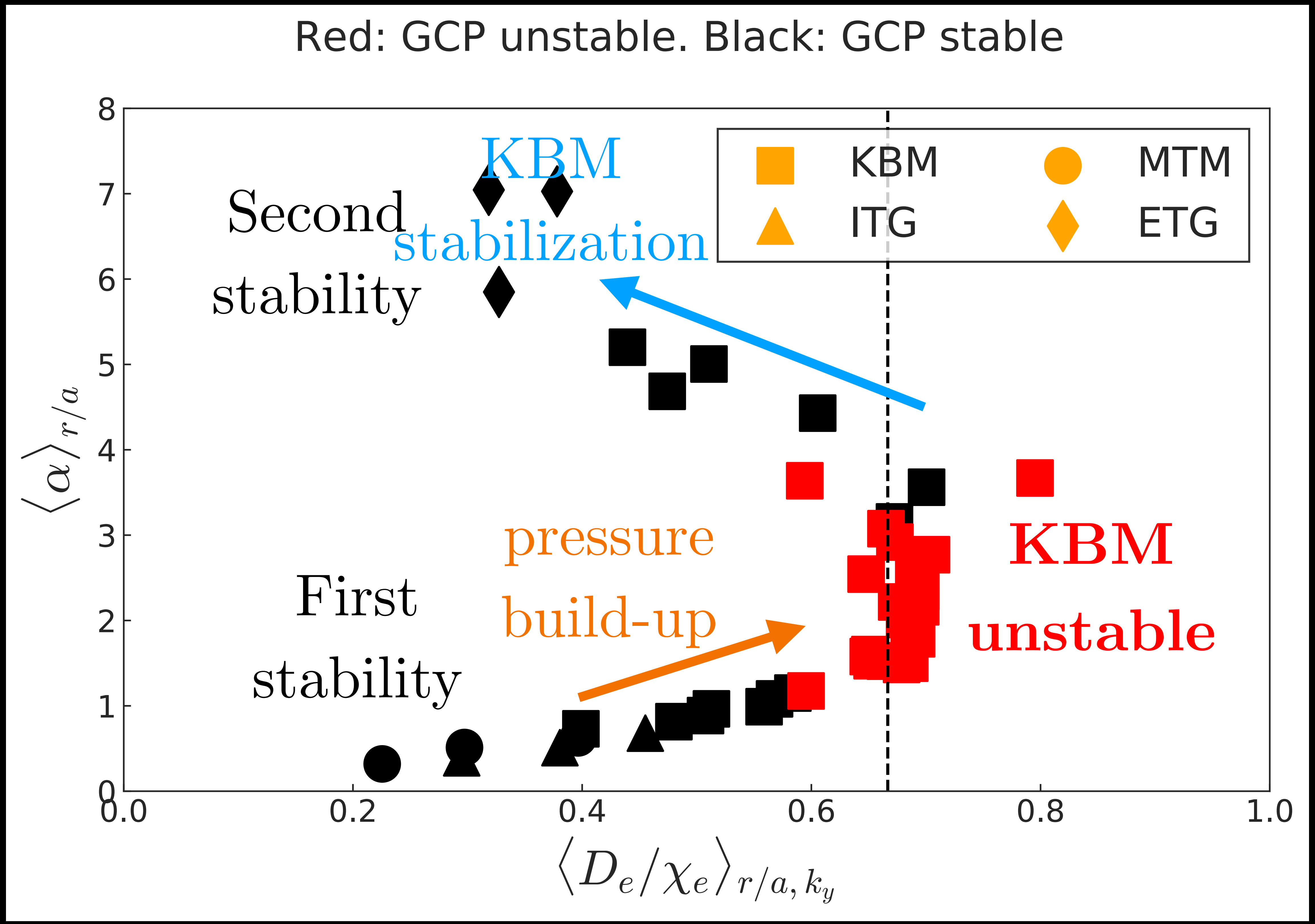
Constant n

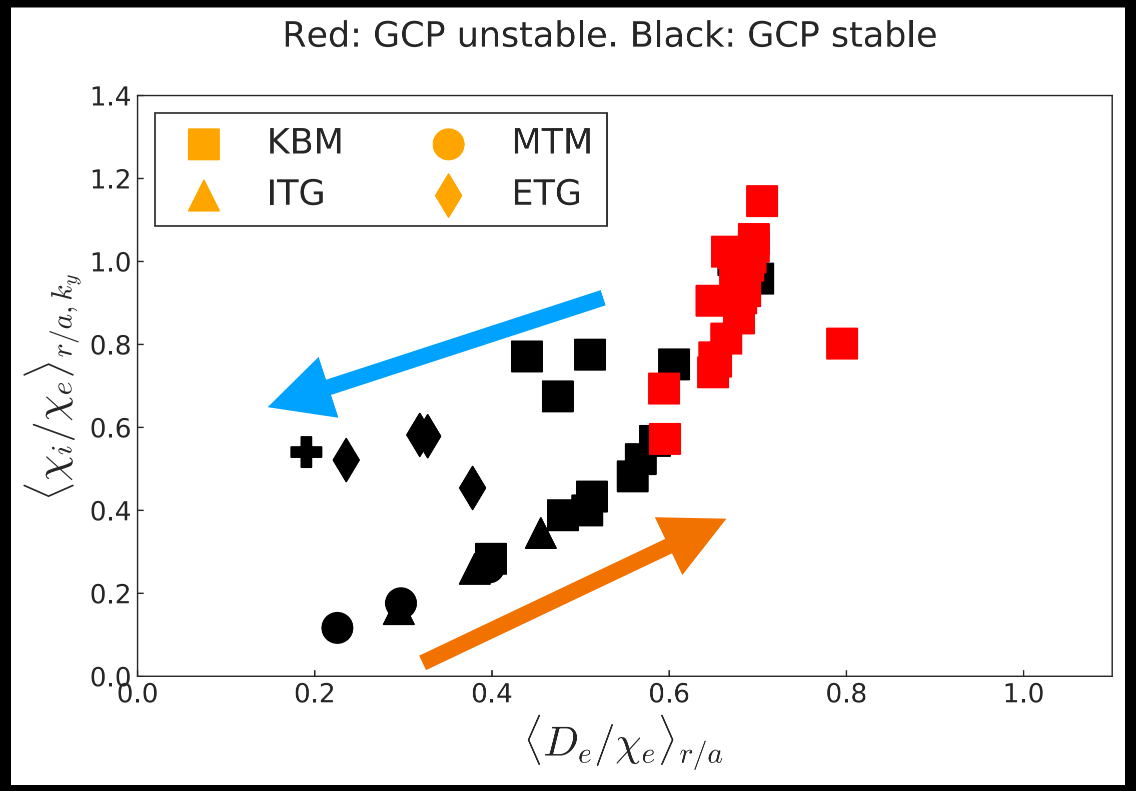


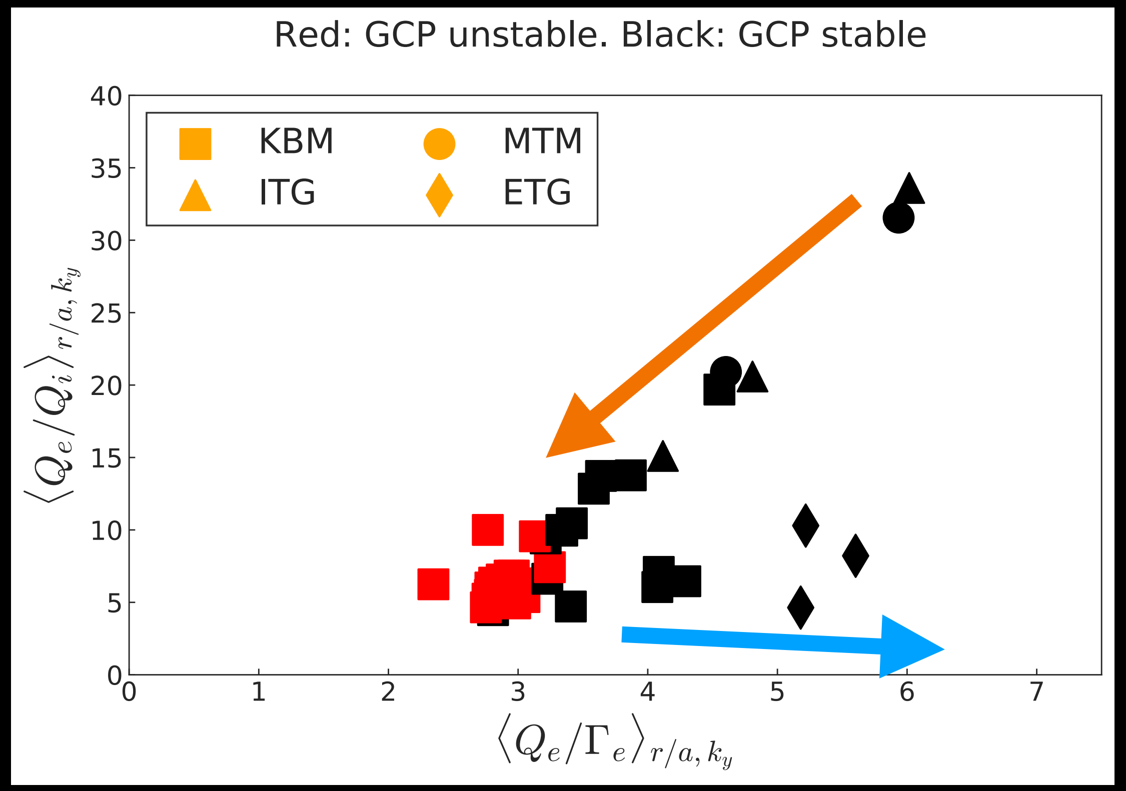




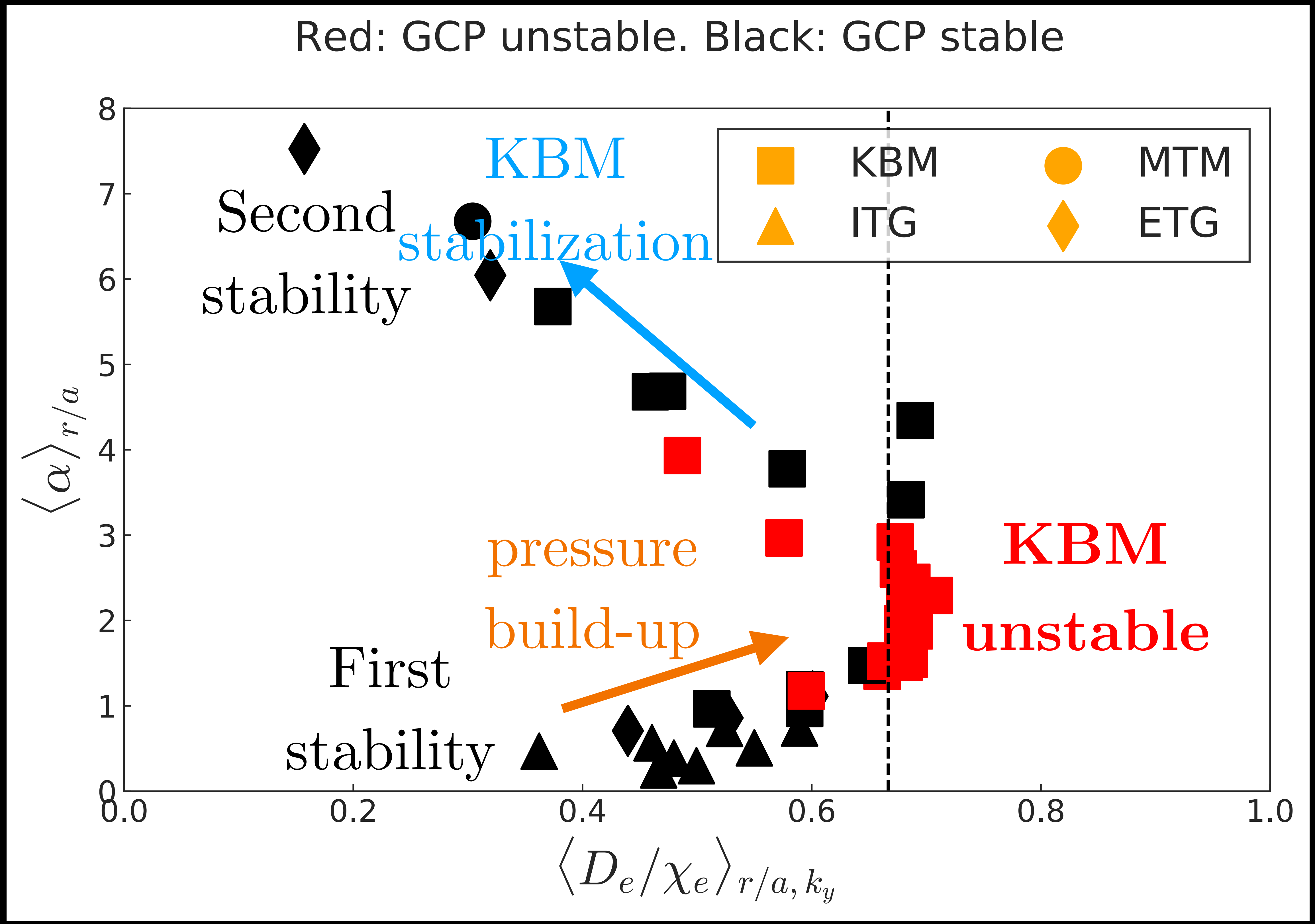
Constant T

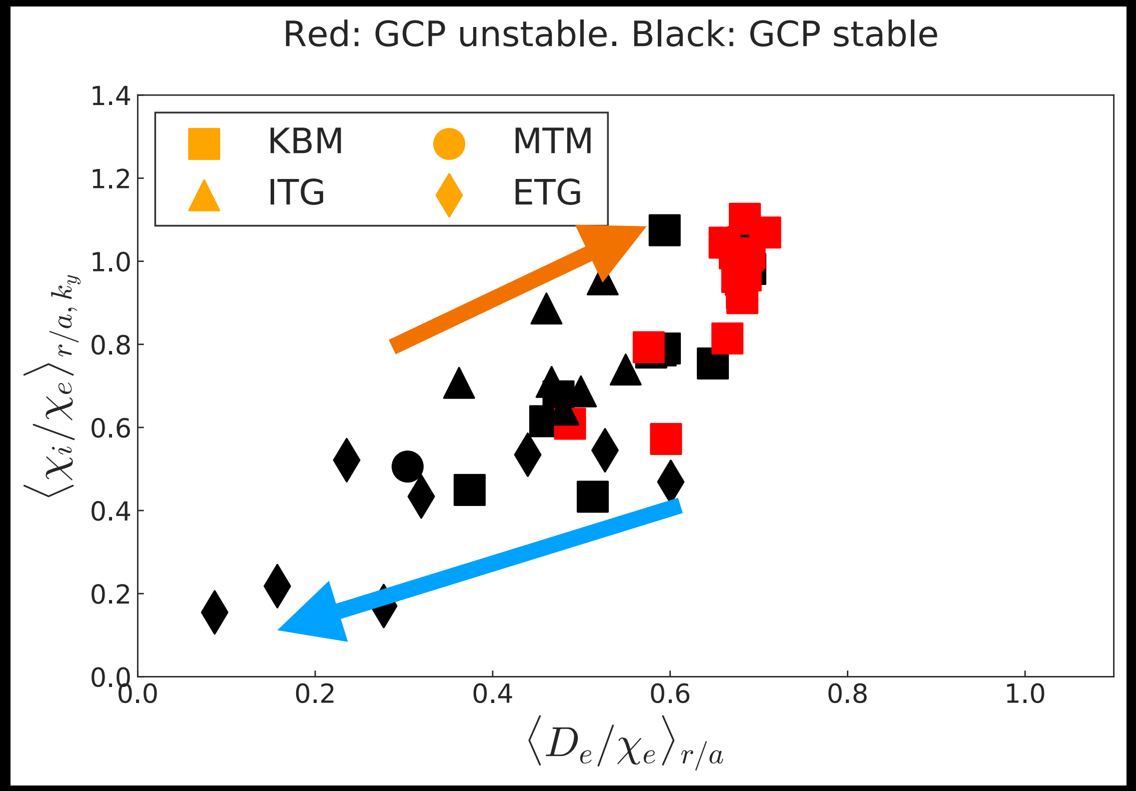


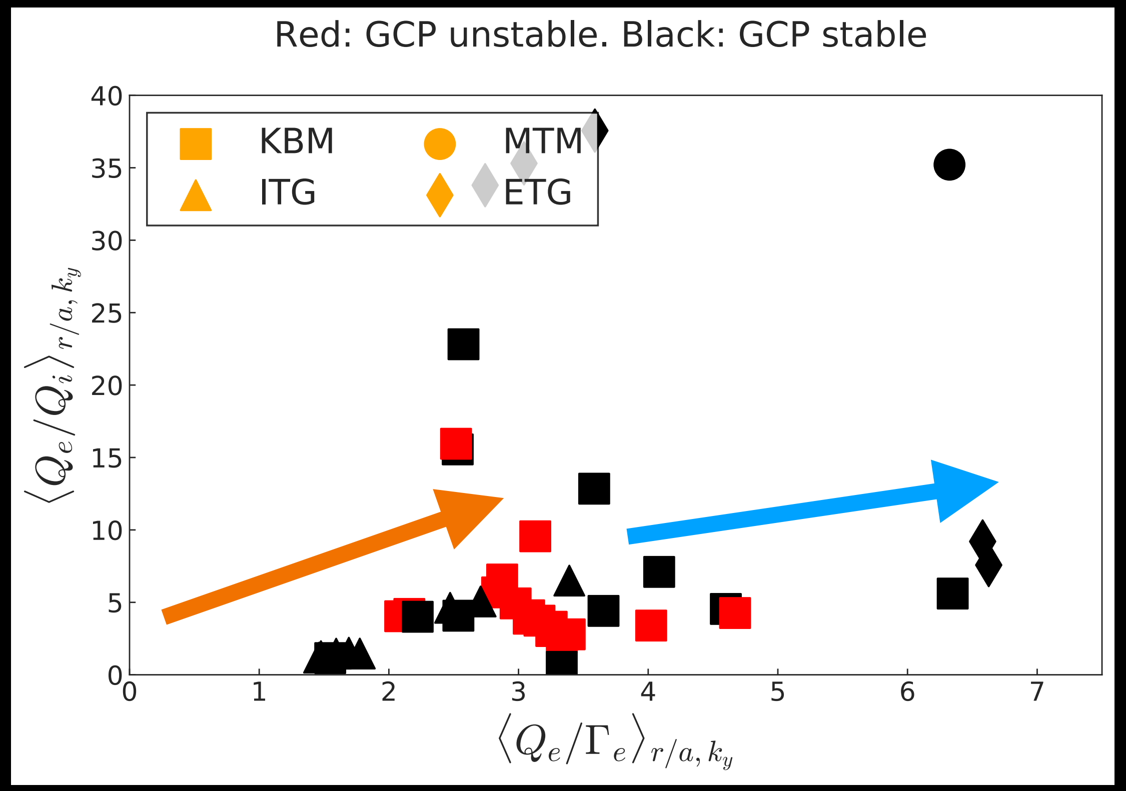




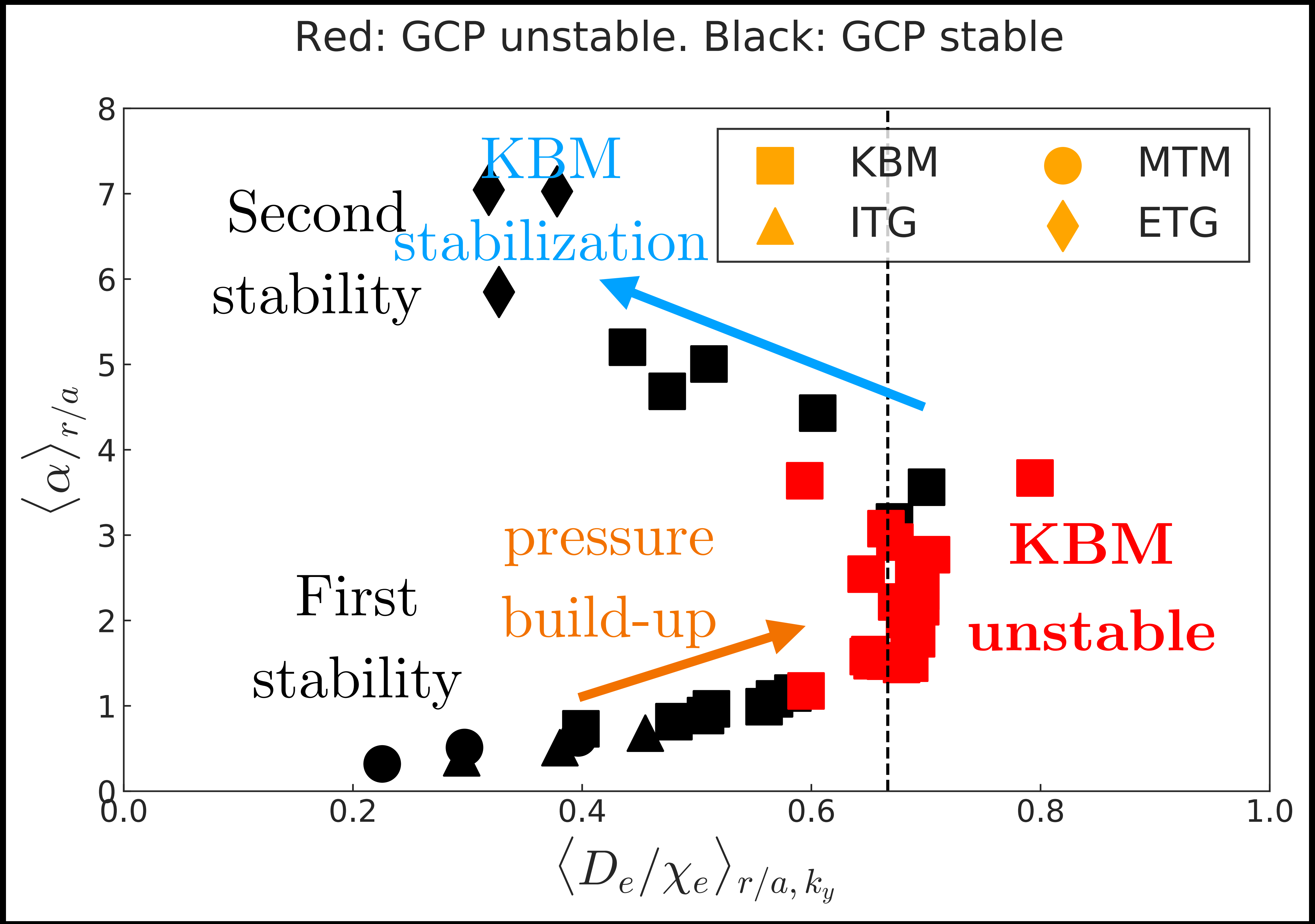
T, n trajectory plots…

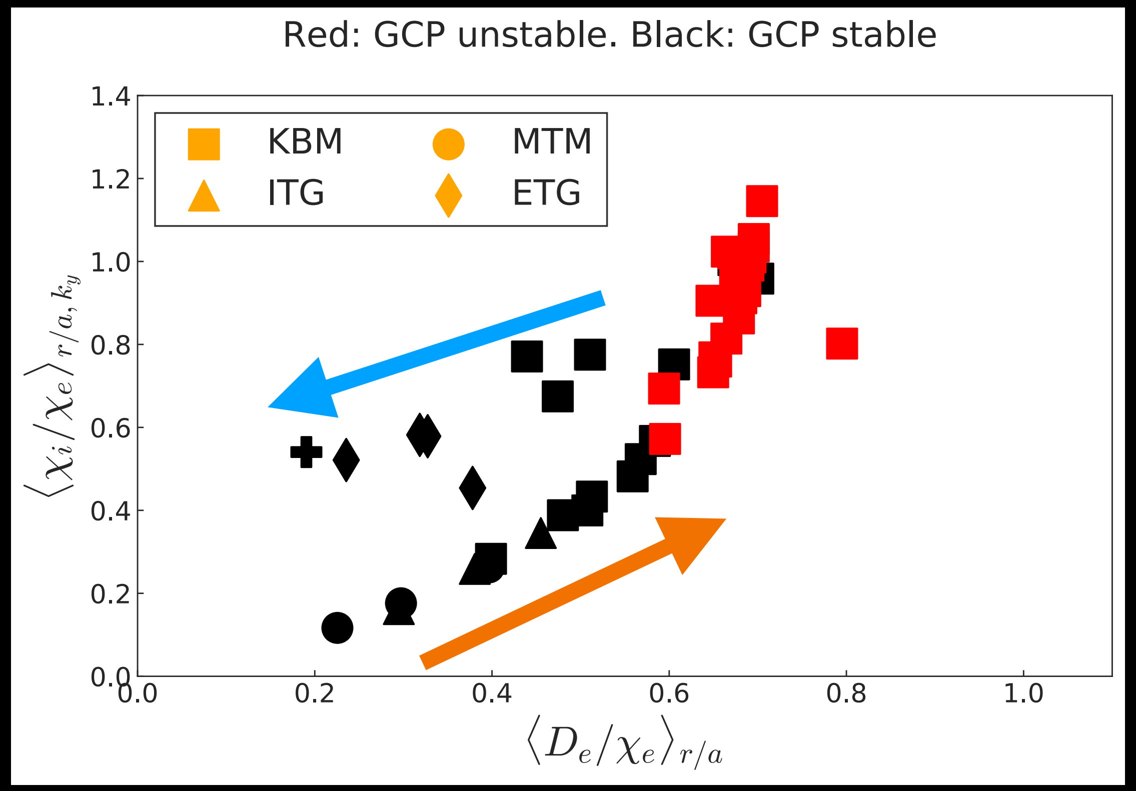


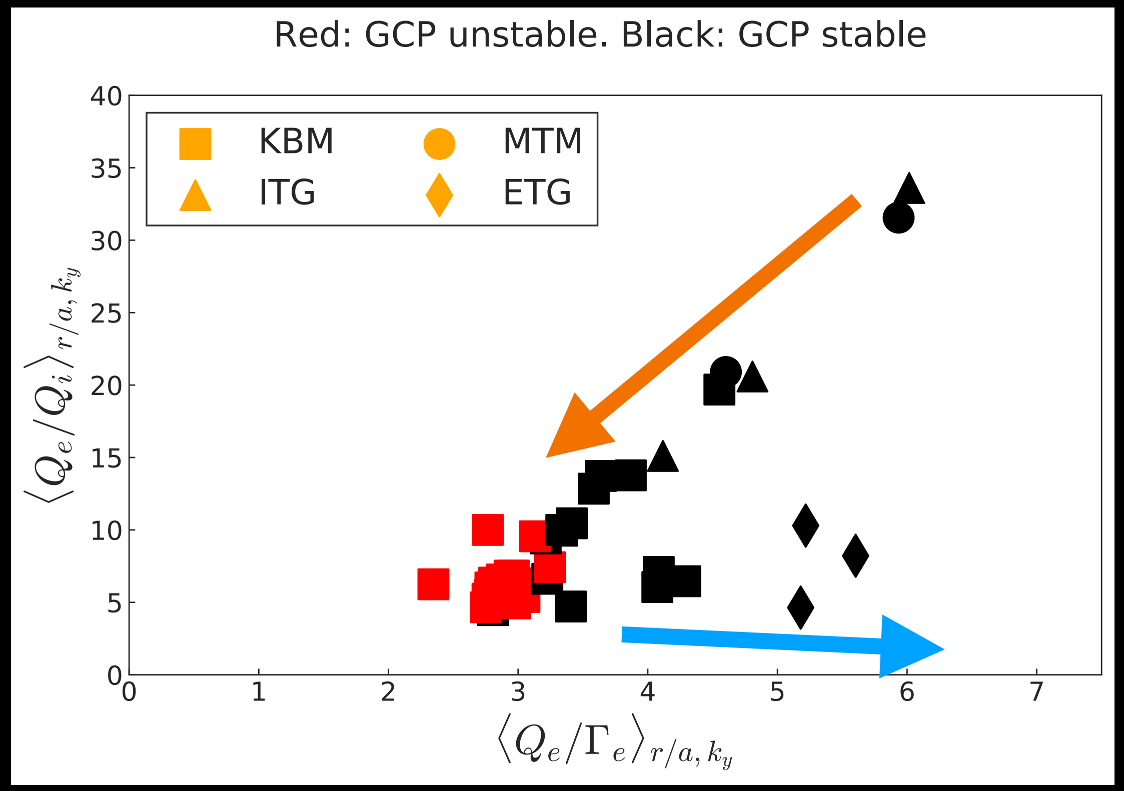




Constant T







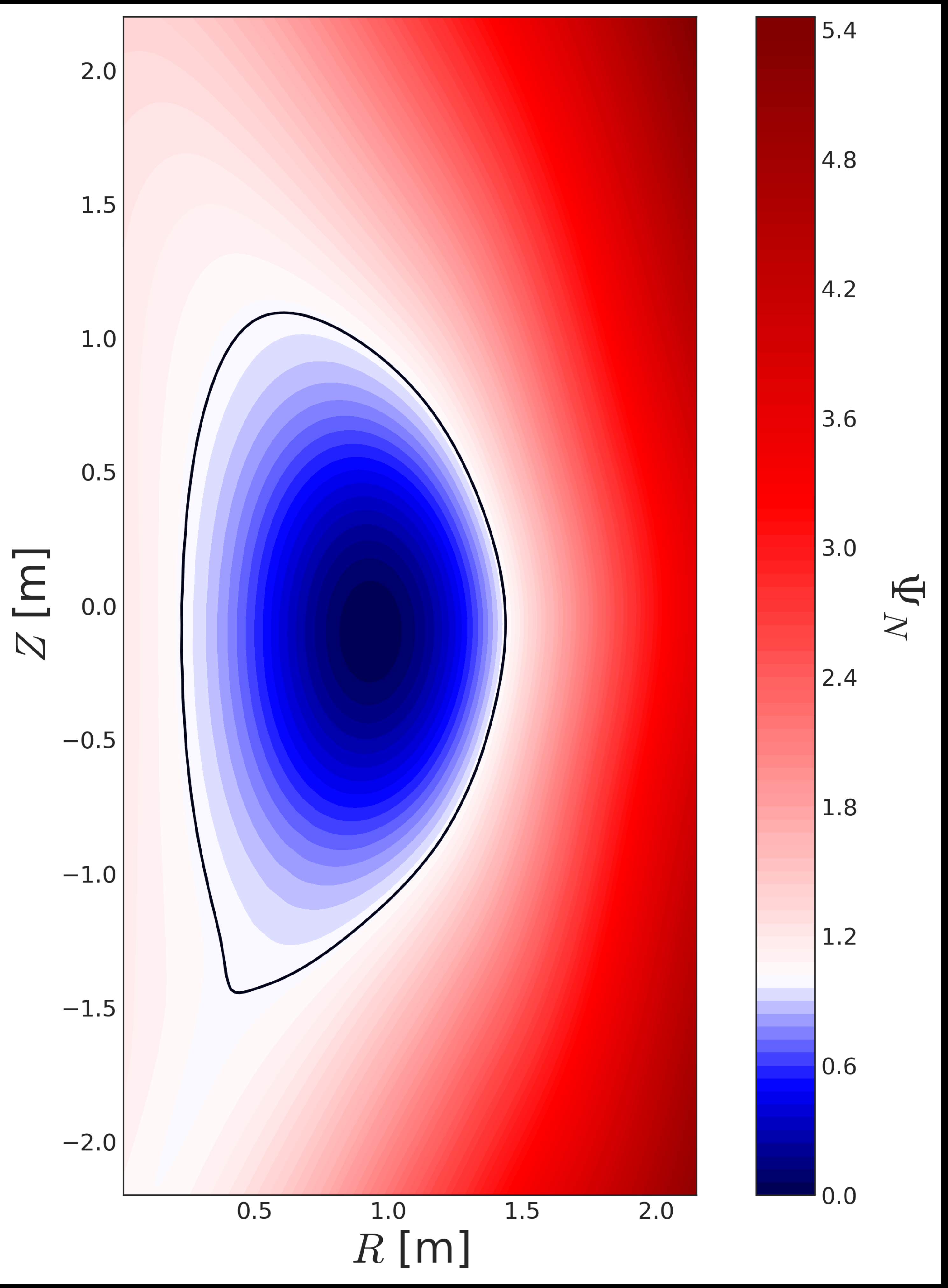
Difference b/w low-A BCP and our results.

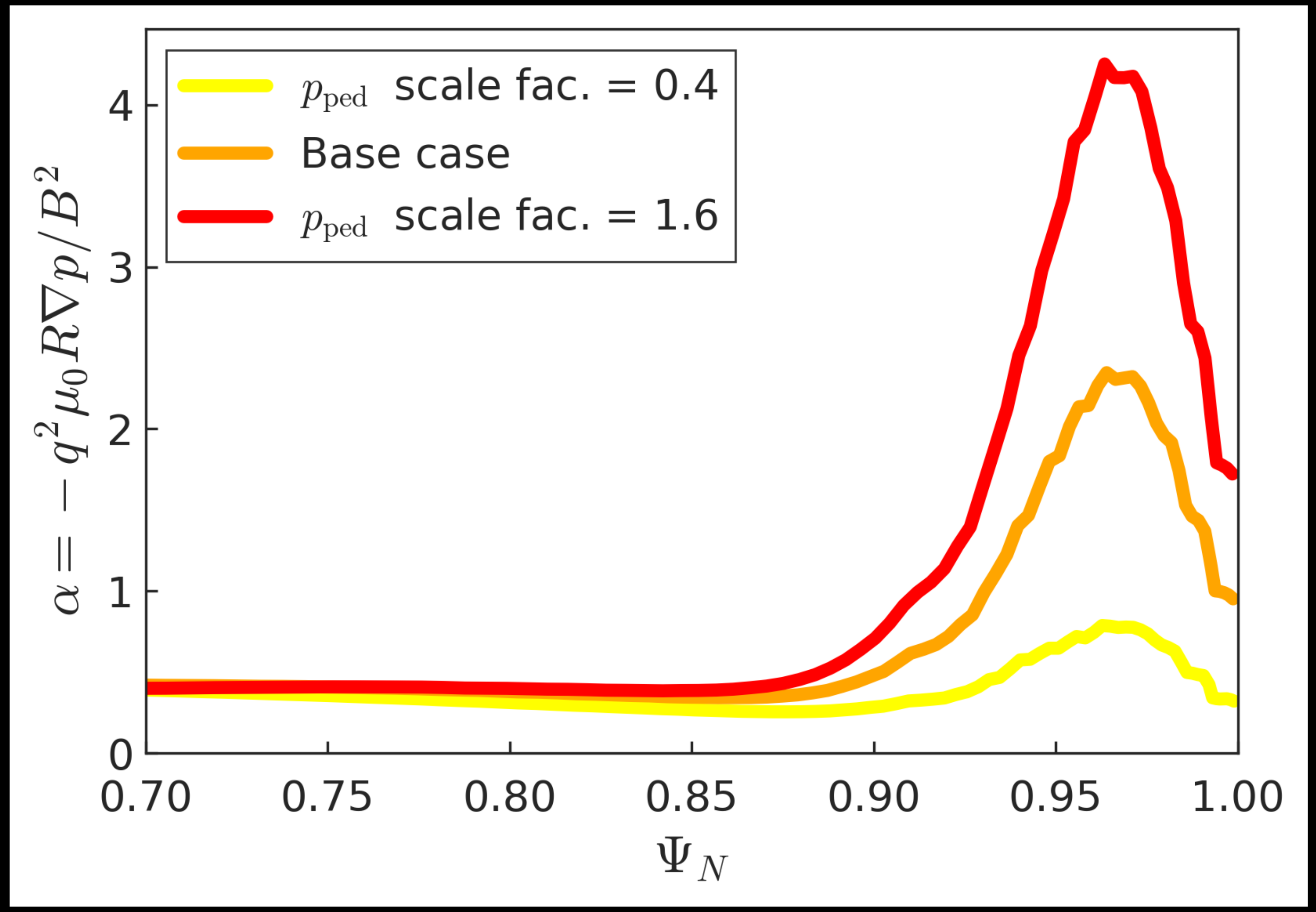
- BCP assumes that both density and temperature profiles can be fit with tanh.

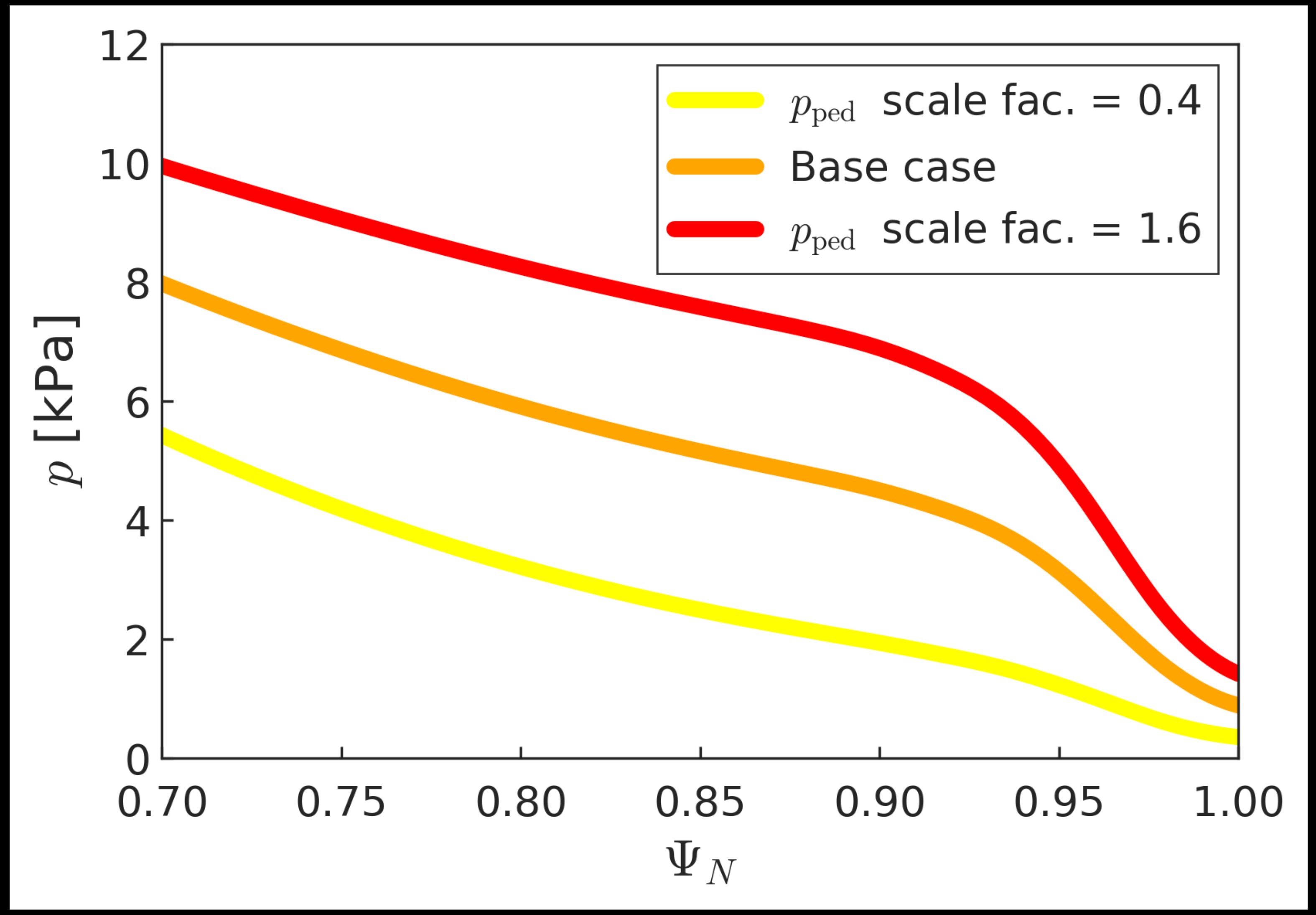
- In 132543 case, there is no parameterized temperature pedestal if the fit is bad. Density pedestal usually fits extremely well. We take $\Delta_{p,\mathrm{ped}} = \Delta_{n,\mathrm{ped}}$.

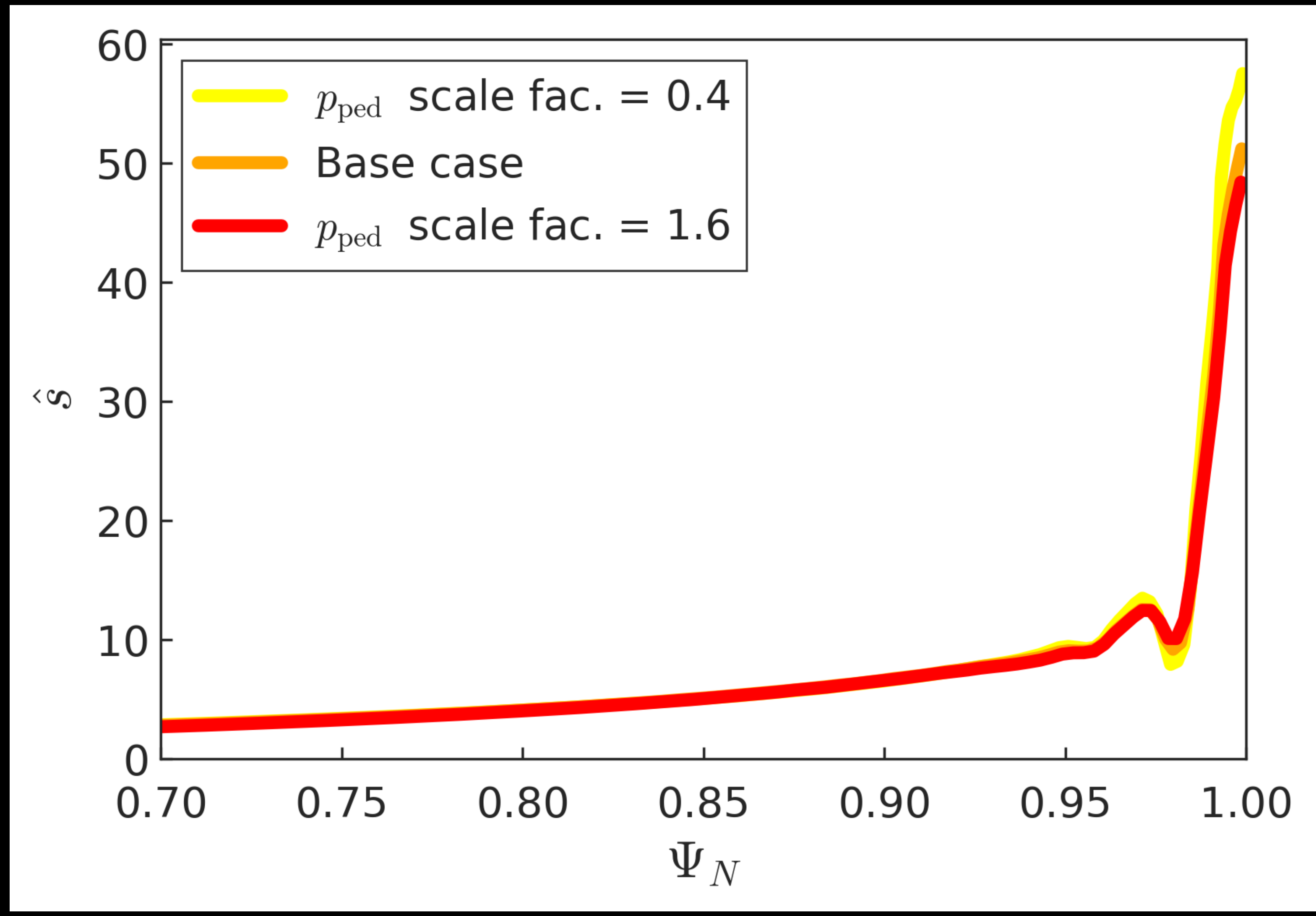
Backup Slides

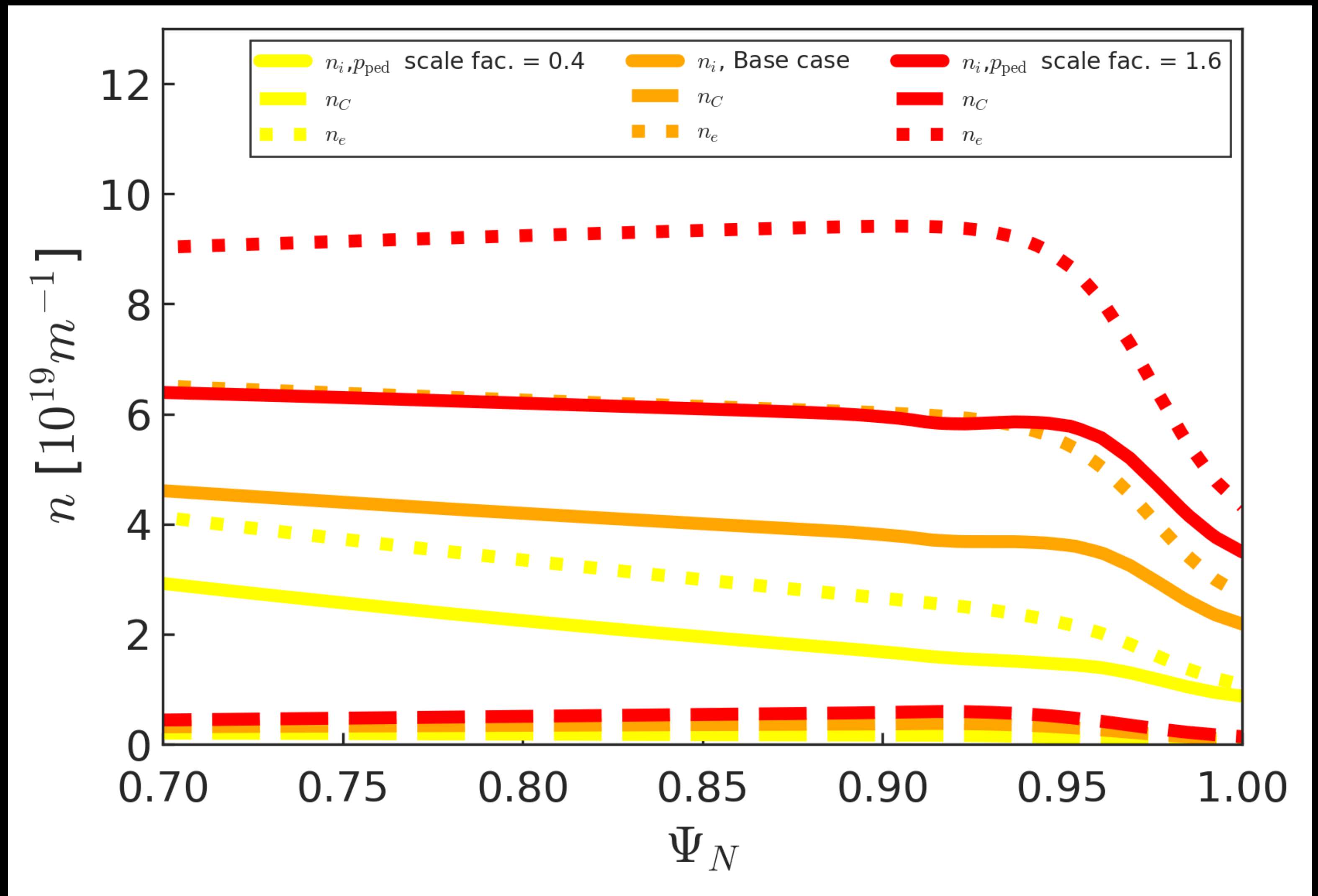
NSTX 132543 Profiles, Constant T











Kinetic, Ideal Comparison

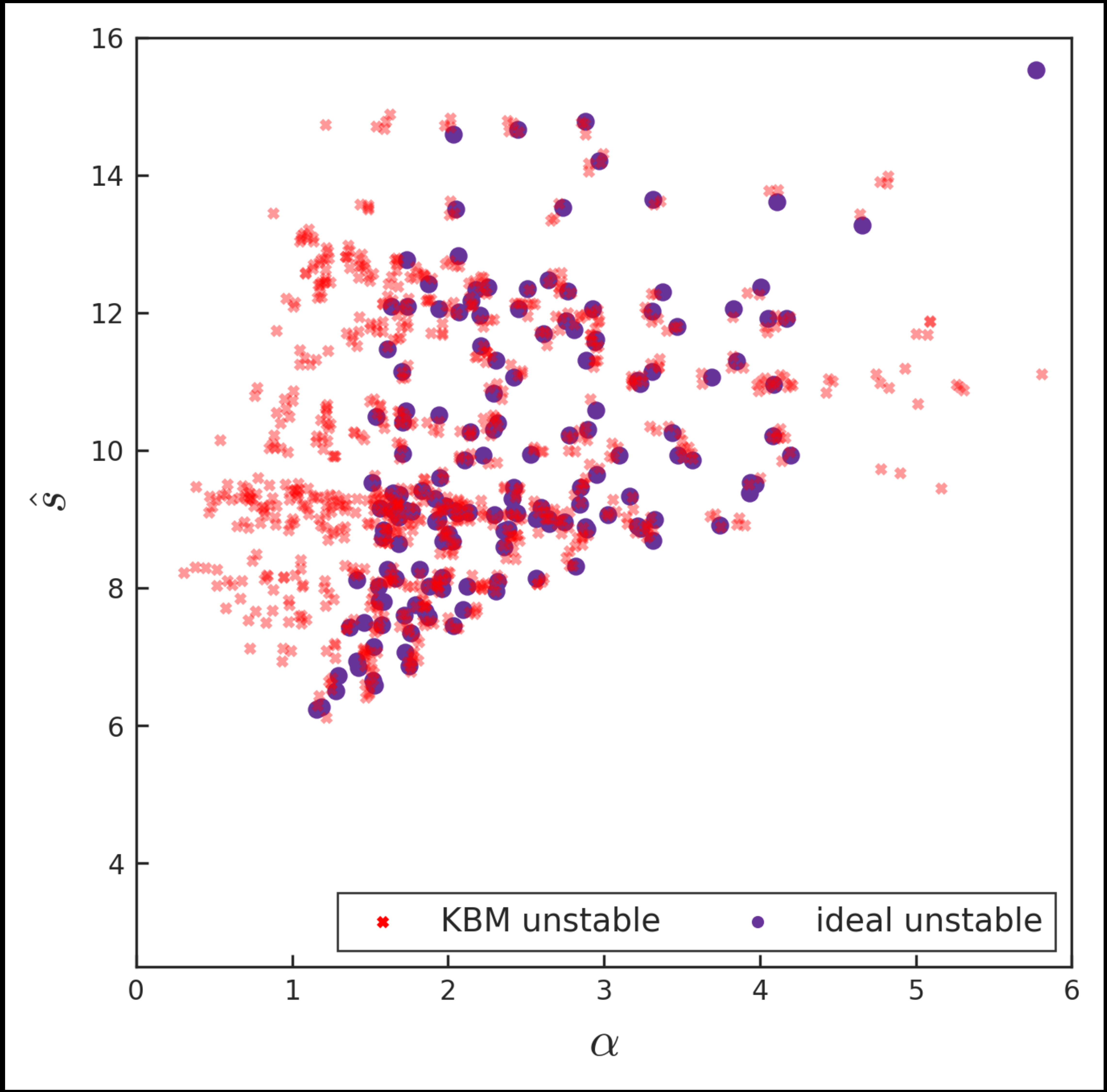
$\hat{s} - \alpha$

- Difference in kinetic and ideal boundaries apparent from s-alpha diagram.

Kinetic, Ideal Comparison

$\hat{s} - \alpha$

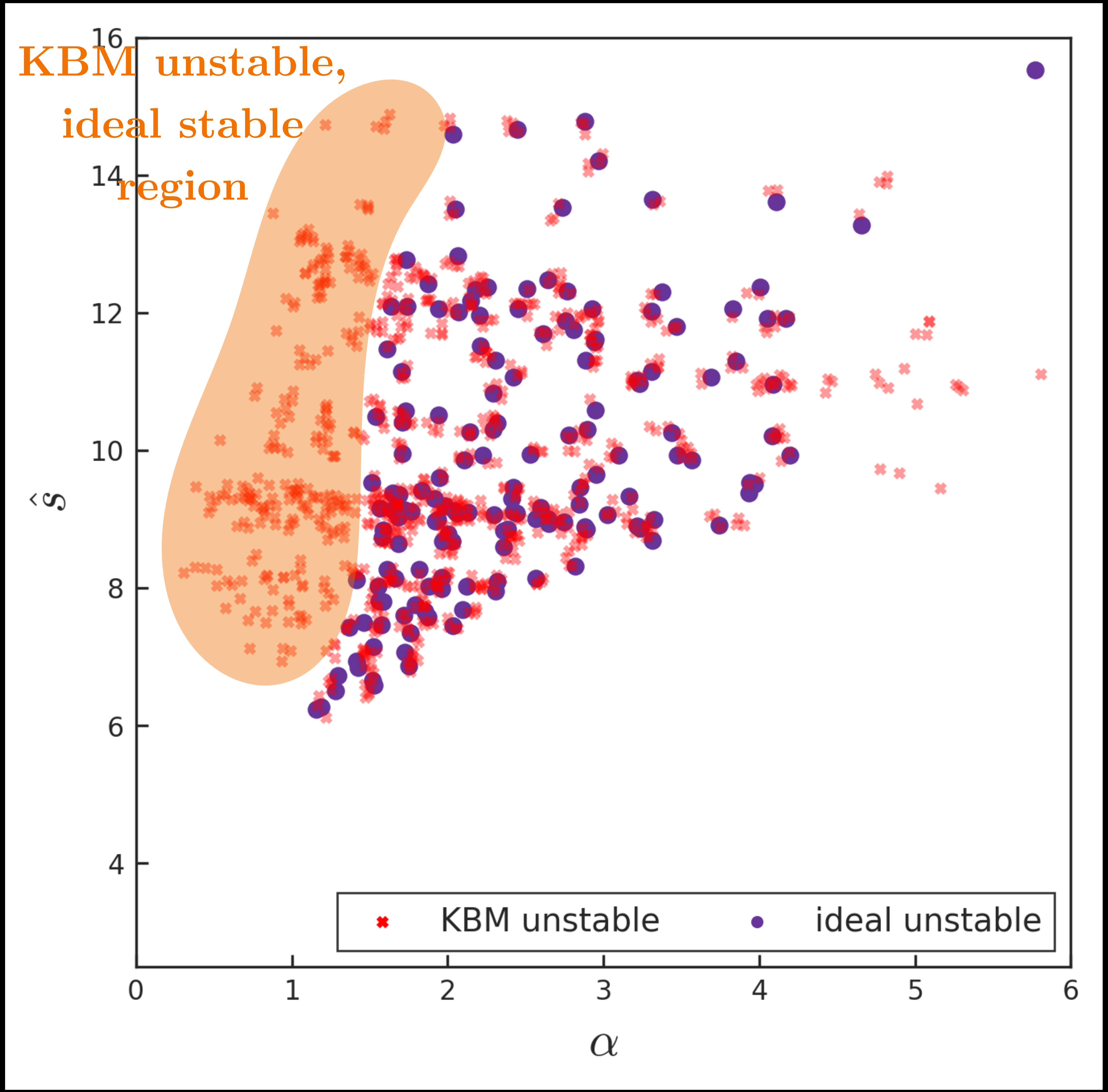
- KBM and ideal $\hat{s} - \alpha$ diagram.



Kinetic, Ideal Comparison

$\hat{s} - \alpha$

- KBM and ideal $\hat{s} - \alpha$ diagram.
- KBM critical α much lower than ideal.



Kinetic, Ideal Comparison

$\hat{s} - \alpha$

- KBM and ideal $\hat{s} - \alpha$ diagram.
- KBM critical α much lower than ideal.
- Lower KBM threshold crucial for accurate Δ scaling.