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Initial results of gyrokinetic analysis of the core plasma in MAST Upgrade

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Overview

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- Capabilities of MAST Upgrade
- Focus on a mid-radius surface in a NBI heated L-mode discharge
- Linear gyrokinetic simulations identifying turbulent instabilities
- Nonlinear gyrokinetic simulations predicting heat fluxes at ion and electron scales
- Attempts at nonlinear multiscale simulations to capture impact of both scales
- Summary

MAST Upgrade

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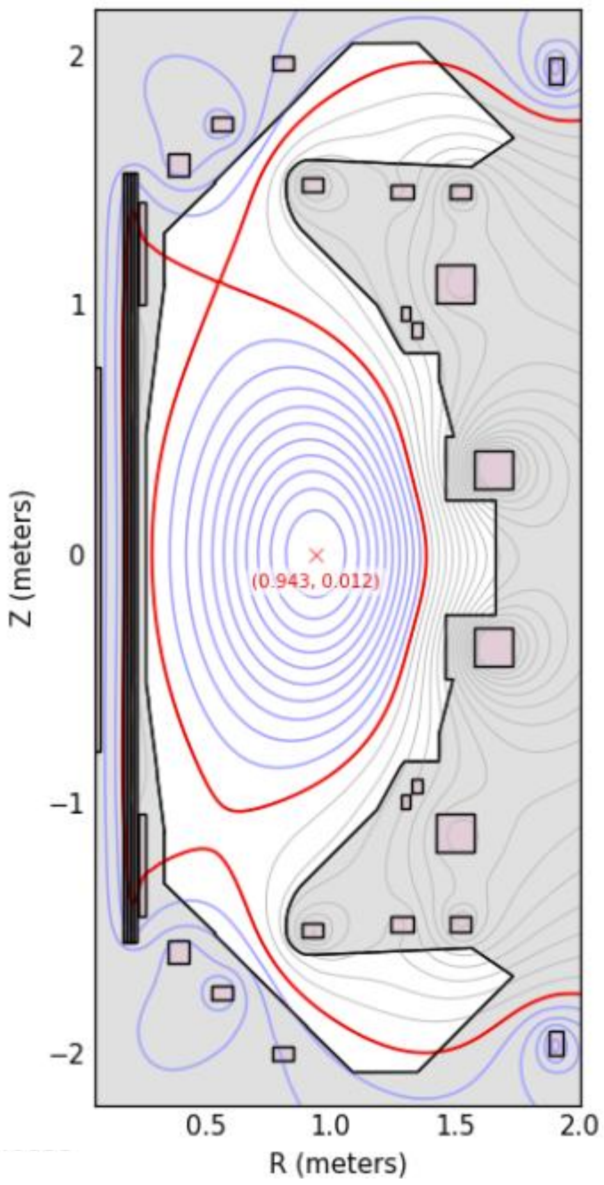
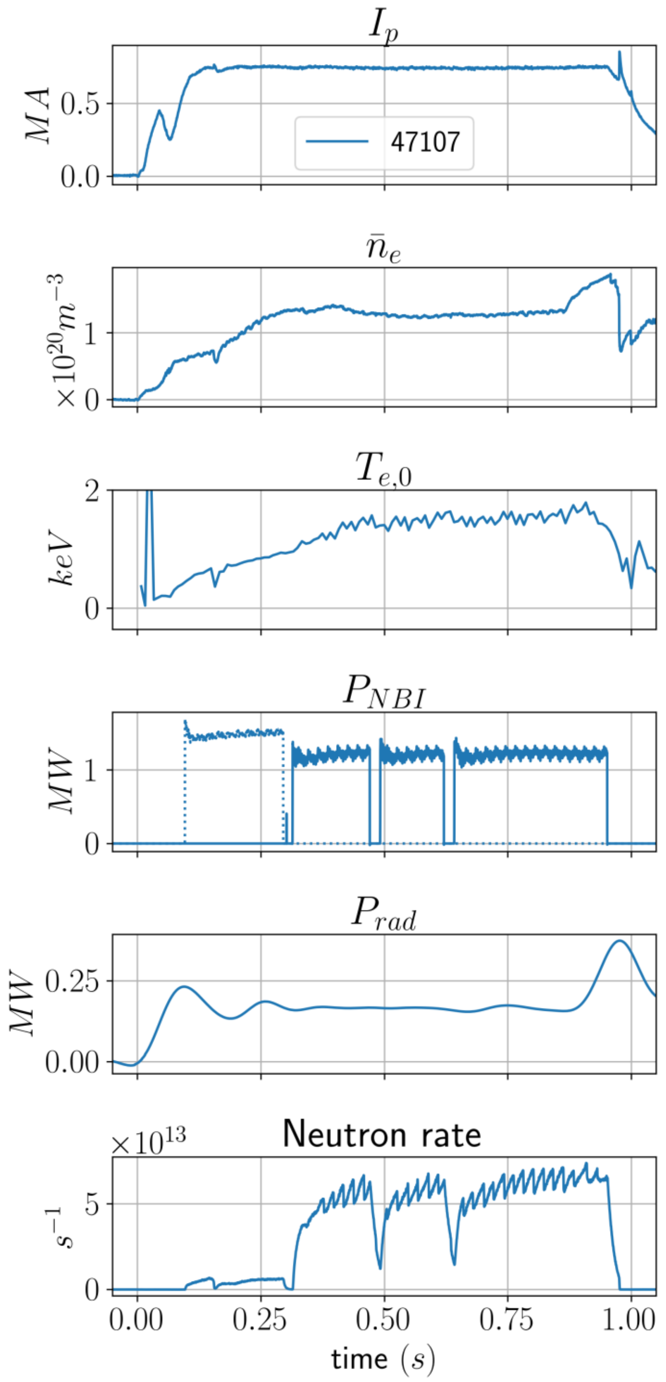
- MAST Upgrade is a major enhancement to MAST
- Currently undergoing 3rd physics campaign
- High resolution diagnostics suite of profiles and turbulence
  - Thomson/Charge exchange for kinetic profiles
  - MSE profile measurements for safety factor profile
  - DBS/BES turbulence diagnostics
- Ideal for turbulence studies in an ST regime

Parameter	MAST-U 3rd Campaign
R / a (m)	0.7 / 0.5
B_φ (T at 0.8m)	0.72
Max Ip (MA)	1.2
Max κ	>2.2
Max δ	0.6
Ohmic heating (MW)	Up to 1
NBI power	4.2MW up to 1.5s
NBI geometry	1 on axis, 1 off axis
Divertor geometries	Conventional, Super-X
Fuelling	Gas valves

MAST-U shot 47107

- Focus on a MU02 L-mode 750kA discharge
- >400ms of steady density/temperature profiles
- Significant sawteeth occurring
- BES measurements were taken
  - Not usable here due to overlap with Carbon emission line
- UCLA DBS system measurements are available



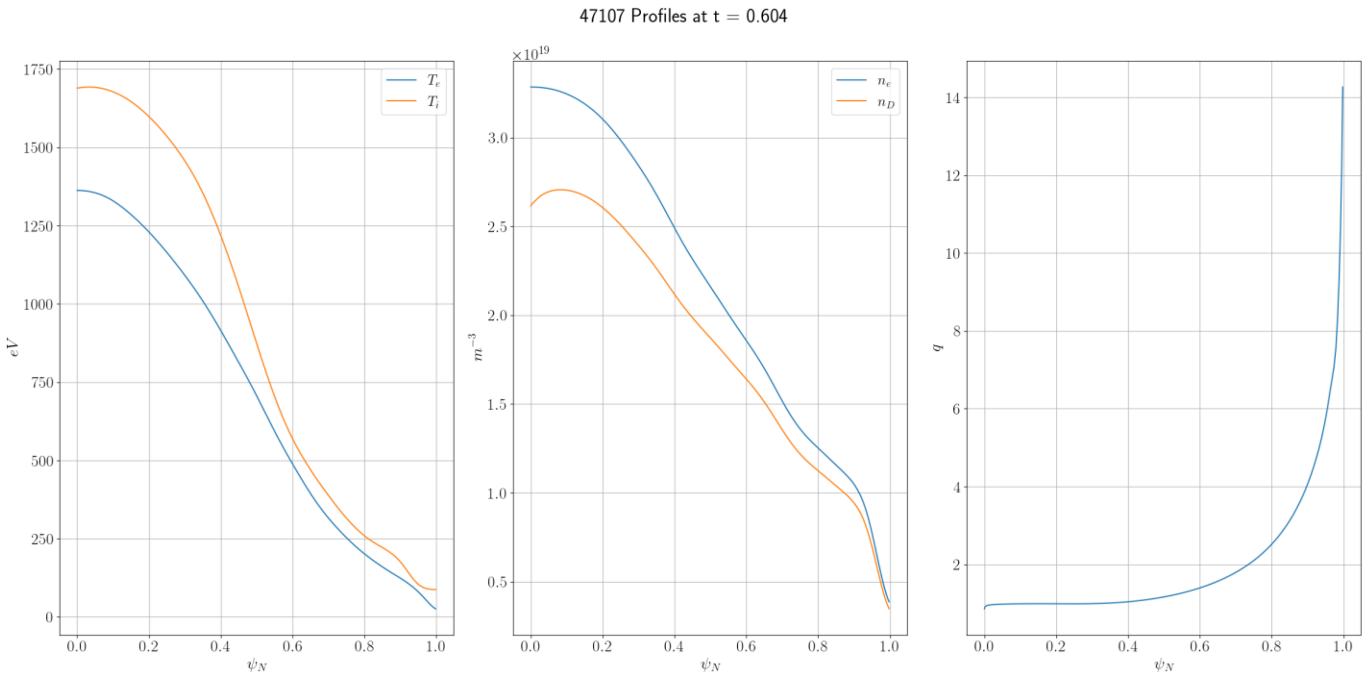


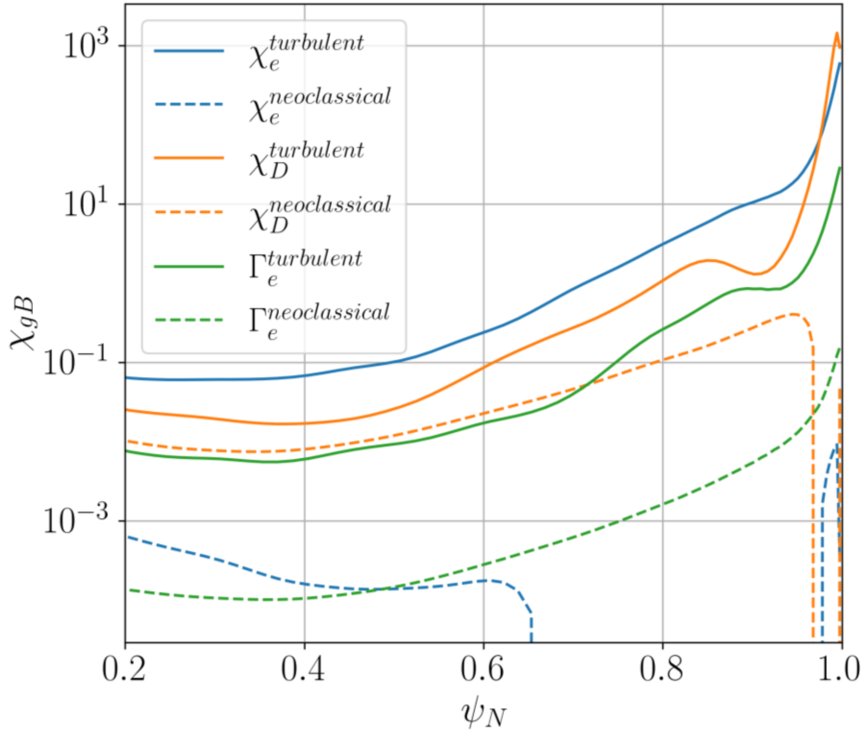
Integrated modelling

- Interpretive transport modelling done using TRANSP
  - MSE constrained equilibrium
  - Careful profile fitting
  - Medium resolution NUBEAM
  - Assume Z_{eff}=1.5 with Carbon impurity

- Examine at t = 0.6s

- Dominant electron heat transport
  - Ion heat and particle transport above neoclassical levels
  - Typically suppressed by ExB shear





Linear gyrokinetics

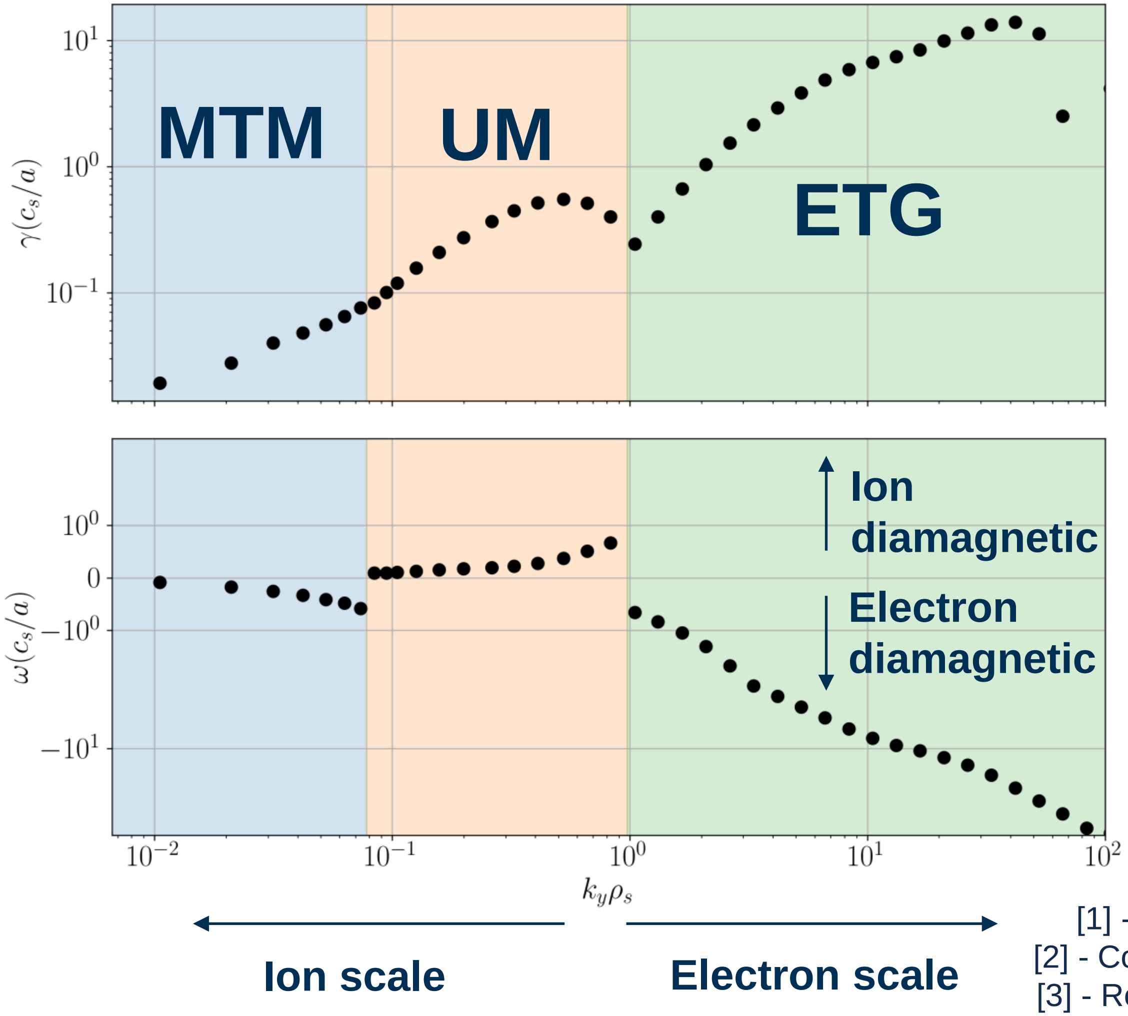
- CGYRO was used to find the dominant linear instability
  - All analysis done using pyrokinetics – A python library aimed to standard gyrokinetic analysis (on github and pip)

- 3 different classes of instability were found

- Microtearing modes
  - Electromagnetic
  - Destabilised by a/L_{Te}

- Ubiquitous modes [1]
  - Electrostatic
  - Branch of TEM seen in MAST [2] and ST40 [3]

- Electron temperature gradient modes
  - Electrostatic
  - Destabilised by a/L_{Te}

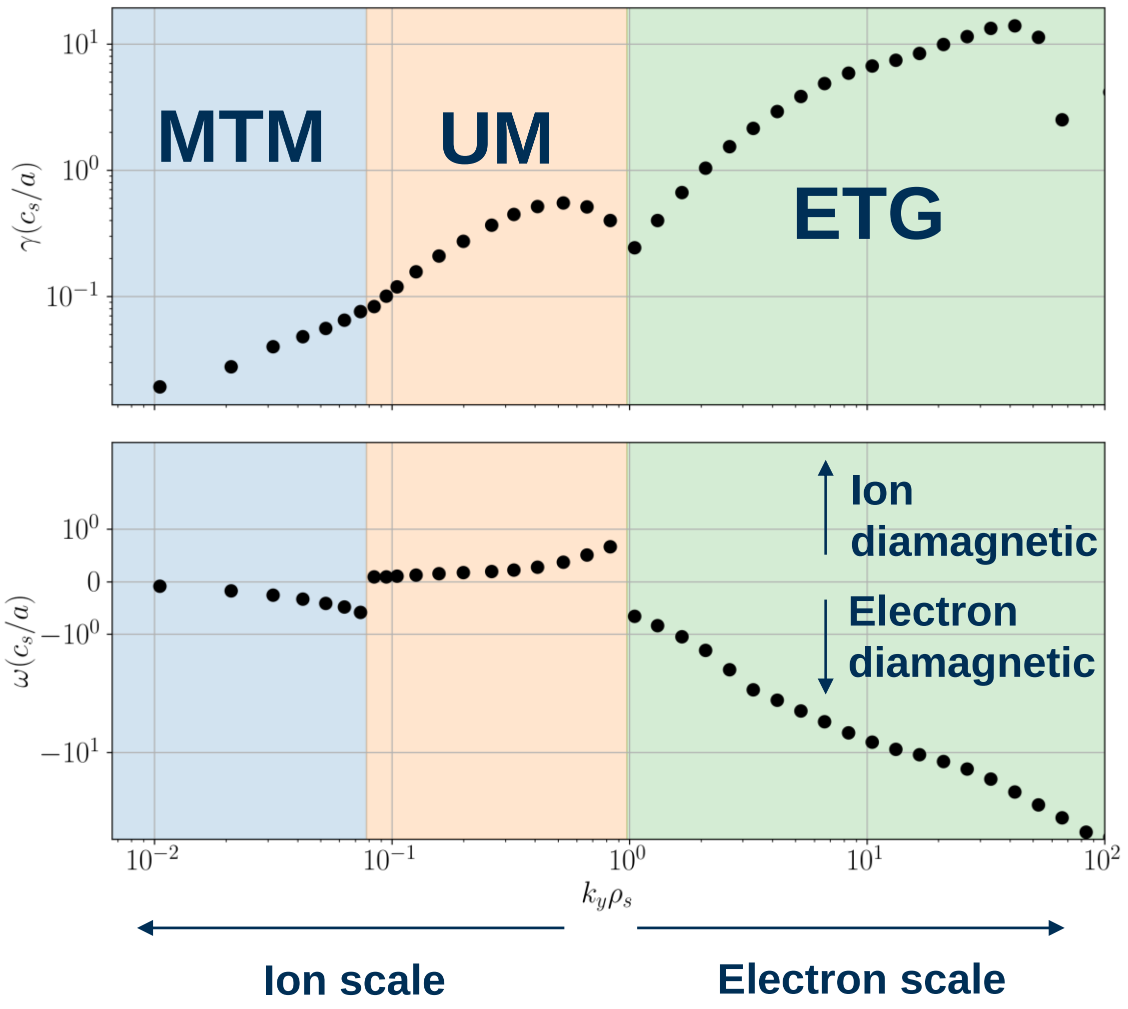


Parameter	Ψ_N=0.658
r/a	0.70
R_{maj}/a	1.62
$\partial R/\partial r$	-0.25
q	1.60
s	2.45
κ	1.57
δ	0.03
β_e	0.8%
ν_{ee} (c_s/a)	0.53
a/L_n	2.93
a/L_{Te}, a/L_{Ti}	6.17, 5.17
$n_{species}$	3
$k_y\rho_s$ (n=1)	0.0105
ρ^*	0.005

[1] - Coppi, B *et al*. PRL 33.22 (1974): 1329
[2] - Connor, J. W., et al. IAEA-CN-149. (2006)
[3] - Ren, Y., et al. PPCF 65.7 (2023): 075007.

Nonlinear simulations

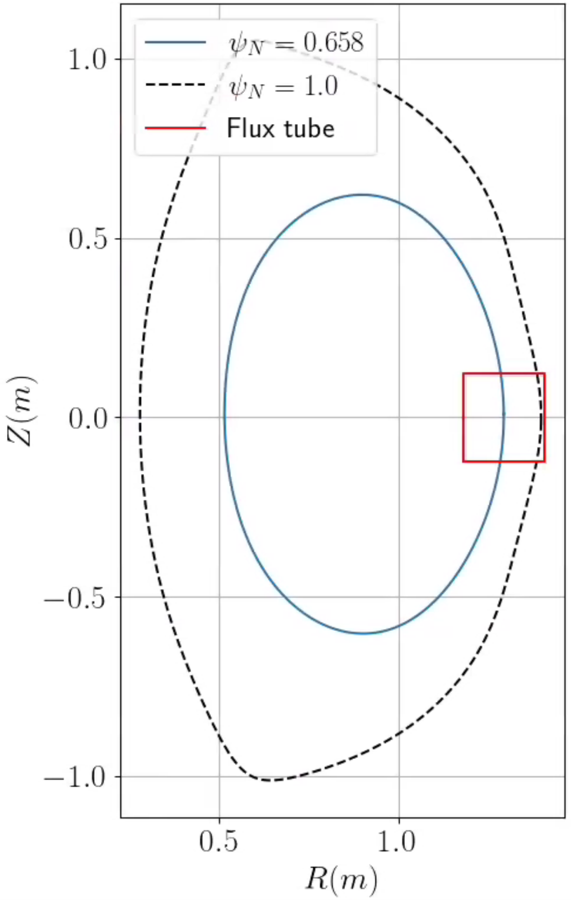
- Linear simulations show 3 regions of interest all with significant overlap
- Multi-scale effects may play a role here
- $\delta B_{||}$ had little impact on the linearly so was dropped in the nonlinear simulations
- Nonlinear simulations include ExB shear unless stated otherwise

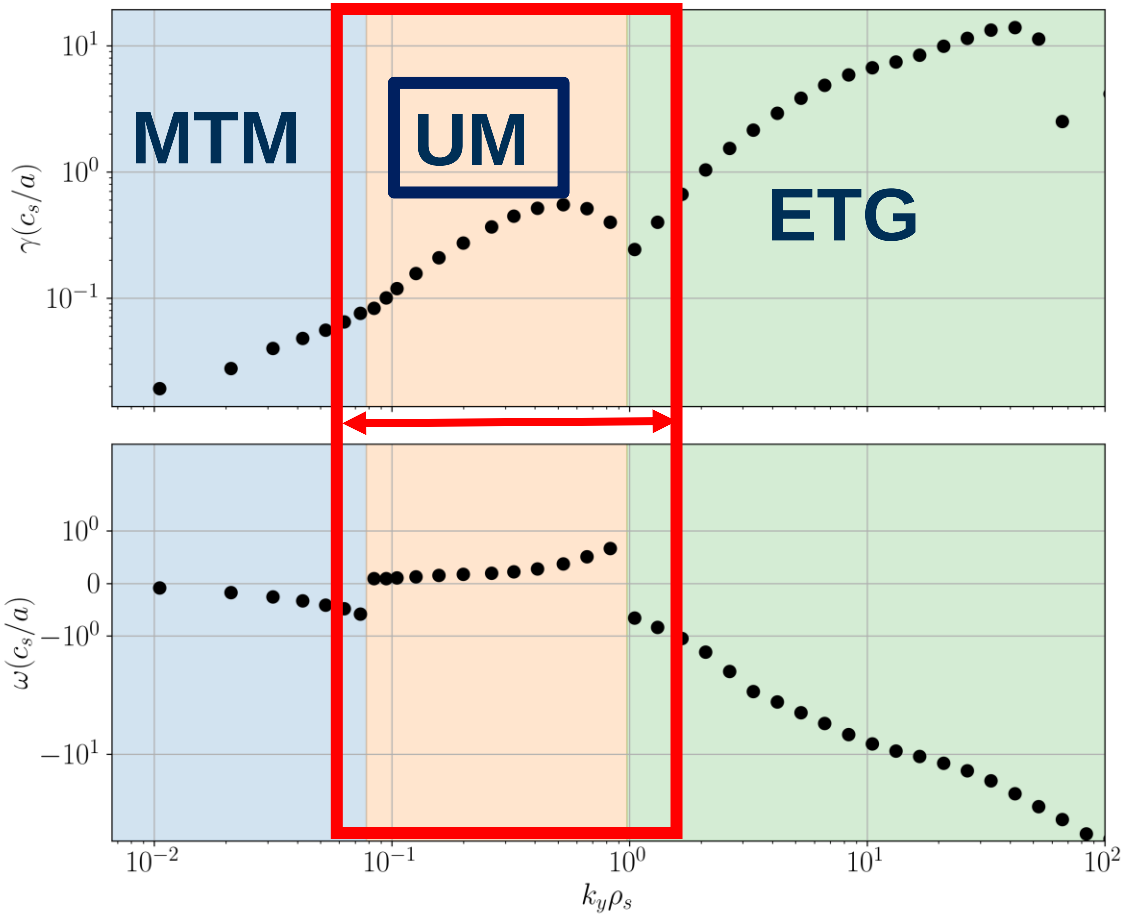


Ion scale: UM simulations

- UM dominant instability from $0.04 < k_y\rho_s < 1.05$
  - Some overlap with MTM here and sub-dominant to ETG

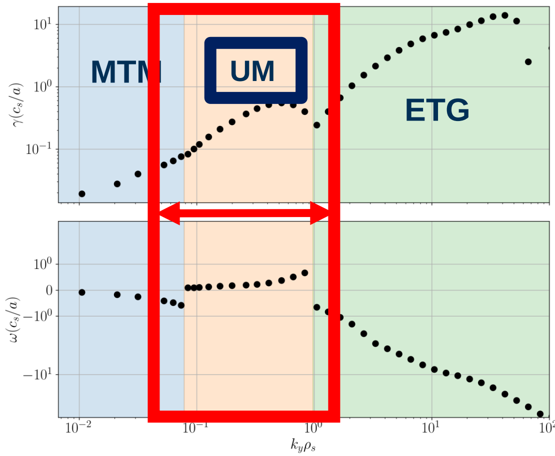
- Start with:
  - $k_{y,min}\rho_s = 0.065$ (*n=6)*
  - $k_{y,max}\rho_s = 1.4$ (*n=115*)
  - $N_{kx} = 256$
  - $N_{ky} = 24$

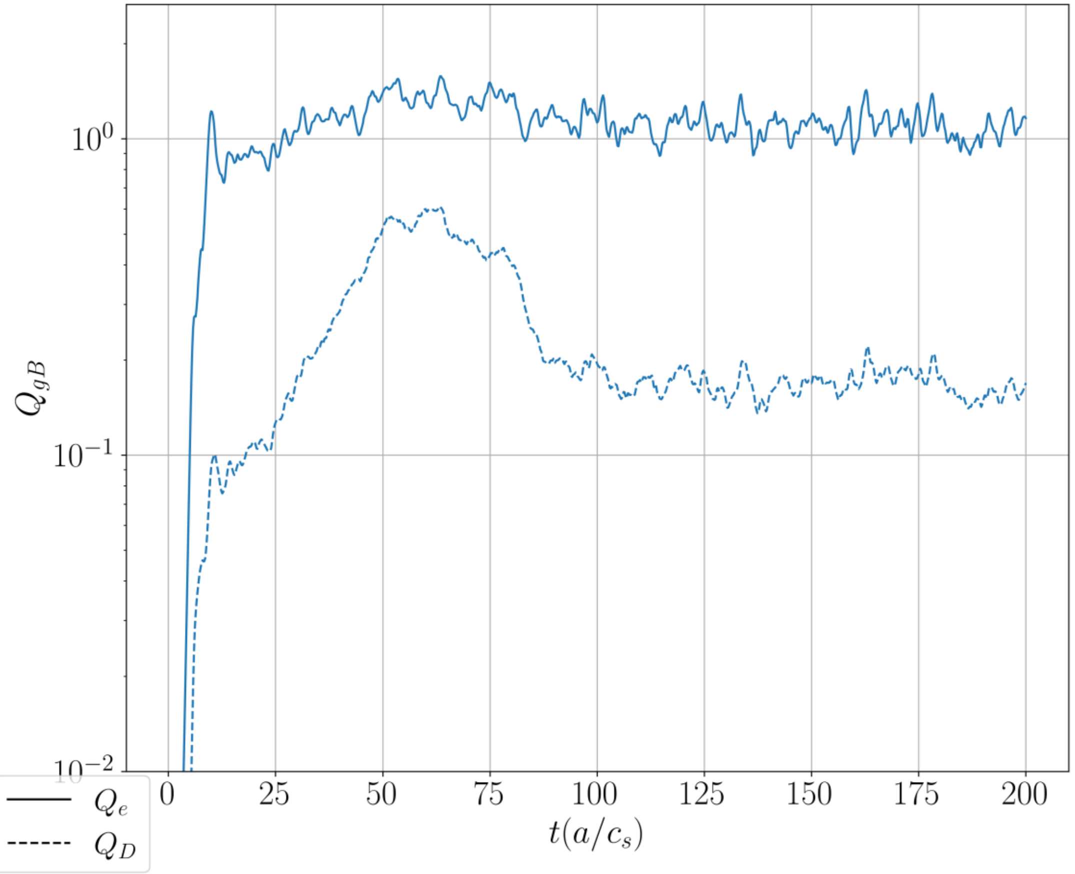


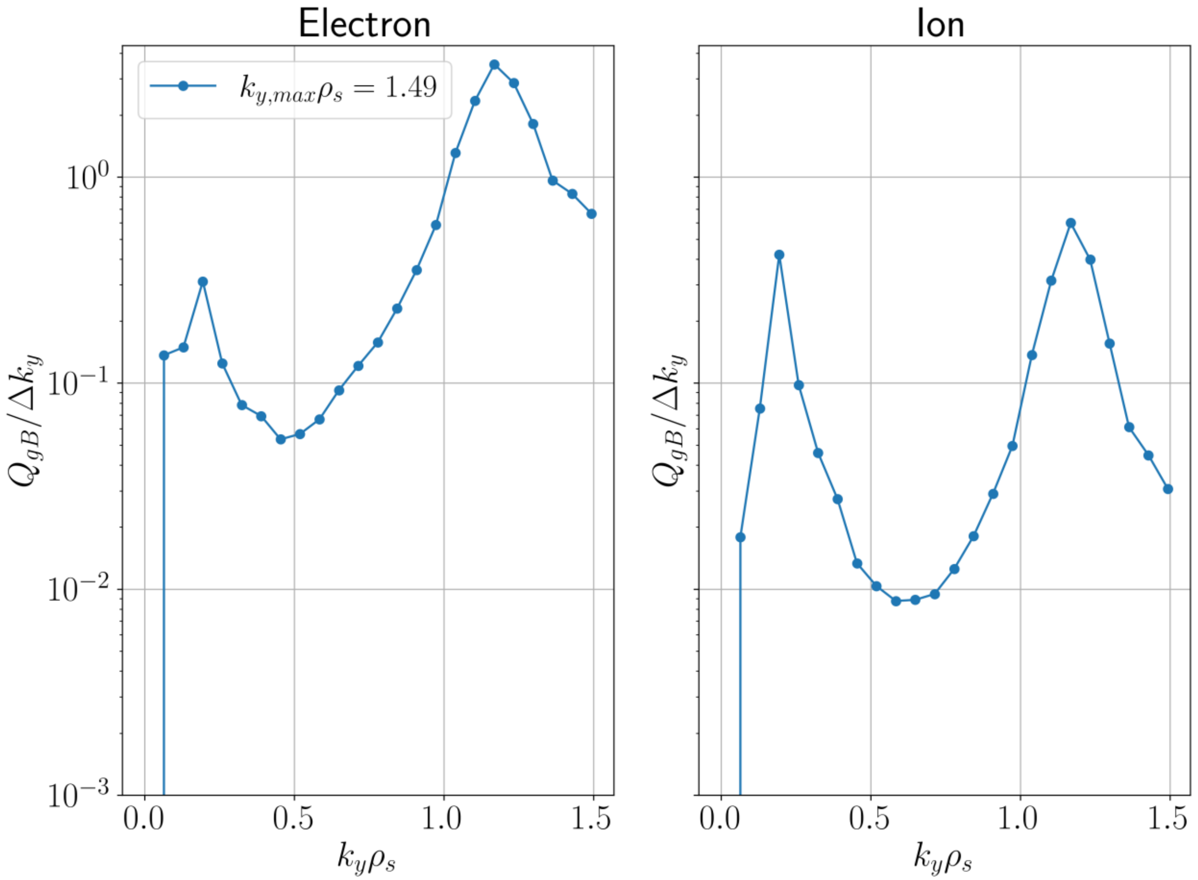


Ion scale: Flux predictions

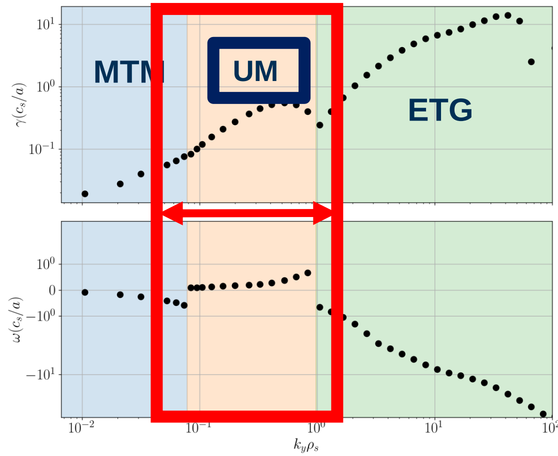
- Fluxes saturate but peak near highest k_y
- Small increase from at ETG at highest k_y



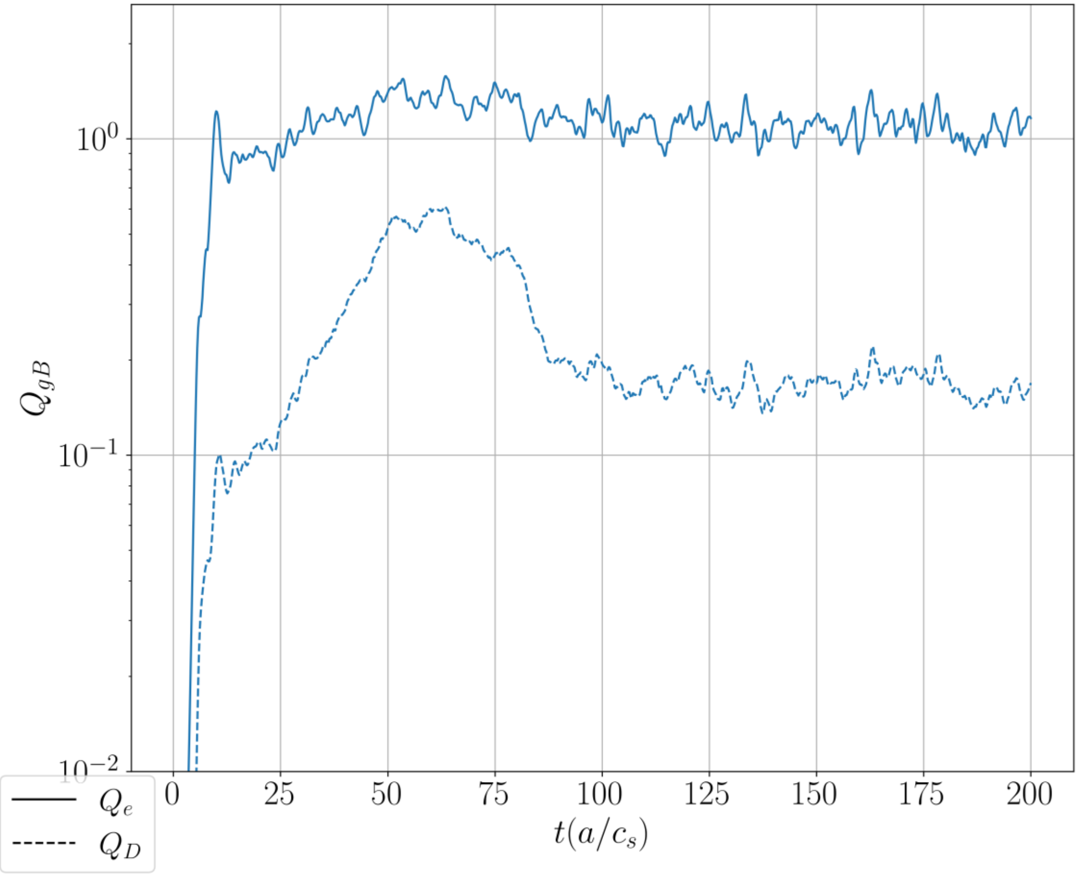


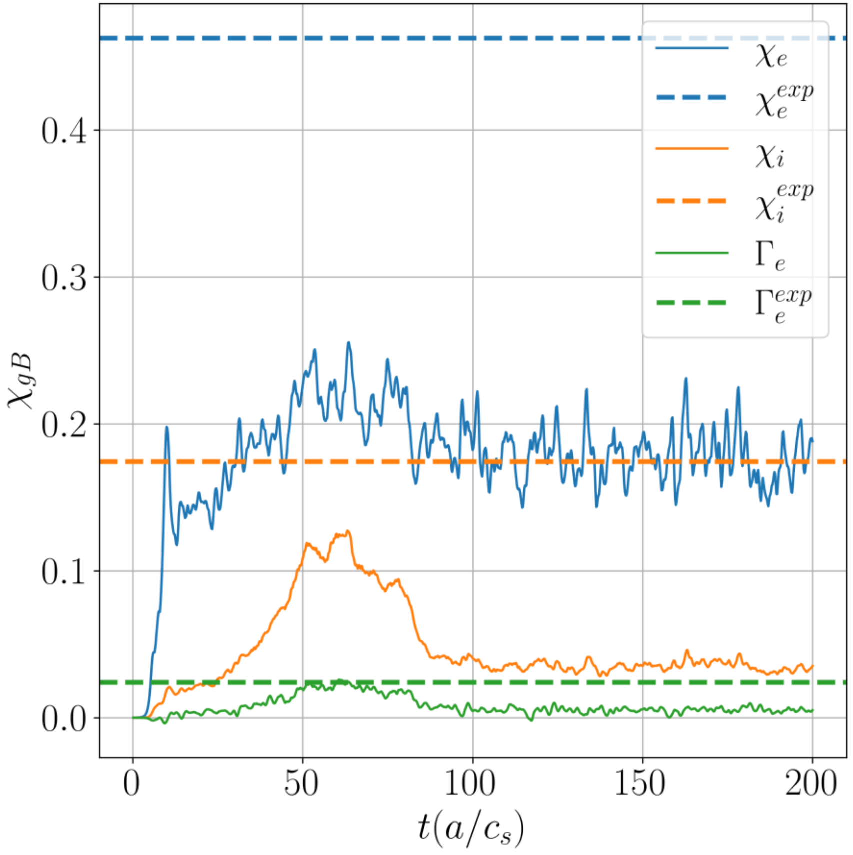


Ion scale: Experimental comparisons



- Fluxes close to experimental values with ion scale alone - likely within experimental uncertainties
- Removing ExB shear increases electron and ion fluxes by 2 orders of magnitude

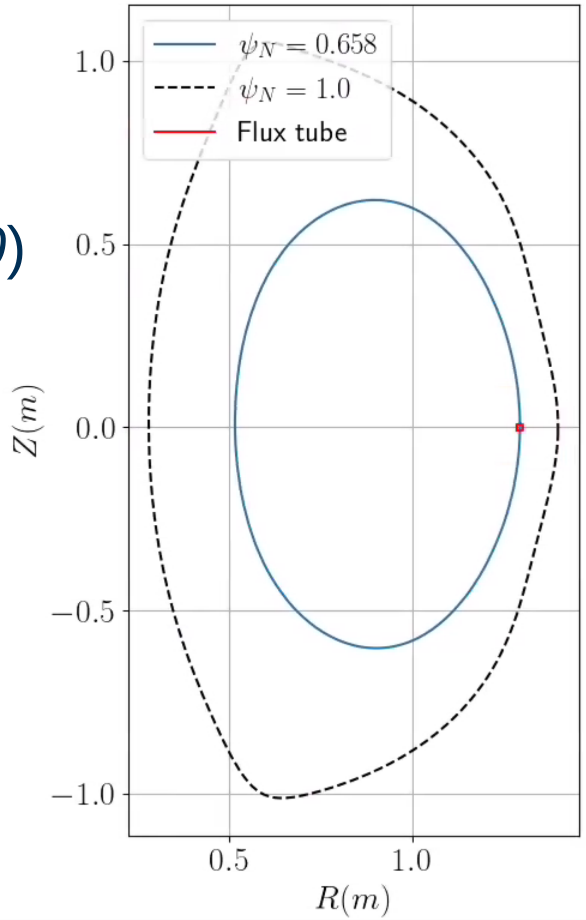


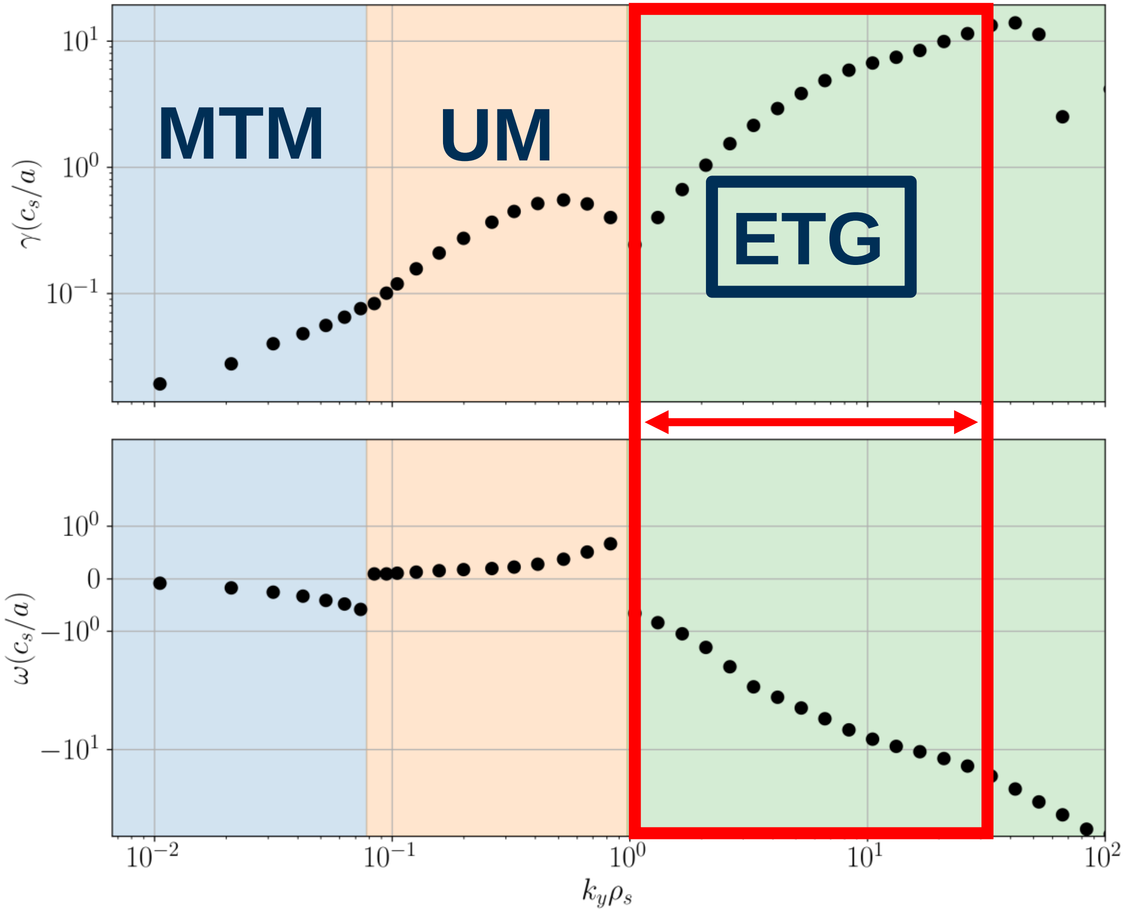


Electron scale: ETG simulations

- ETG unstable from $1.0 < k_y\rho_s < 80$

- Start with
  - $k_{y,min}\rho_s = 1.05$ (*n=100*)
  - $k_{y,max}\rho_s = 36.8$ (*n=3500*)
  - $N_{ky} = 36$
  - $N_{kx} = 256$





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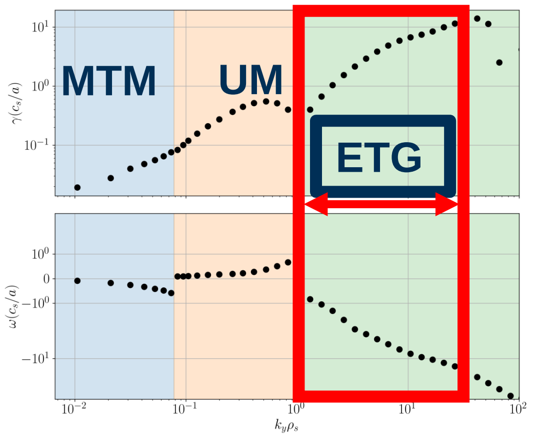
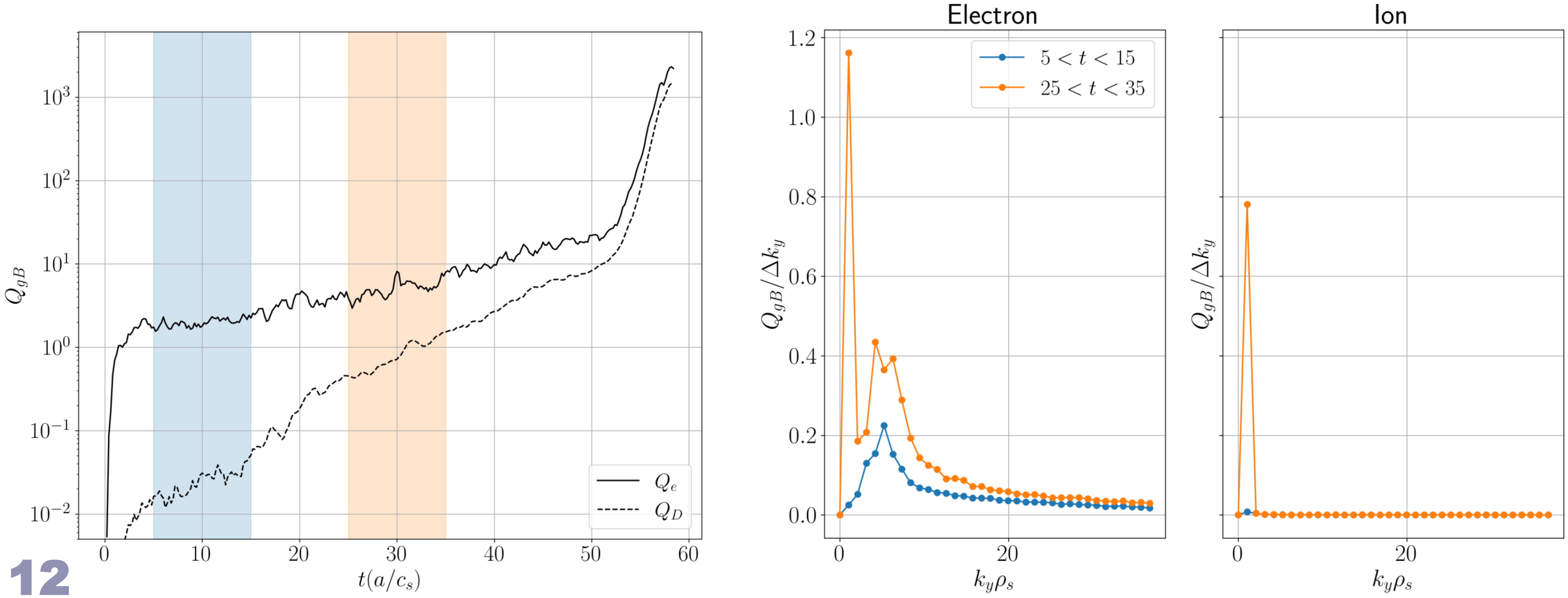


- Initial saturation period followed by blow up of flux
- Lowest k_y ion flux is the particular cause of problem



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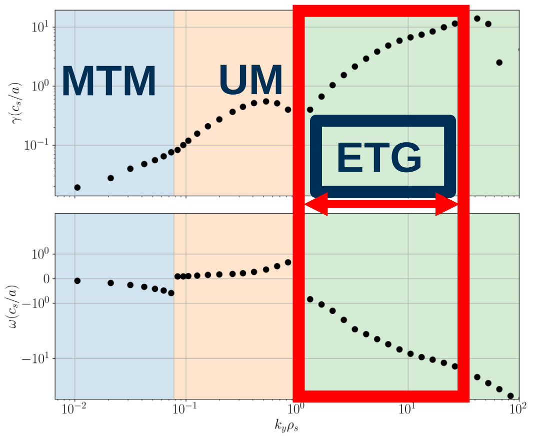

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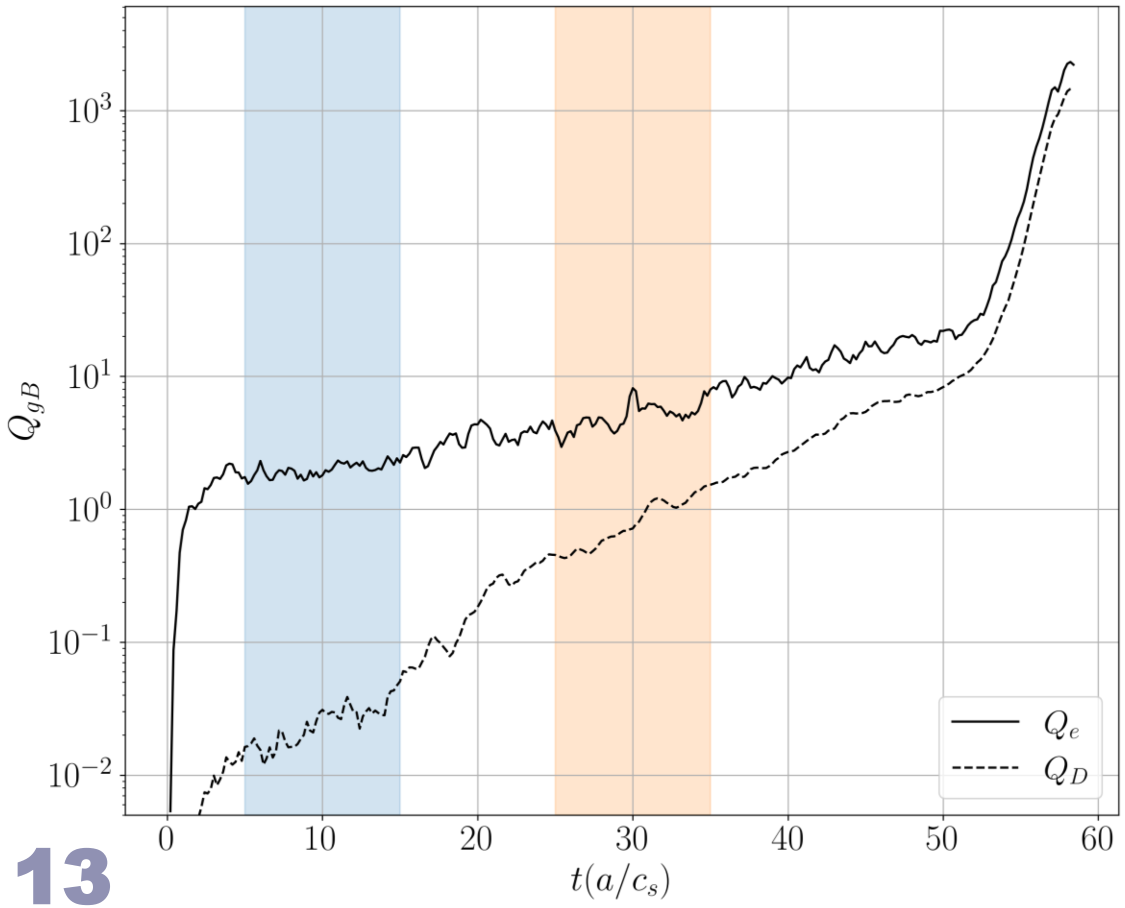
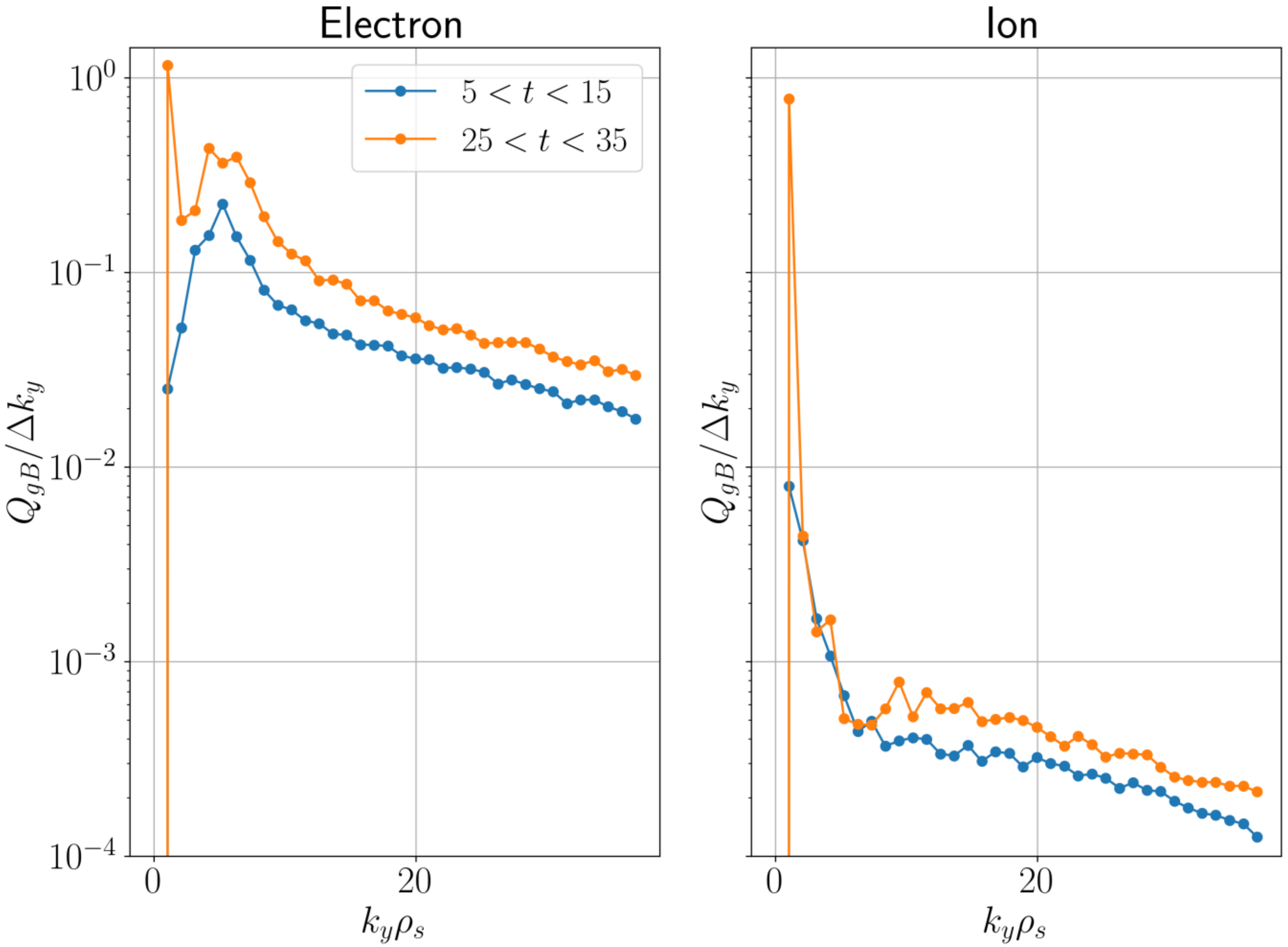
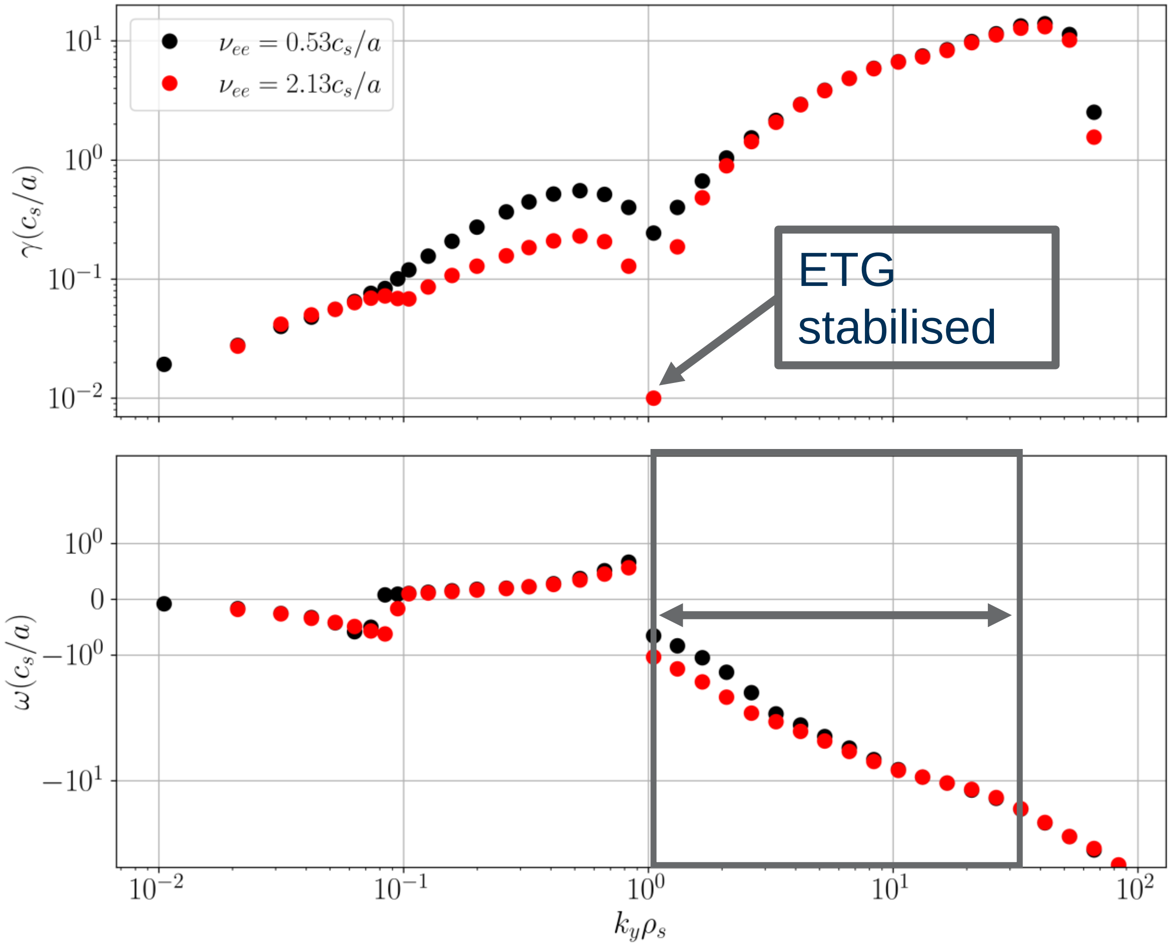




Electron scale: Artificial low k_y cut-off

- Increasing ν_{ee} by a factor 4 opens up a stability window at lowest k_y
- No longer see a blow up obtain saturation after t ~ 60 c_s/a



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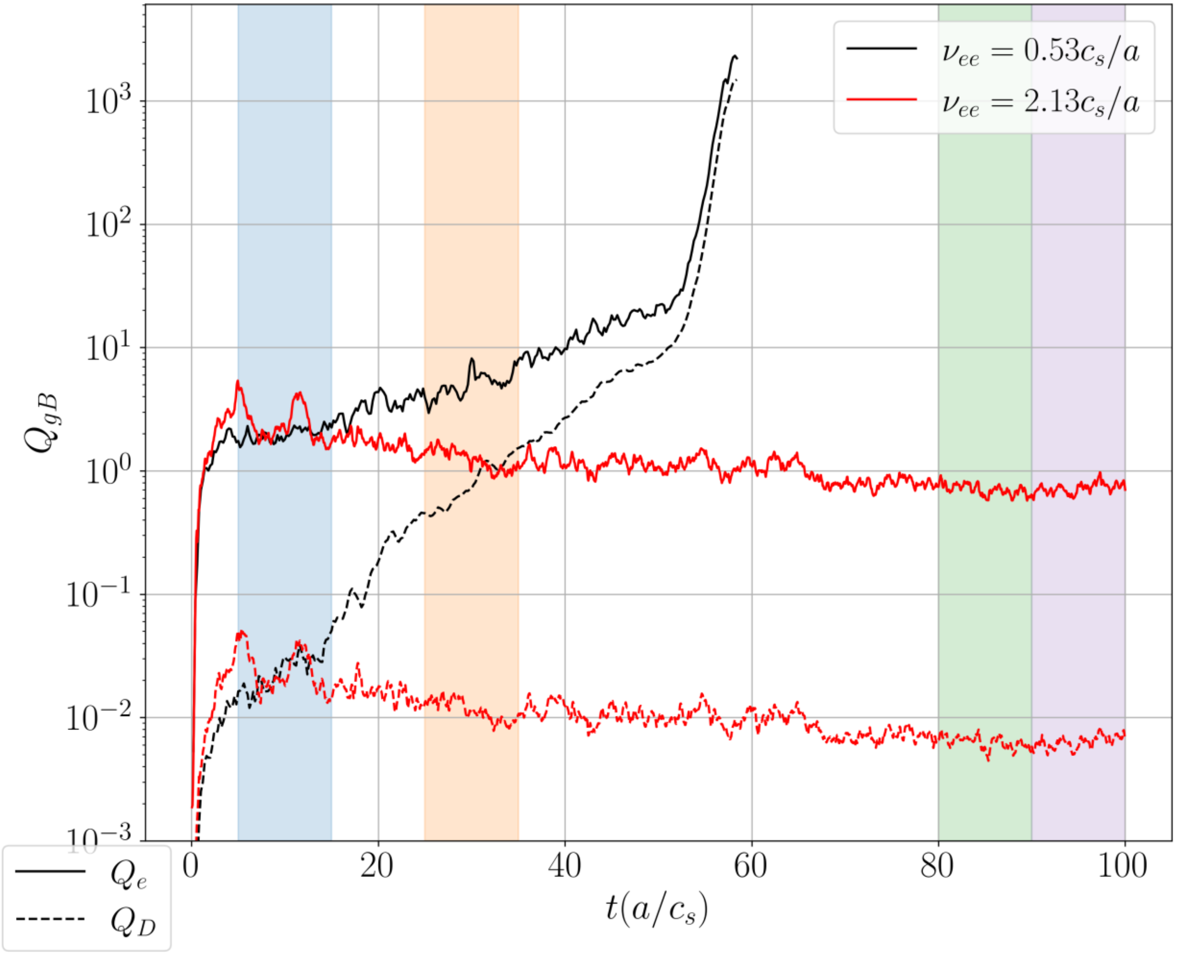

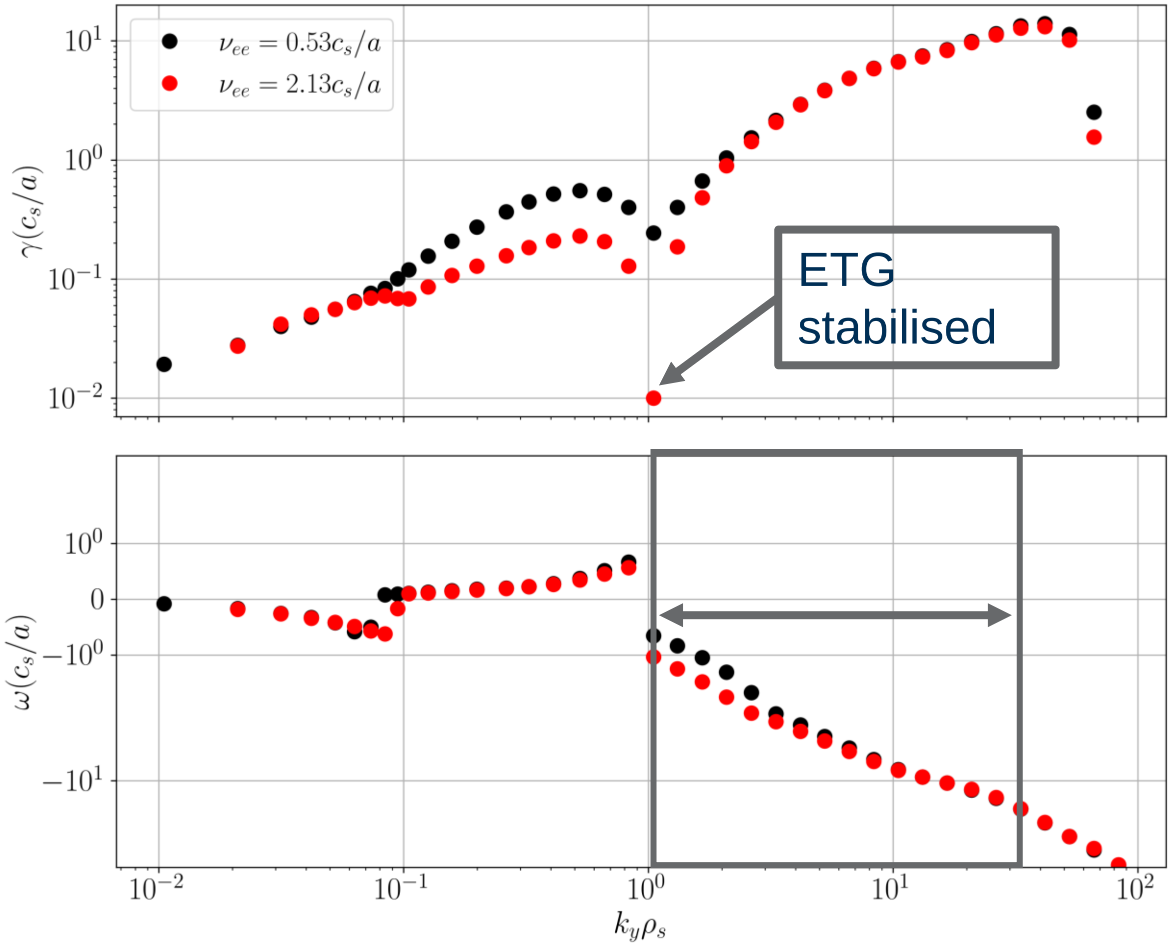

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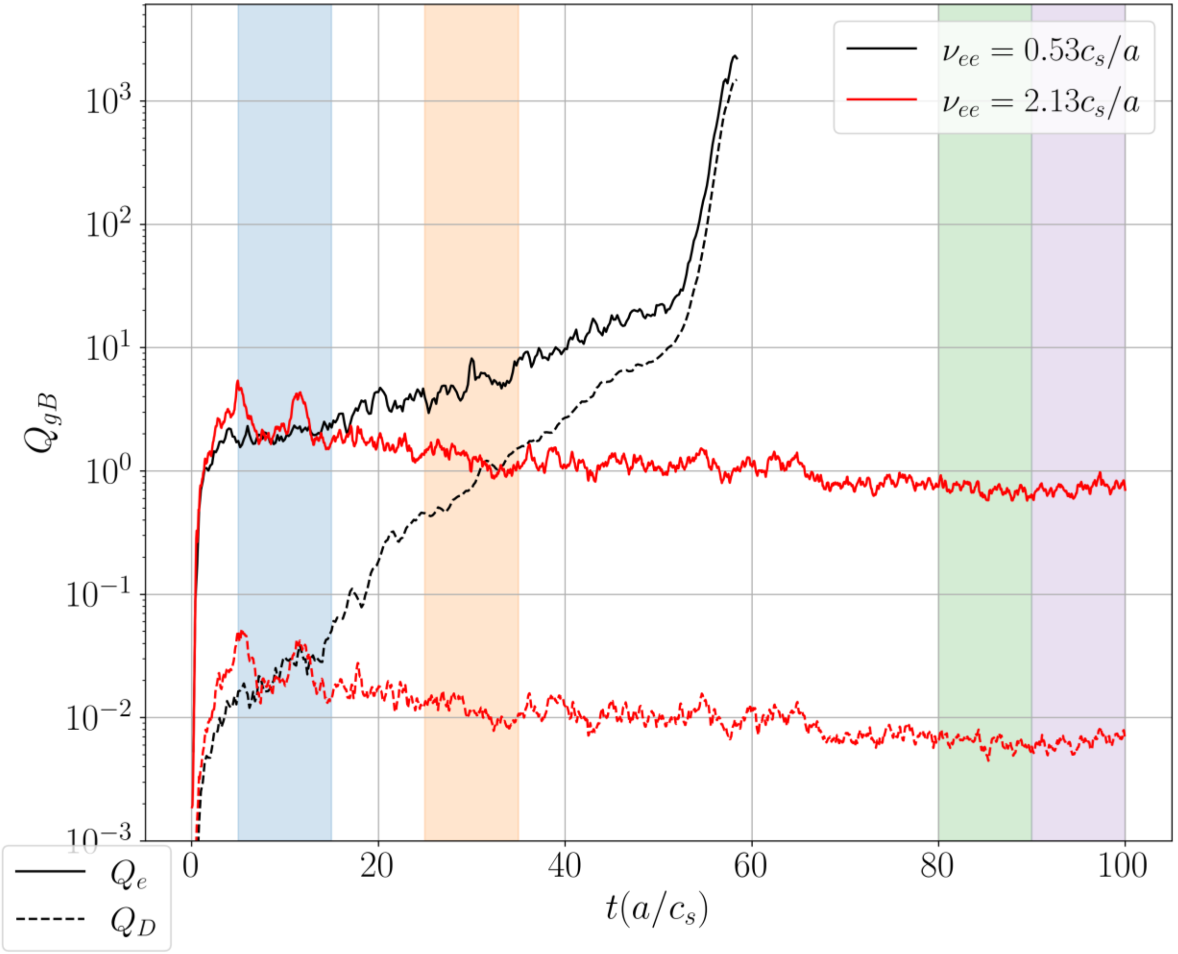

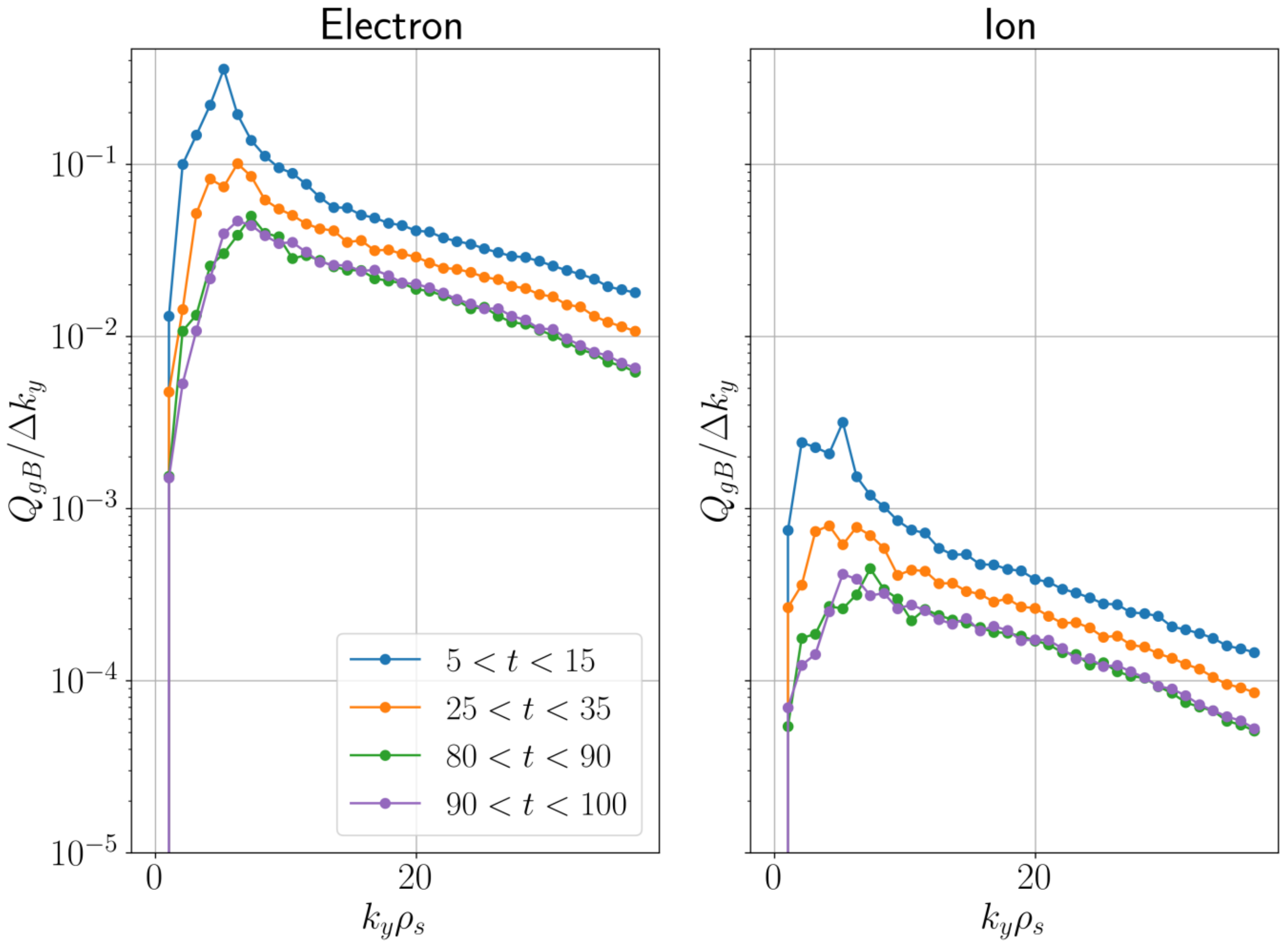

Overlap of modes

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- Electron scale simulations (ETG) require
  - At least $k_{y,max}\rho_s = 50$ to capture peak in spectrum
  - *UM drives significant flux at low k_y region if unstable*
- Ion scale simulations (UM) require
  - $k_{y,max}\rho_s > 1$ to fully resolve linear spectrum and peak in nonlinear flux
  - *ETG drive becoming significant at high k_y region*
- Need multiscale simulations resolving both ends of the spectrum…

Multiscale attempts

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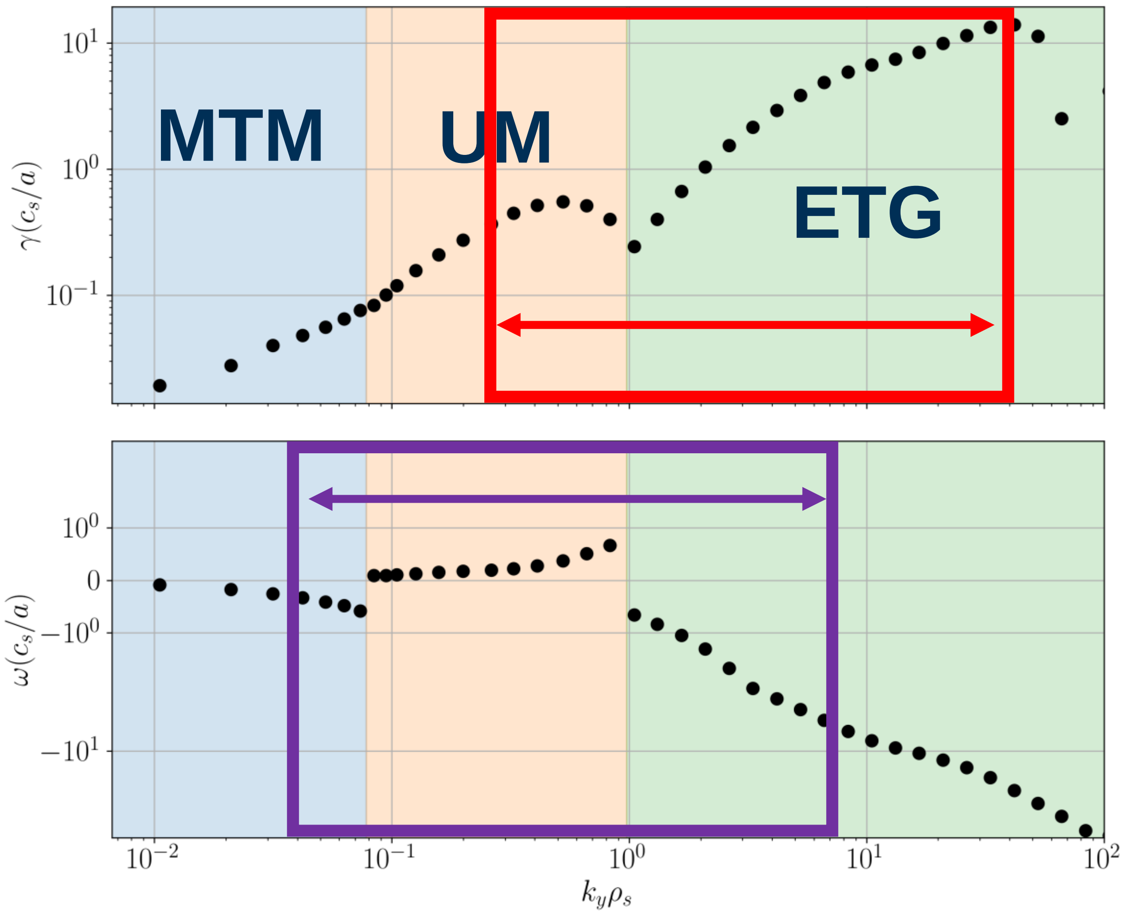
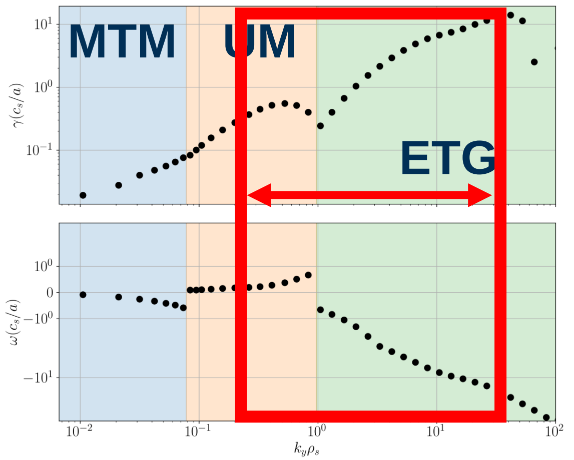
- Method 1: Resolve electron scale with some ion scale
- Method 2: Resolve ion scale with some electron scale
- Multiscale made possible thanks to use of GPU-CGYRO [1]
  - Up to N_{ky} = 128
  - Up to N_{kx} = 768

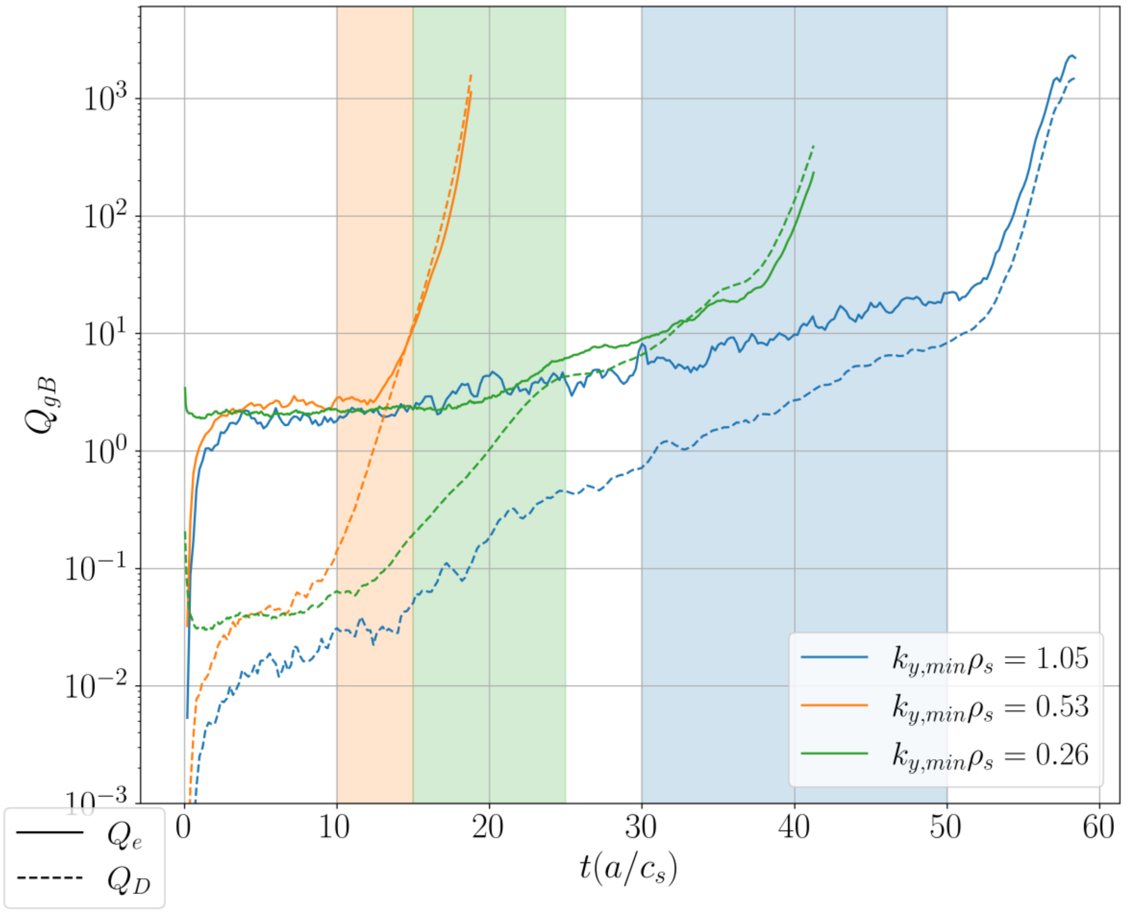


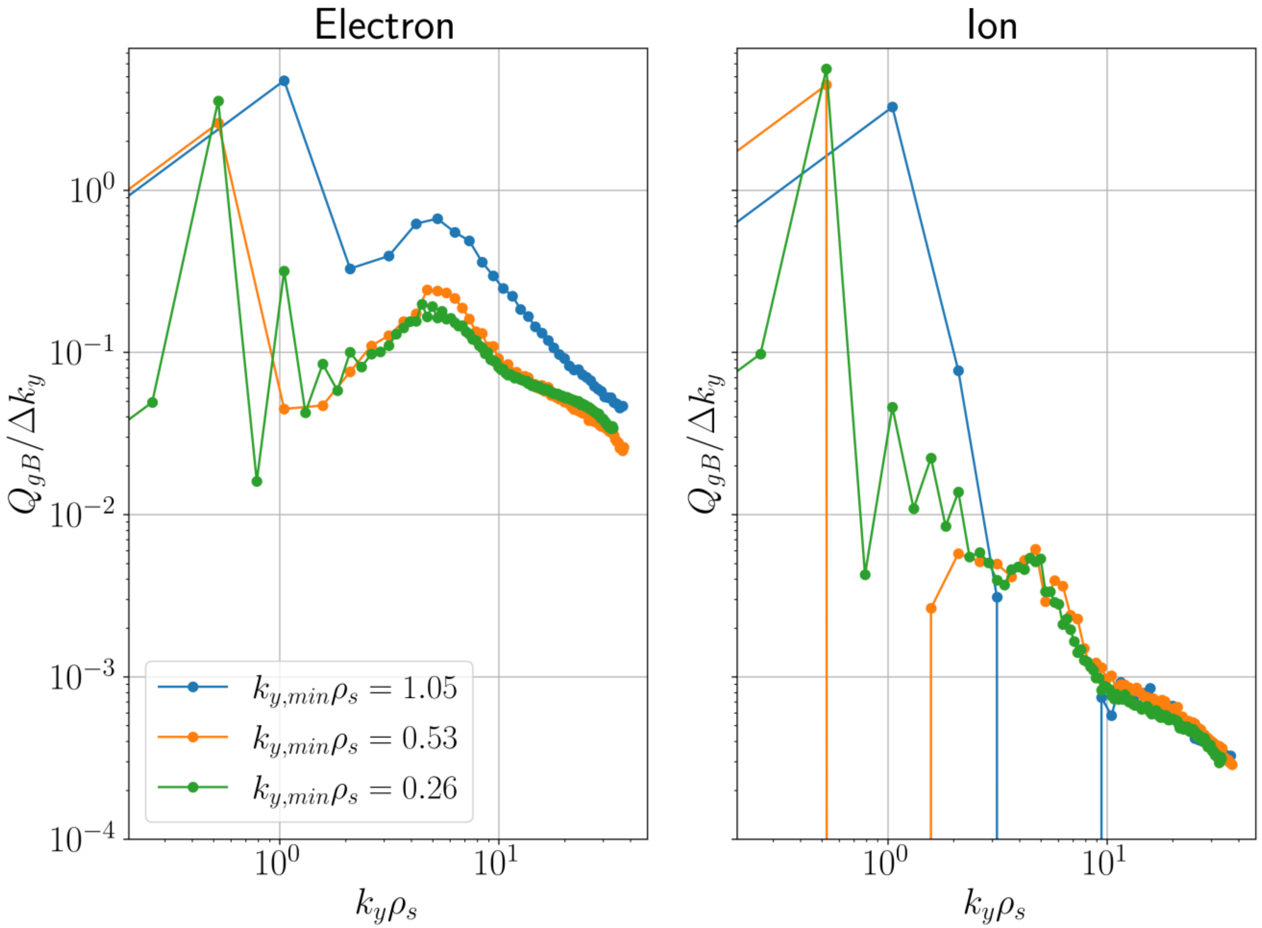
[1] - Sfiligoi, Igor, Emily Belli, and Jeff Candy *Aries* 1152.82.1: 40-1.

Multiscale: Method 1

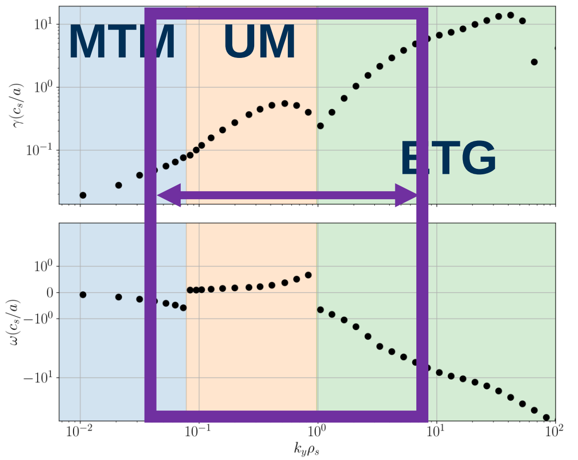


- 3 different scales agree up to t = 10 a/c_s
- Large increase in flux seen for even when $k_{y,min}\rho_s$ = 0.26

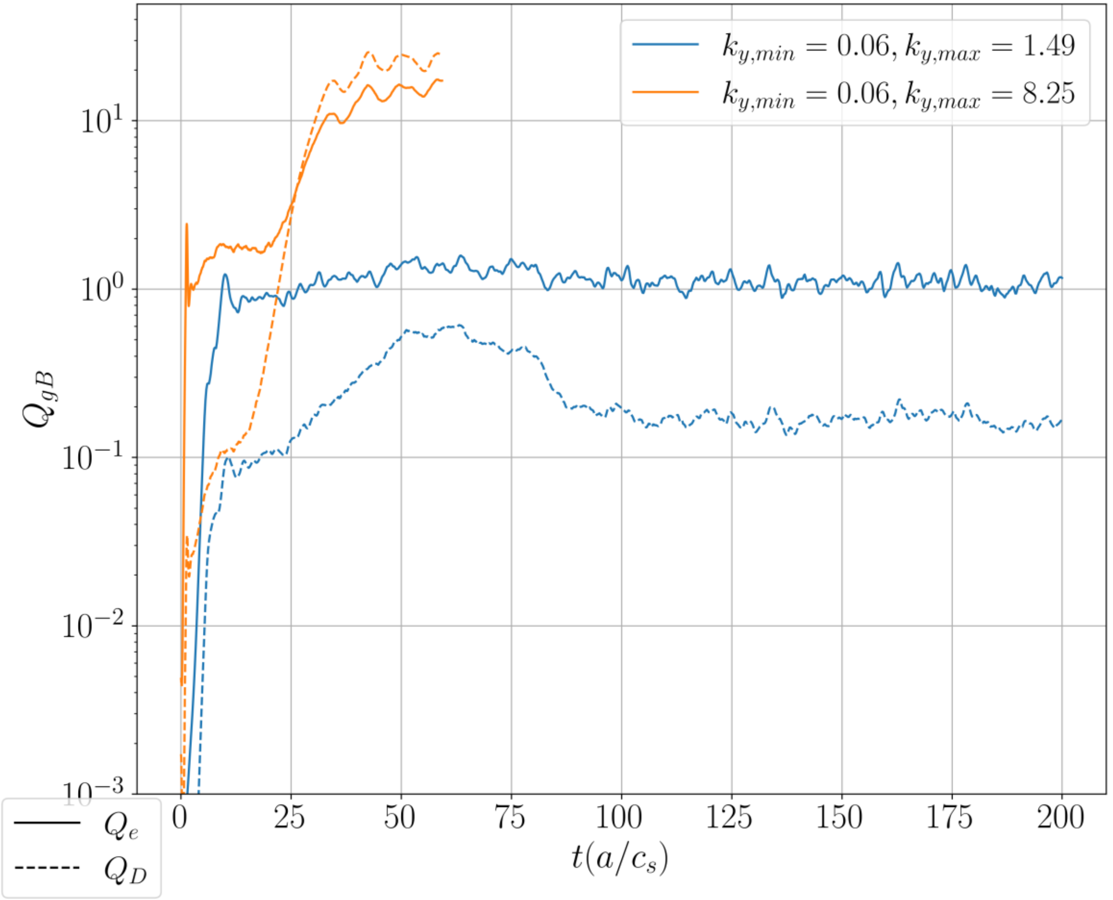


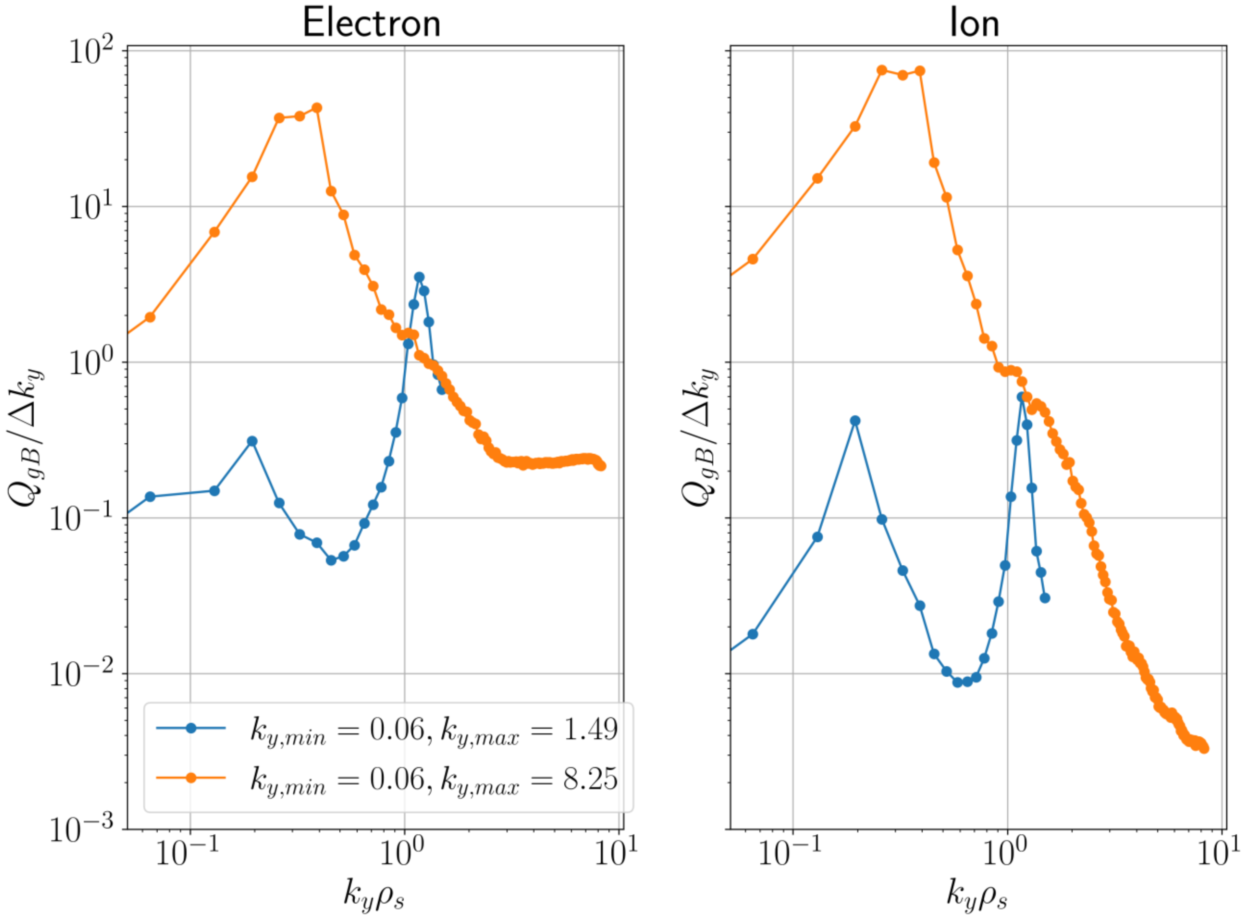


Multiscale: Method 2



- Fluxes begin to saturate but at much higher levels that ion scale
  - Need to run for longer…
- Not captured peak in ETG spectrum





Conclusions

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- Initial gyrokinetic simulations have been conducted for MAST Upgrade finding MTM, UM and ETG modes across a range a k_y

- MTM, UM and ETG growth rate spectrum exhibits no scale separation
  - Ion scale simulations with UM saturate near experimental levels
  - Electron scale simulations with ETG only saturate with an artificial low k_y cut-off

- *Preliminary* multiscale simulations were attempted
  - Full ion scale needs to be captured for saturation
  - Likely need full electron scale to get a converged result
  - Impact of MTM not yet determined…
  - Further work examining these is needed

- Future work will make direct comparisons to the DBS systems via synthetic diagnostics