# Gyrokinetic Linear Stability Analysis of NSTX L-mode Plasmas

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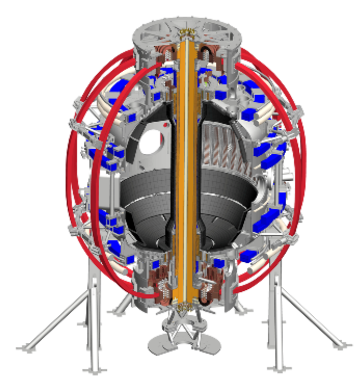


# Abstract

NSTX offered unique opportunities in studying transport and turbulence with low aspect ratio, strong plasma shaping and strong E×B shear. NSTX L-mode plasmas have some favorable properties to facilitate the study of the relation between microturbulence and thermal transport: easier to obtain stationary profiles; easier to maintain MHD quiescence; no complications from edge transport barrier. Studies of NSTX RF/NBI-heated L-mode plasmas have provided new insight into the role of ion and electron-scale turbulence in driving anomalous transport. Here we present linear stability analysis of some NSTX L-mode plasmas with GS2 gyrokinetic code. GS2 is an initial value gyrokinetic code which, in its linear mode, finds the fastest growing mode for a given pair of poloidal and radial wavenumbers. The linear simulations used local Miller equilibria and plasma parameters derived from measured experimental profiles with electromagnetic effects, electron and ion collisions and carbon impurity.

# Motivation

- L-mode plasmas offer some favorable properties to facilitate the study of the relation between microturbulence and thermal transport
  - Easier to obtain stationary profiles
  - Easier to maintain MHD quiescence
  - No complications from edge transport barrier
- The purpose of this poster is to
  - Document unstable modes in a wide range of L-mode plasma parameters from different operational scenarios and radial locations
  - Document linear stability threshold, particularly for ETG modes, and to compare with Jenko threshold which was derived based on high-aspect-ratio tokamak equilibria
    - The discrepancy between GS2-evaluated and Jenko thresholds will pave the way to develop similar formula for low-aspect-ratio spherical tokamak (ST) plasmas

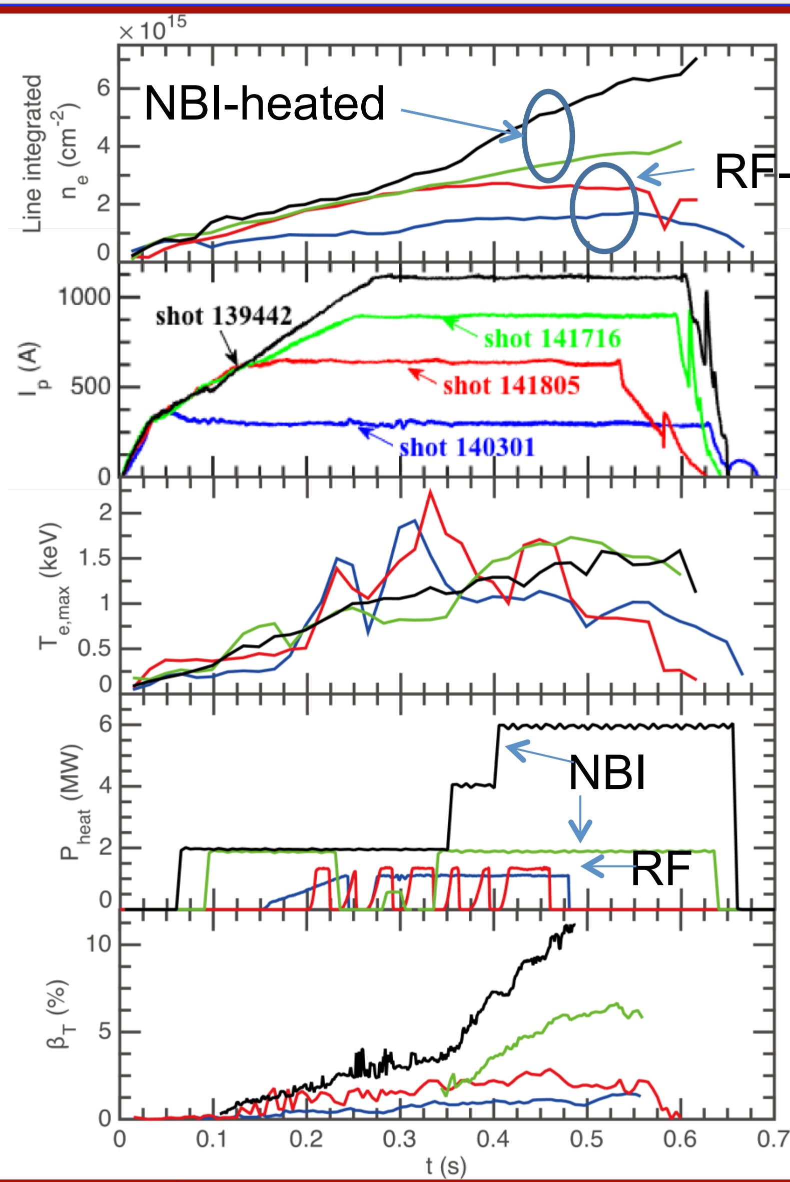
# Methods and NSTX L-plasmas

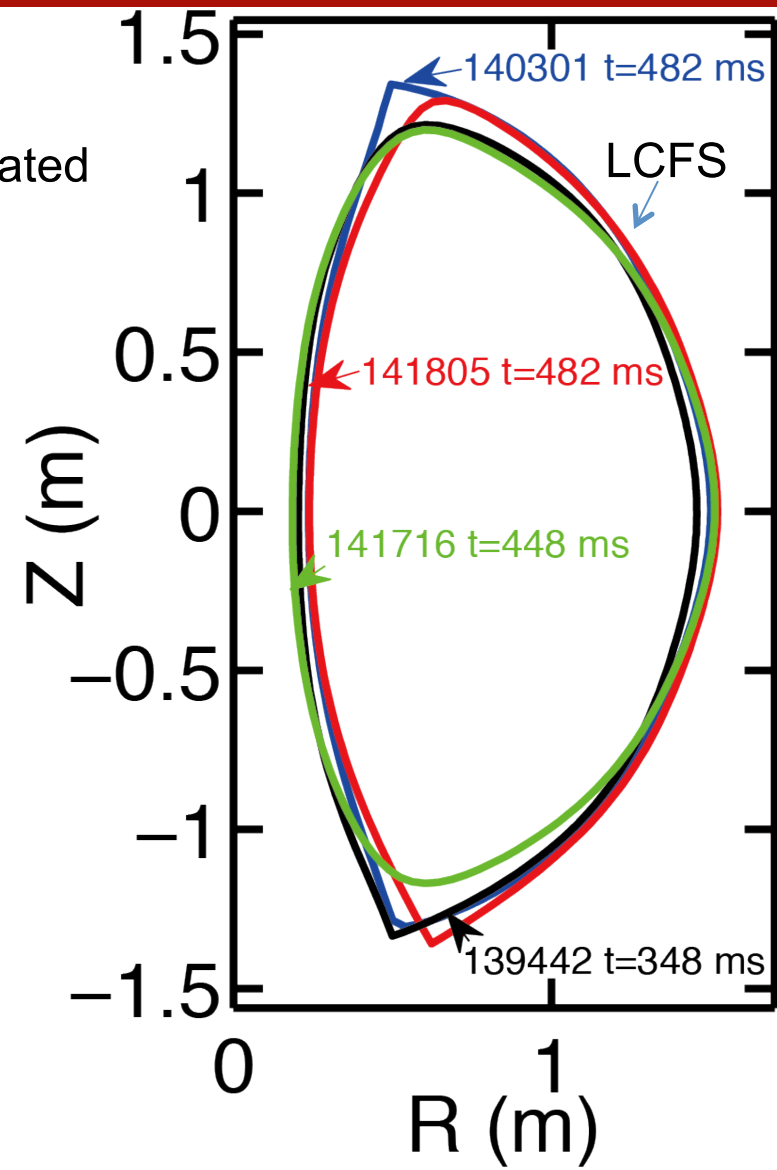
- Using GS2 continuum gyrokinetic code for linear stability analysis
  - GS2 is an initial value code which, in its linear mode, finds the most unstable mode given a pair of poloidal and radial wavenumbers
- Analyses were carried out for several NSTX L-mode plasmas with different heating schemes, boundary conditions and $I_p$ etc.
  - RF-heated L-mode plasmas with low (shot 140301) and high plasma current (shot 141805)
  - NBI-heated L-mode plasmas with center-stack-limited (shot 141716) and diverted (L-mode phase of shot 139442) boundary conditions

# Outline

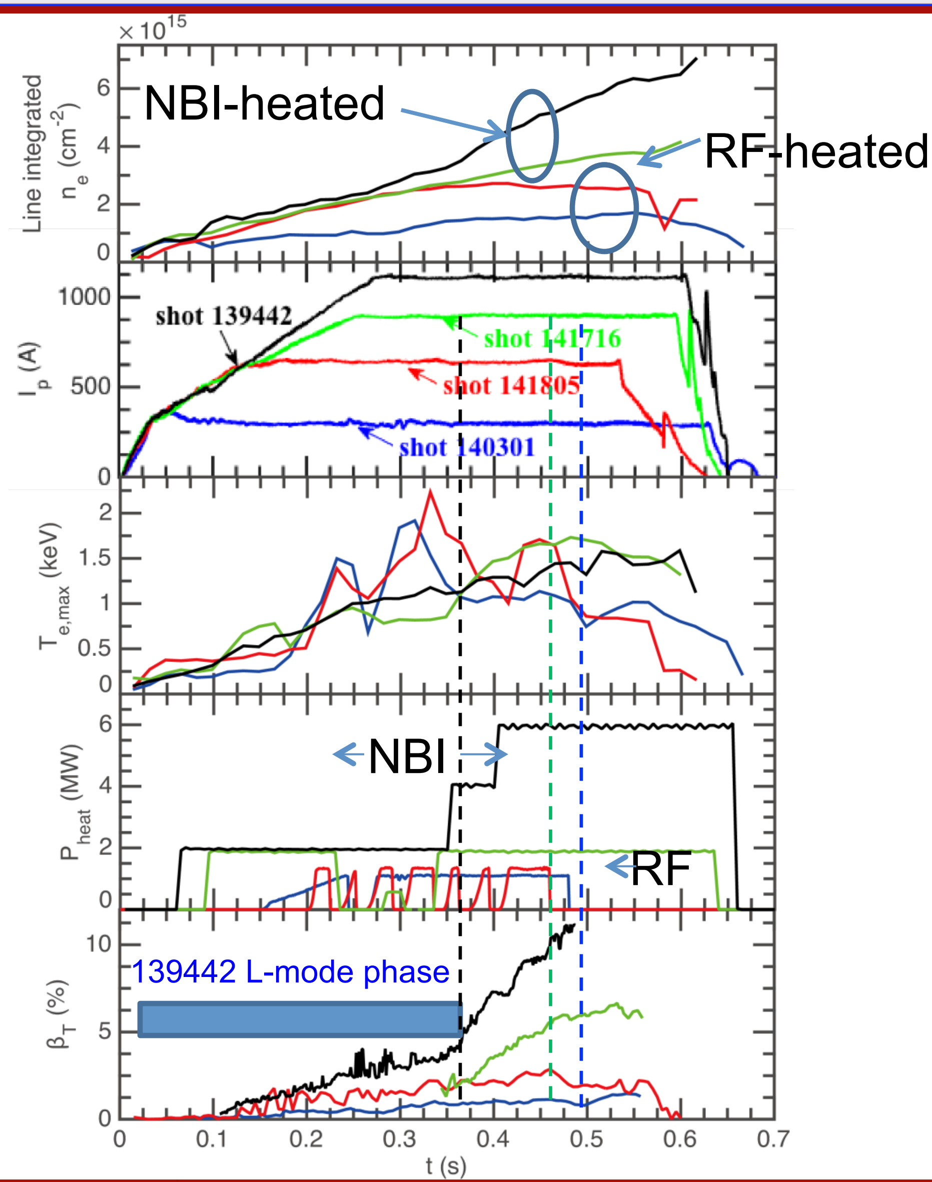
- Overview of the selected NSTX L-mode plasmas
  - Equilibrium time traces and plasma shaping
- Linear stability of plasmas at different radial locations (r/a~ 0.5 -0.9) and time points
  - Linear growth rates and real frequencies from ion scale to electron scale
  - Found ITG/TEM at ion scale and ETG at electron scale
- ETG linear threshold of the selected L-mode plasmas calculated with the GS2 code and the comparison with Jenko ETG linear threshold
  - Agreements and discrepancies identified
- Summary

# An Overview of the Selected NSTX L-mode Plasmas (I)



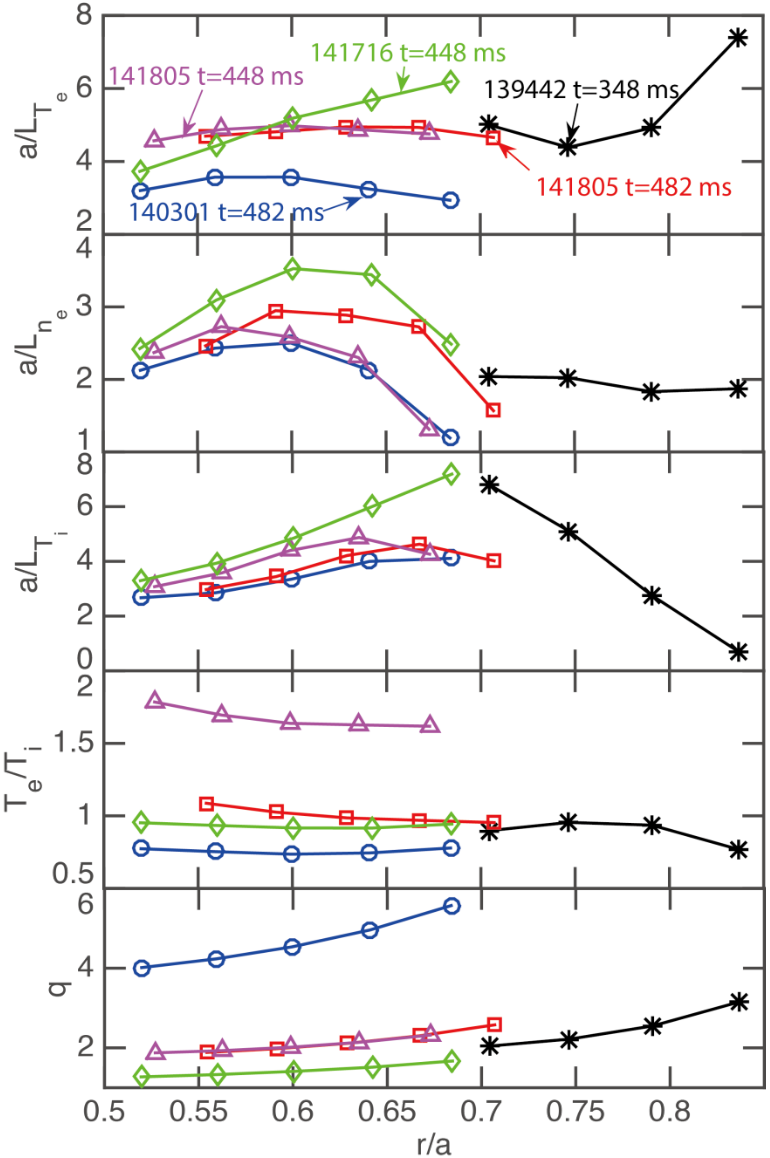
# An Overview of the Selected NSTX L-mode Plasmas (II)




| RF-heated plasmas | | |
|---|---|---|
| Shot # | $I_p$ (kA) | $P_{heat}$(MW) |
| 140301 | 300 | 1 |
| | Lowest density and plasma beta (t=482 ms) | |
| 141805 | 600 | 1.2 |
| | Higher density and plasma current (t=448, 482 ms) | |

| NBI-heated plasmas | | |
|---|---|---|
| Shot # | $I_p$ (kA) | $P_{heat}$(MW) |
| 139442 | 1100 | 2 |
| | higher density and plasma beta (t=348 ms) | |
| 141716 | 900 | 2 |
| | higher density and plasma beta (t=448 ms) | |

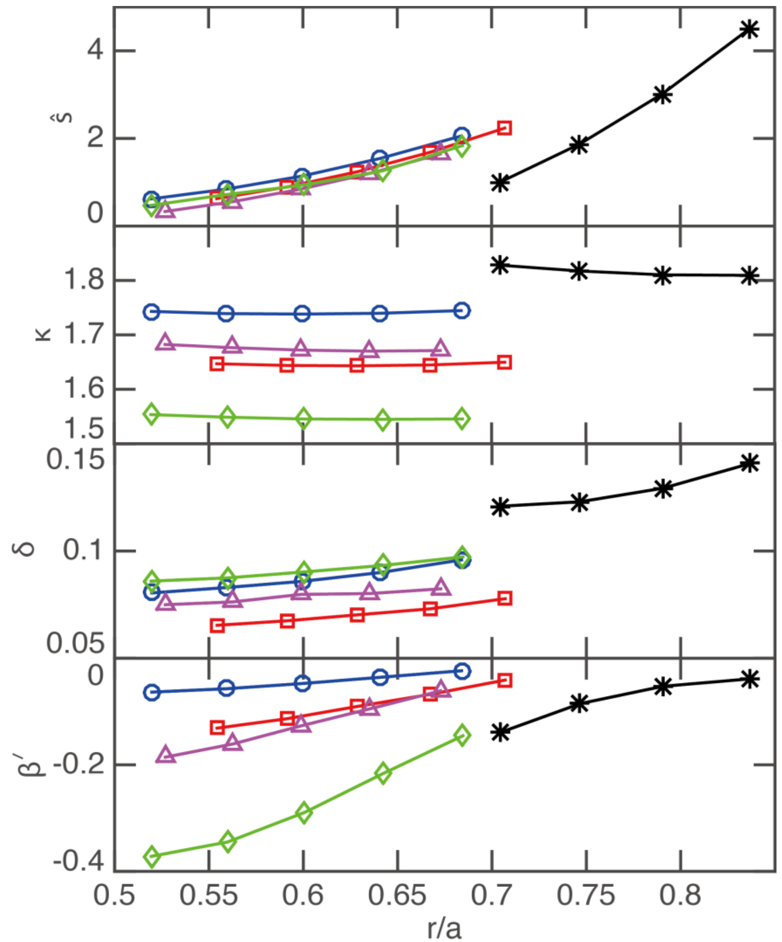
# Comparison of Relevant Dimensionless Quantity Profiles for the Plasmas (I)




- RF-heated shots 140301, 141805 and NBI-heated shot 141716 provide core-relevant parameters
- The L-mode phase of NBI-heated shot 139442 provides more edge-relevant parameters
- Large range of normalized gradients, from about 1 to 7
- Significant changes are also obvious in $T_e/T_i$ and q

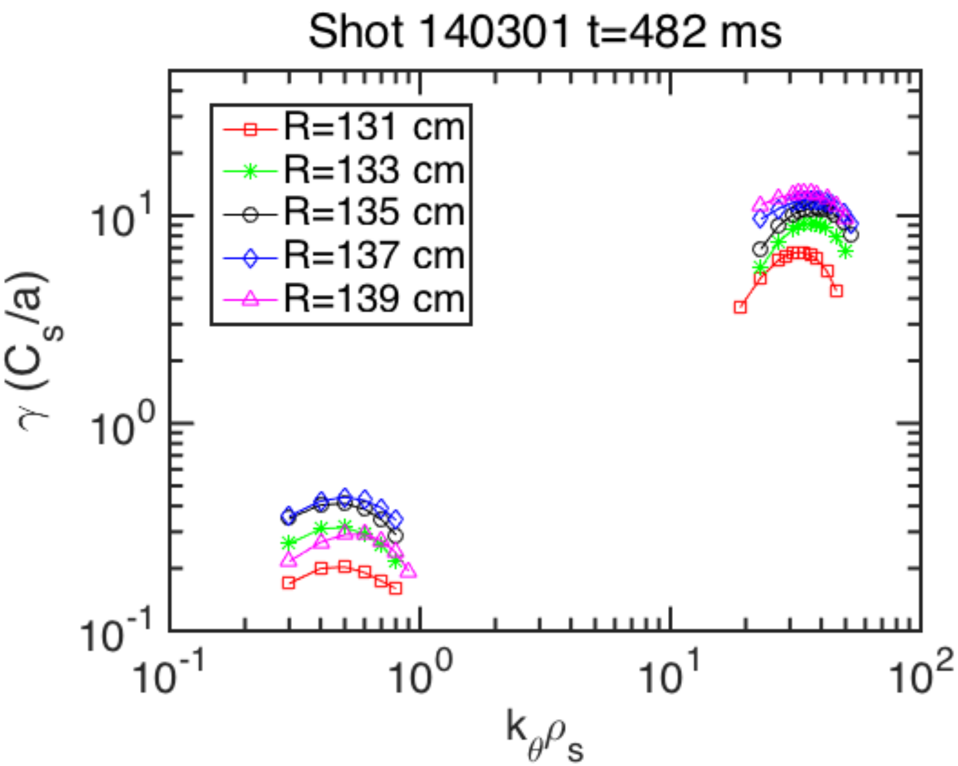
# Comparison of Relevant Dimensionless Quantity Profiles for the Plasmas (II)

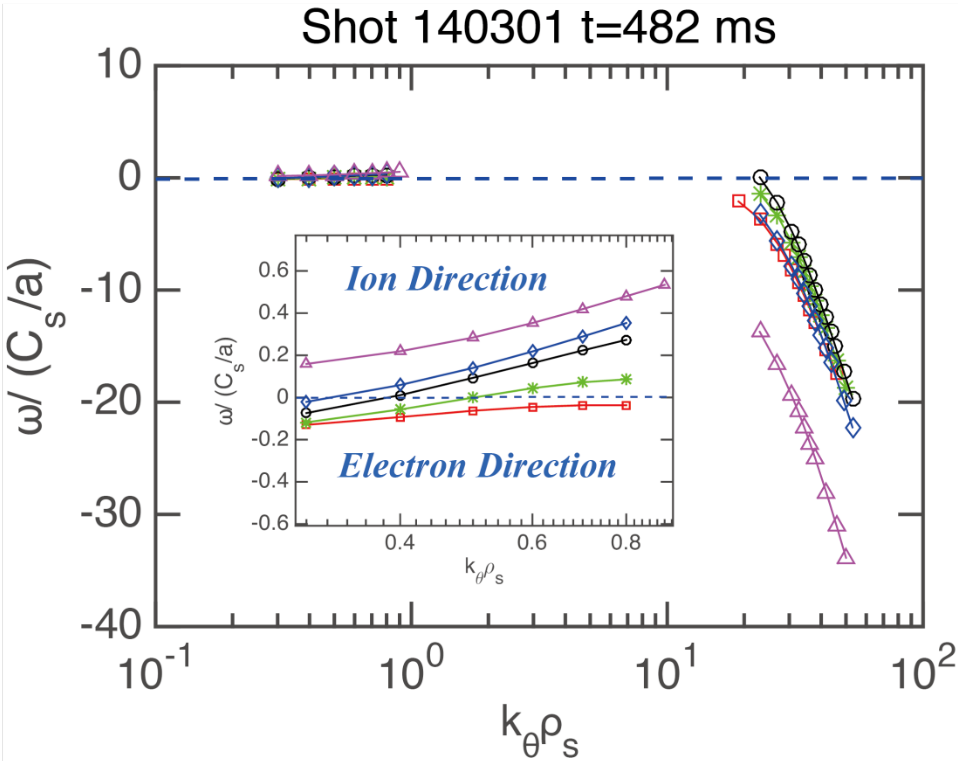
- Very similar magnetic shear seen for shots 140301, 141805 and 141716
- Elongation ranges from about 1.5 to 1.8
- Local triagularity is small for all discharges
- NBI-heated L-mode plasma 141761 has largest $\beta'$



# Linear Stability for RF-heated L-mode Plasma Shot 140301 at t=482 ms

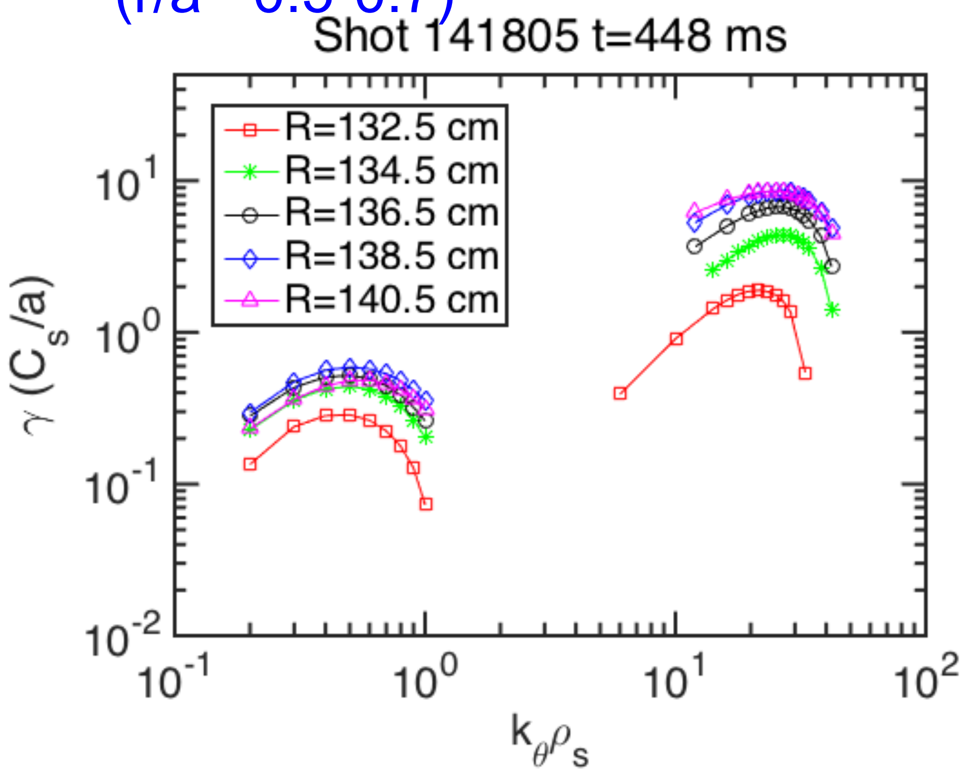
- Clear growth rate peaks are seen for both ion and electron scale
- Ion-scale mode propagation direction gradually changes from electron direction to ion direction from R=131 to 139 cm (r/a~ 0.5-0.7)

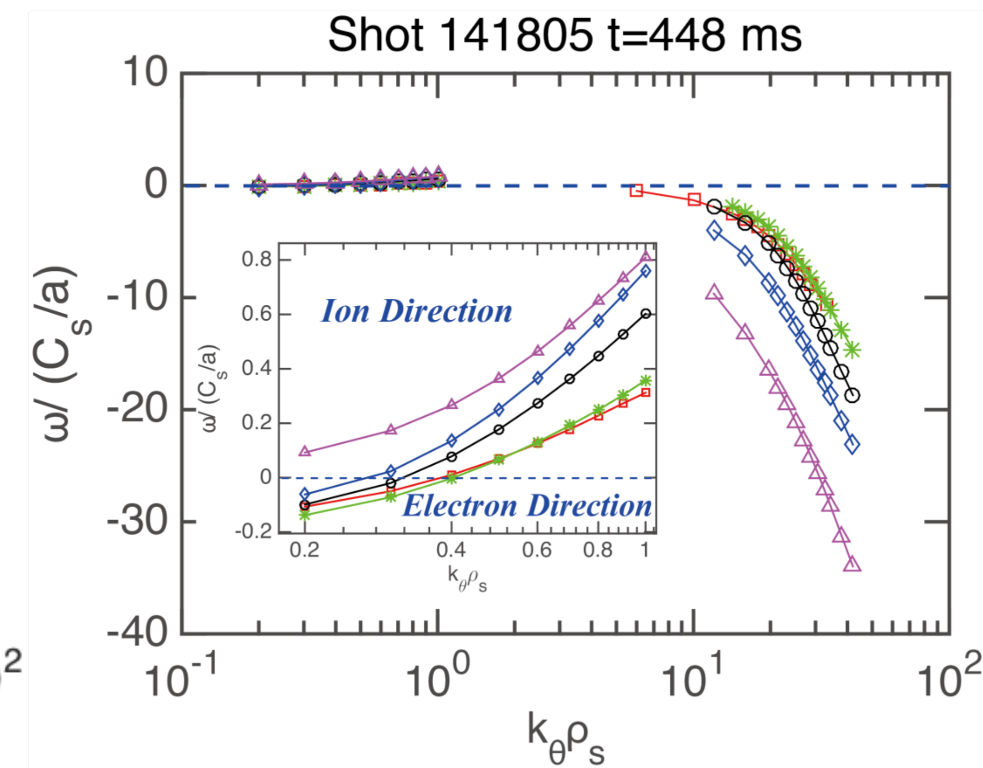


# Linear Stability for RF-heated L-mode Plasma Shot 141805 at t=448 ms

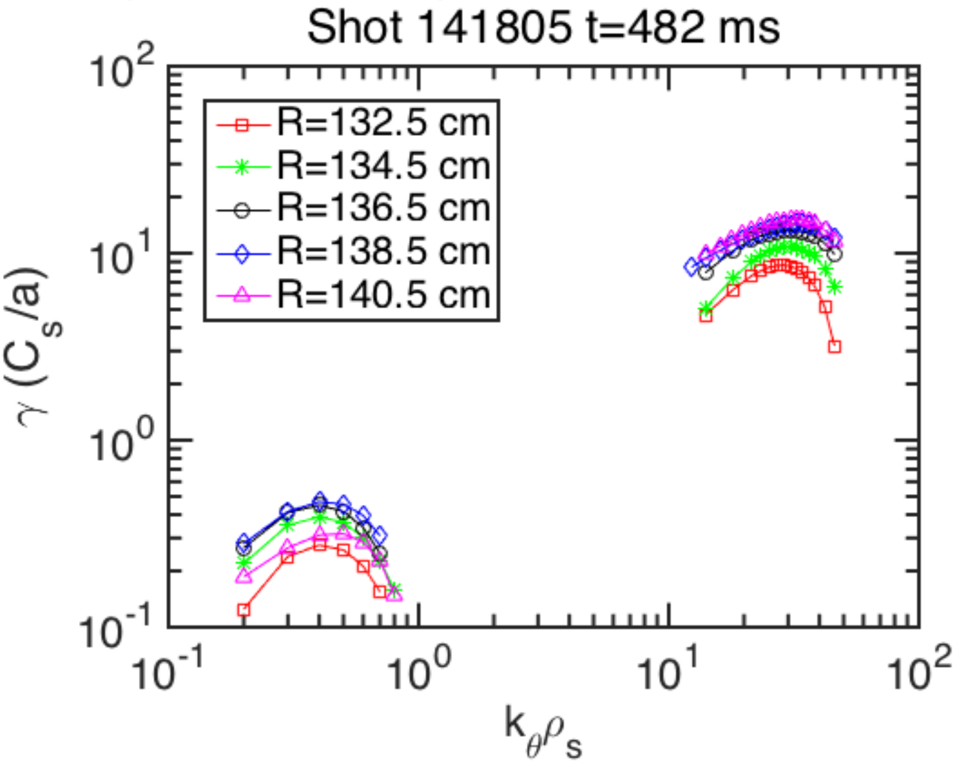
- Qualitatively similar to shot 140301
  - Clear growth rate peaks are seen for both ion and electron scale
  - Ion-scale mode propagation direction gradually changes from electron direction to ion direction from R=132.5 to 140.5 cm (r/a~ 0.5-0.7)

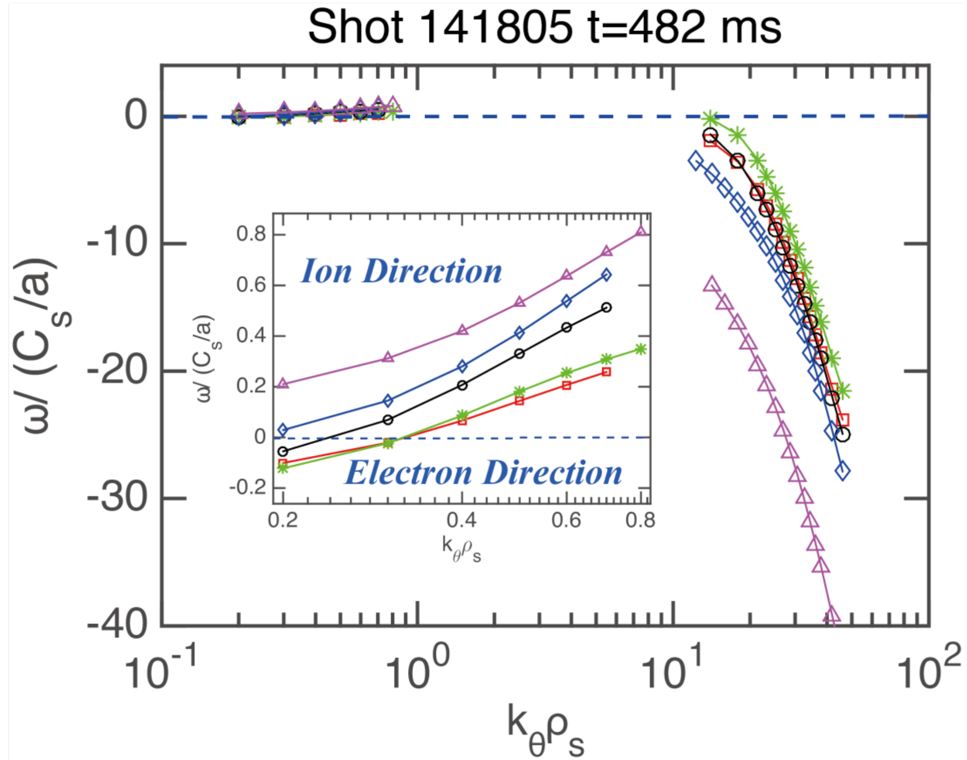


# Linear Stability for RF-heated L-mode Plasma Shot 141805 at t=482 ms

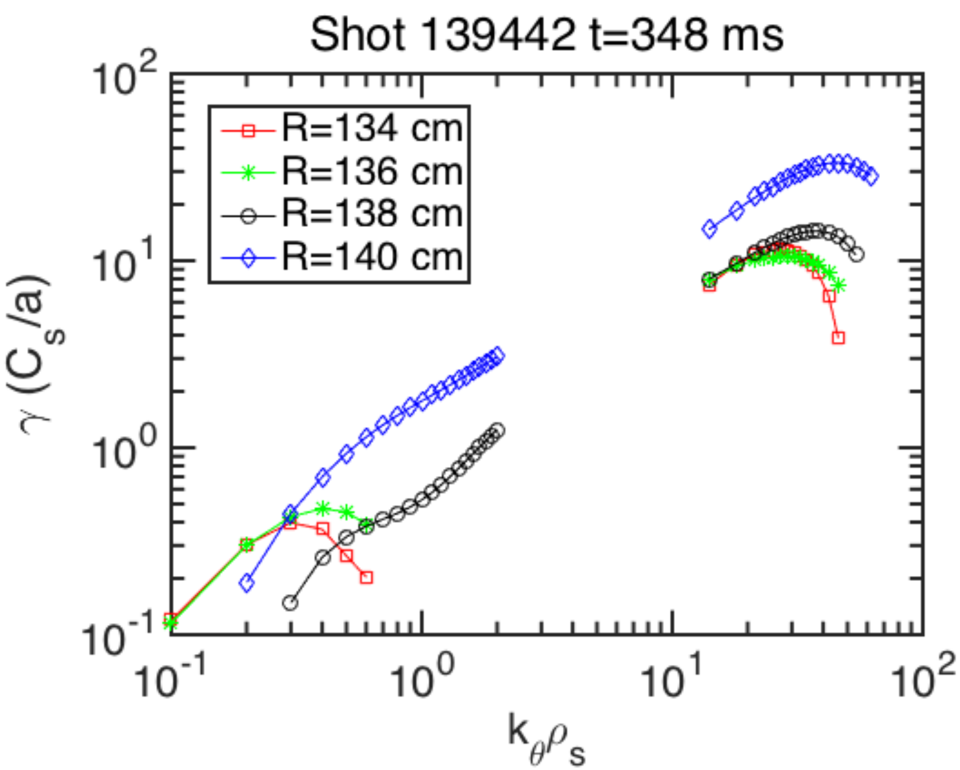
- Qualitatively similar to t=448 ms
  - Clear growth rate peaks are seen for both ion and electron scale
  - Propagation direction of some ion-scale modes gradually changes from electron direction to ion direction from R=132.5 to 140.5 cm (r/a~ 0.5-0.7)

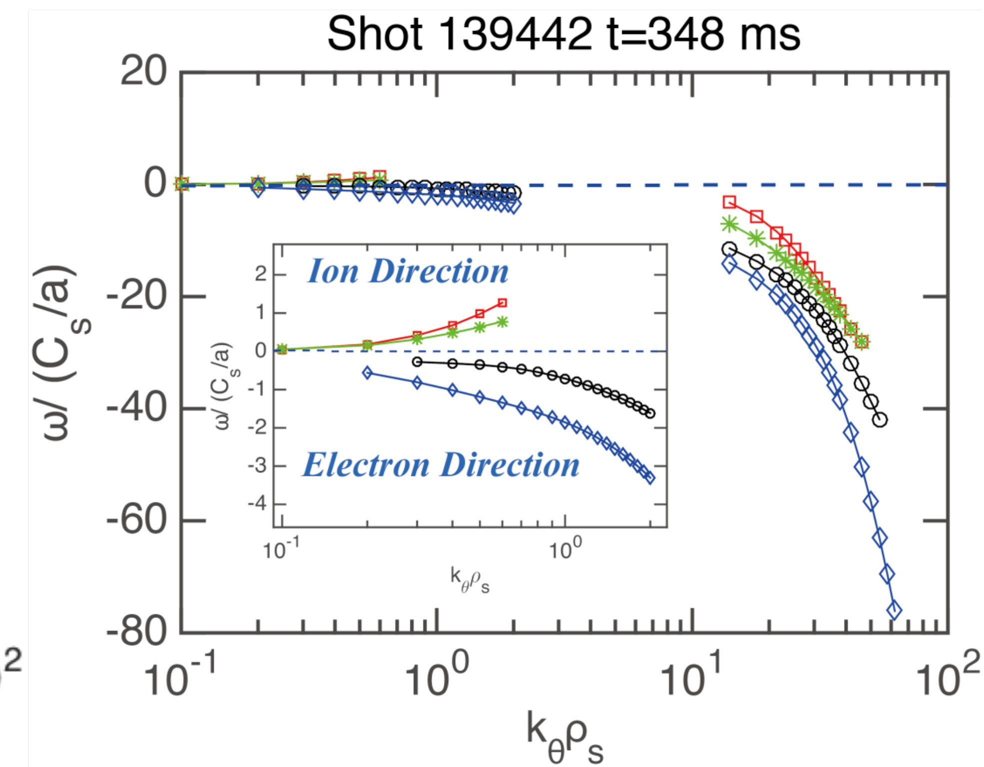


# Linear Stability for the L-mode Phase of NBI-heated Shot 139442 at t=348 ms

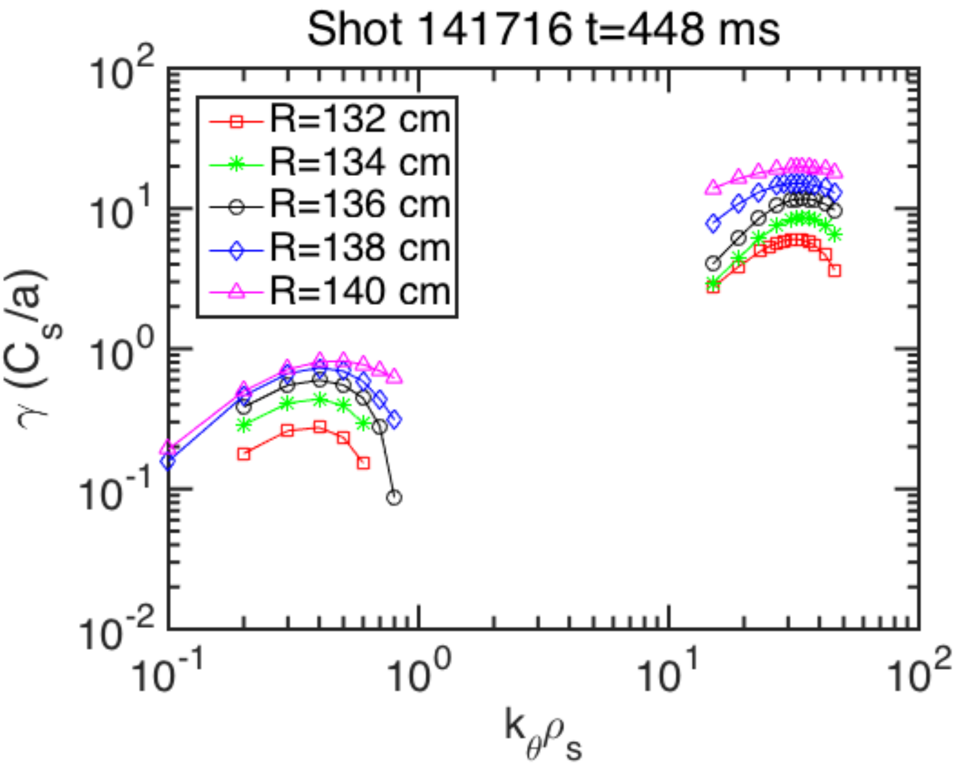
- Clear growth rate peaks are only seen for two smaller radial locations
- Two larger radial locations show unstable modes exist all the way from ion to electron scale
- Distinct propagation direction difference for the two group of radial locations
  - Ion-direction propagation for the inner two radial locations and electron-direction for the outer radial locations

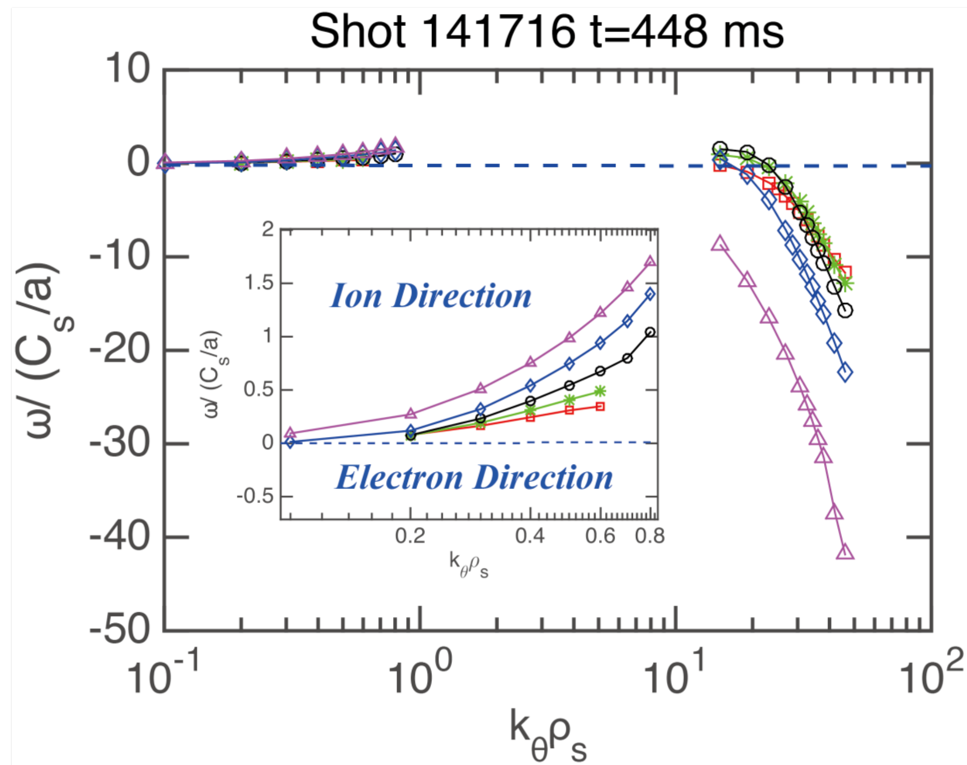


# Linear Stability for NBI-heated L-mode Plasma Shot 141716

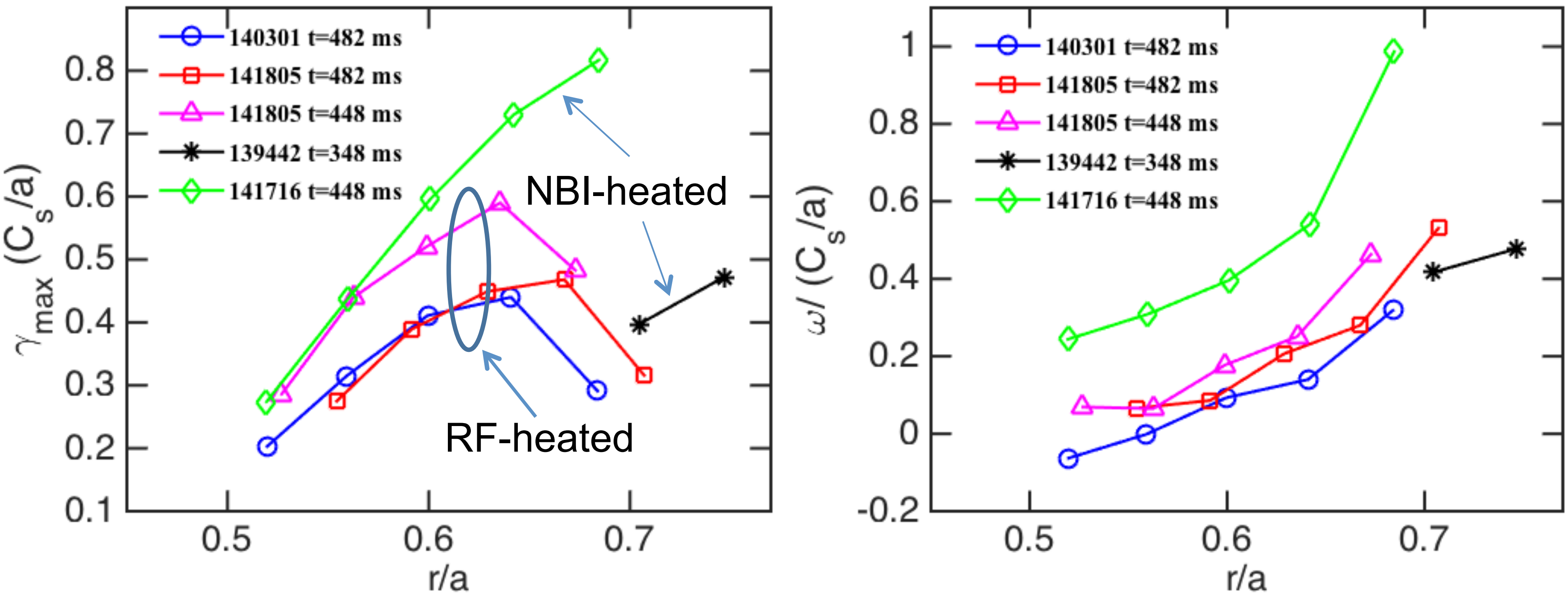
- Similar to shots 140301 and 141805
  - Clear growth rate peaks are seen for both ion and electron scale
- However, ion-scale mode propagation directions are exclusively in the ion direction, showing ion temperature gradient may play a more important role here



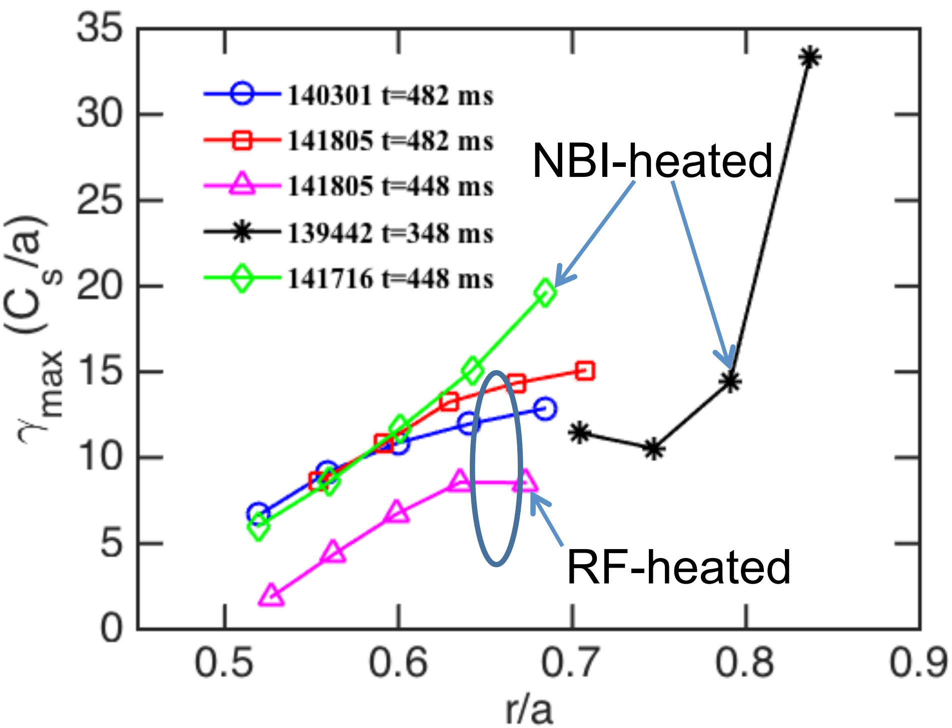
# RF-heated and NBI-heated Plasmas Show Difference and Similarity in Ion-scale Linear Stability Profile

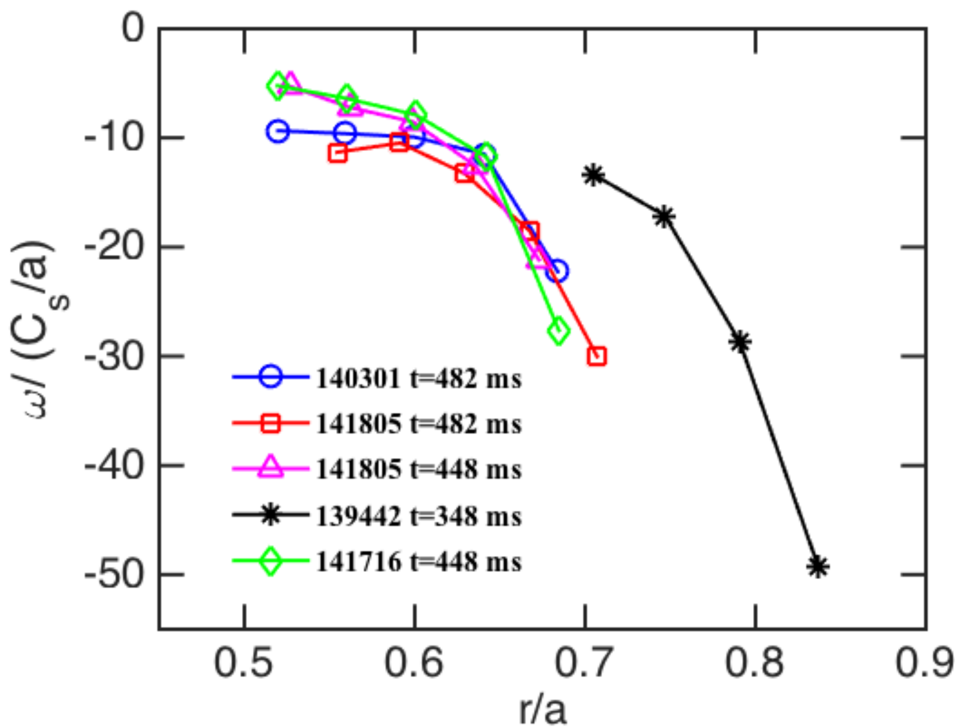
- The real frequency at maximum linear growth rate all increases towards larger radius
- RF-heated plasmas show peak linear growth rates at r/a~ 0.63
- Linear growth rates for NBI-heated plasma increase towards larger radius (may peak at larger radius not evaluated)



# RF-heated and NBI-heated Plasmas Show More Similarity in Electron-scale Linear Stability Profile

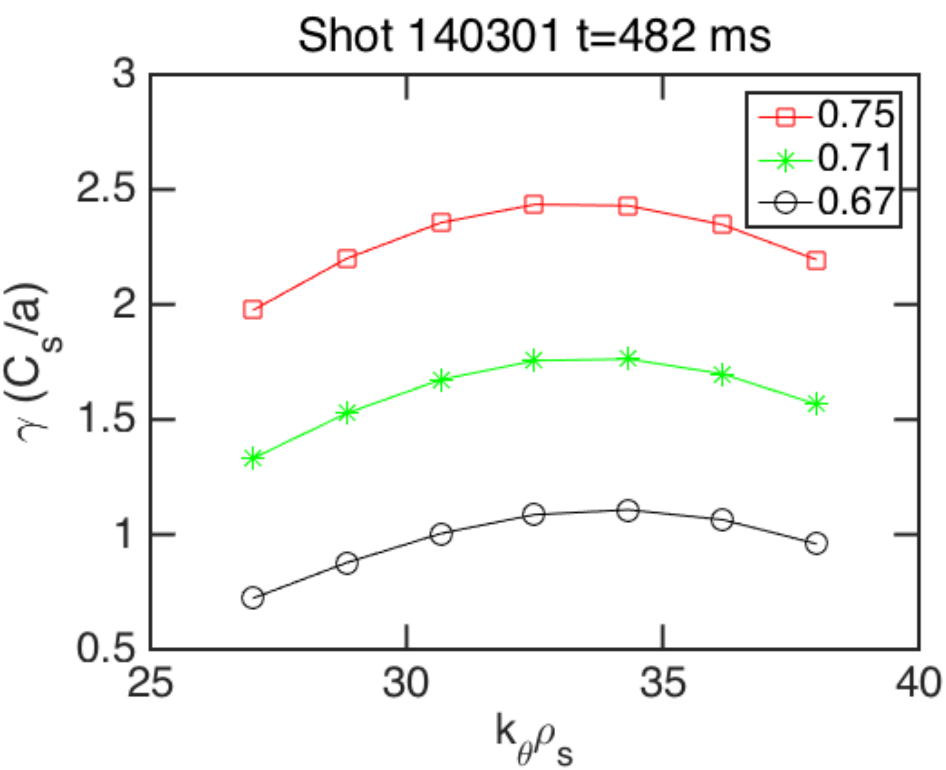
- ETG modes show increasing linear growth rate and real frequency towards larger radius
  - Very similar linear growth rate cross all plasmas at smaller radius (larger difference further out),
  - Except for t=448 ms of shot 141805 (much smaller linear growth rate), likely due to the large $T_e/T_i$ at t=448 ms
    - However, real frequencies are still similar to other cases

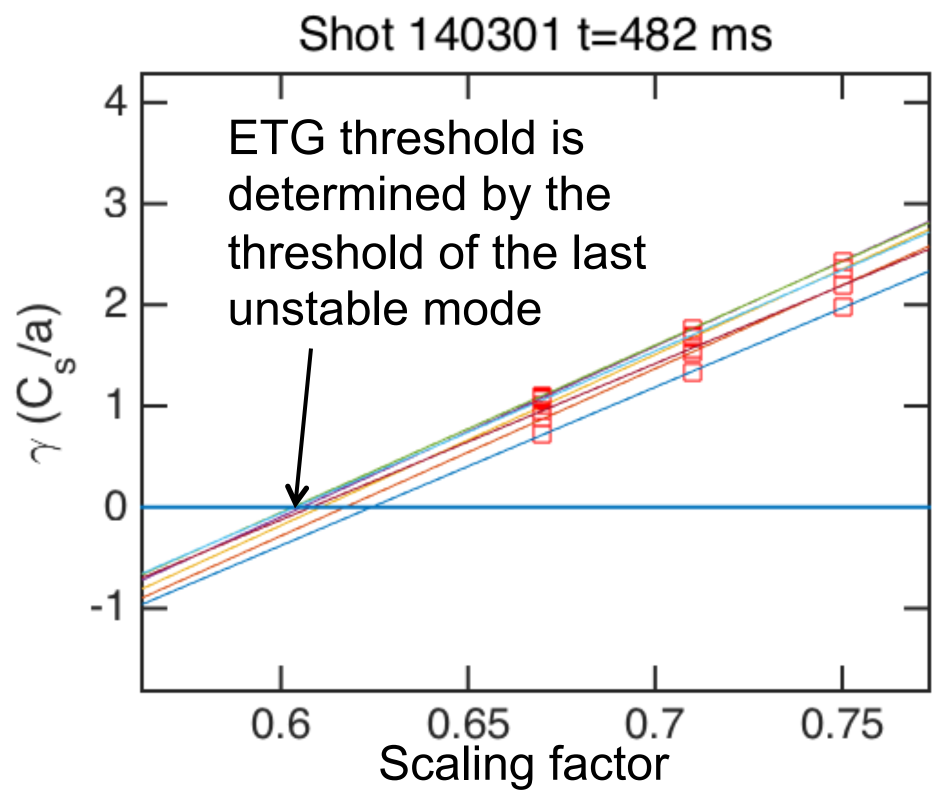


# ETG Linear Stability Threshold was Calculated Using Standard Technique

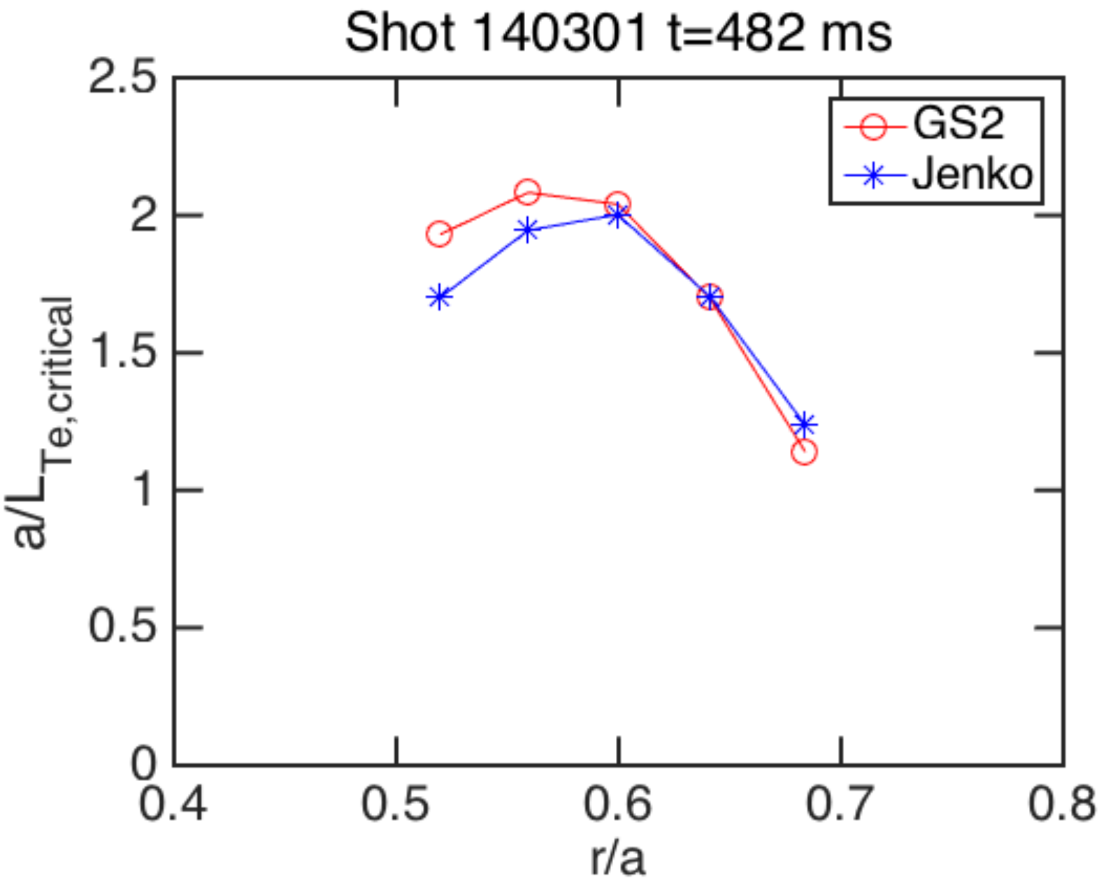
- Electron temperature gradient is scanned by multiplying different scaling factors with $\beta'$ kept constant
- Linear extrapolation of linear growth rate to zero for all calculated wavenumbers to determine linear ETG threshold



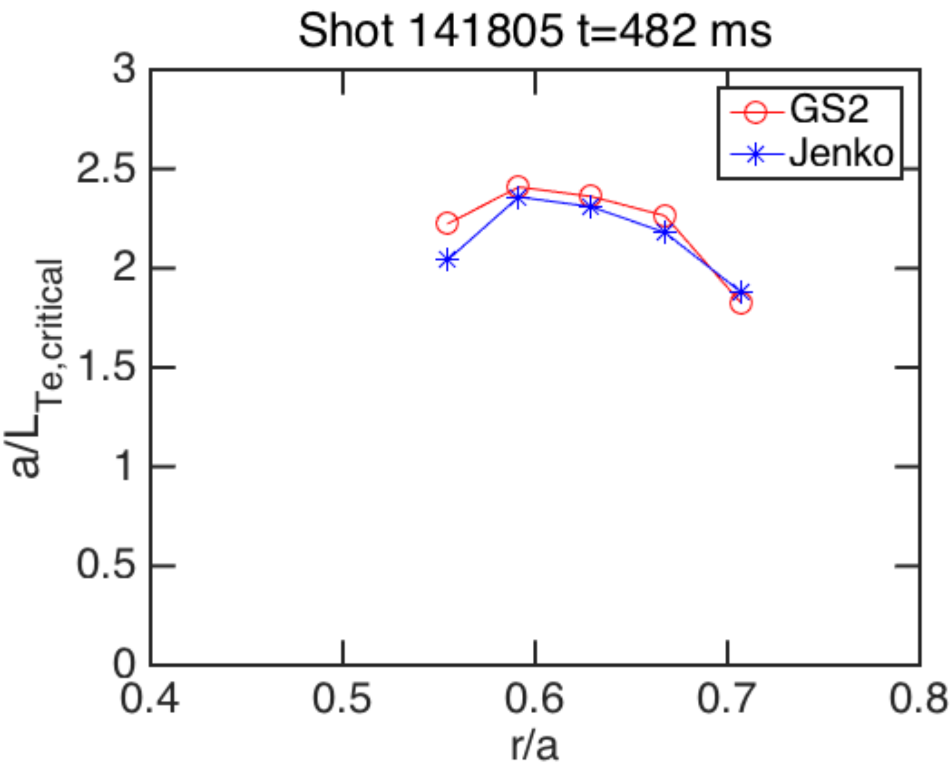
# RF-heated Shot 140301 Shows Good Agreement between GS2 and Jenko ETG Thresholds

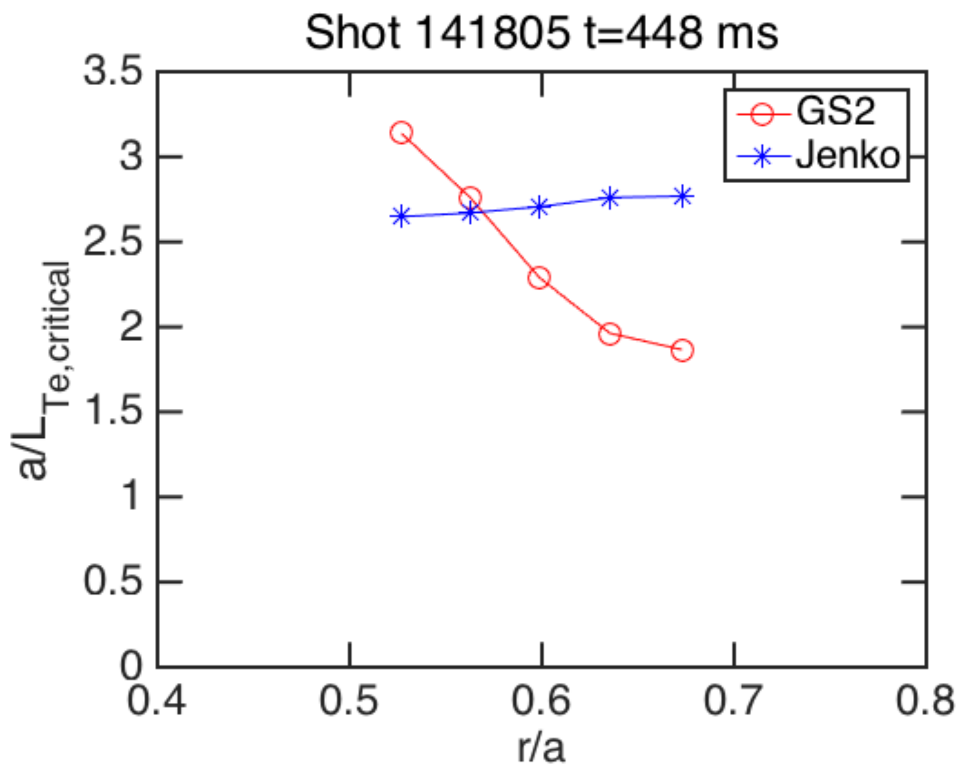
- ETG linear threshold peaks at about r/a=0.56
- Very good agreement between GS2 and Jenko ETG linear thresholds at larger radius and somewhat larger difference at smaller radius



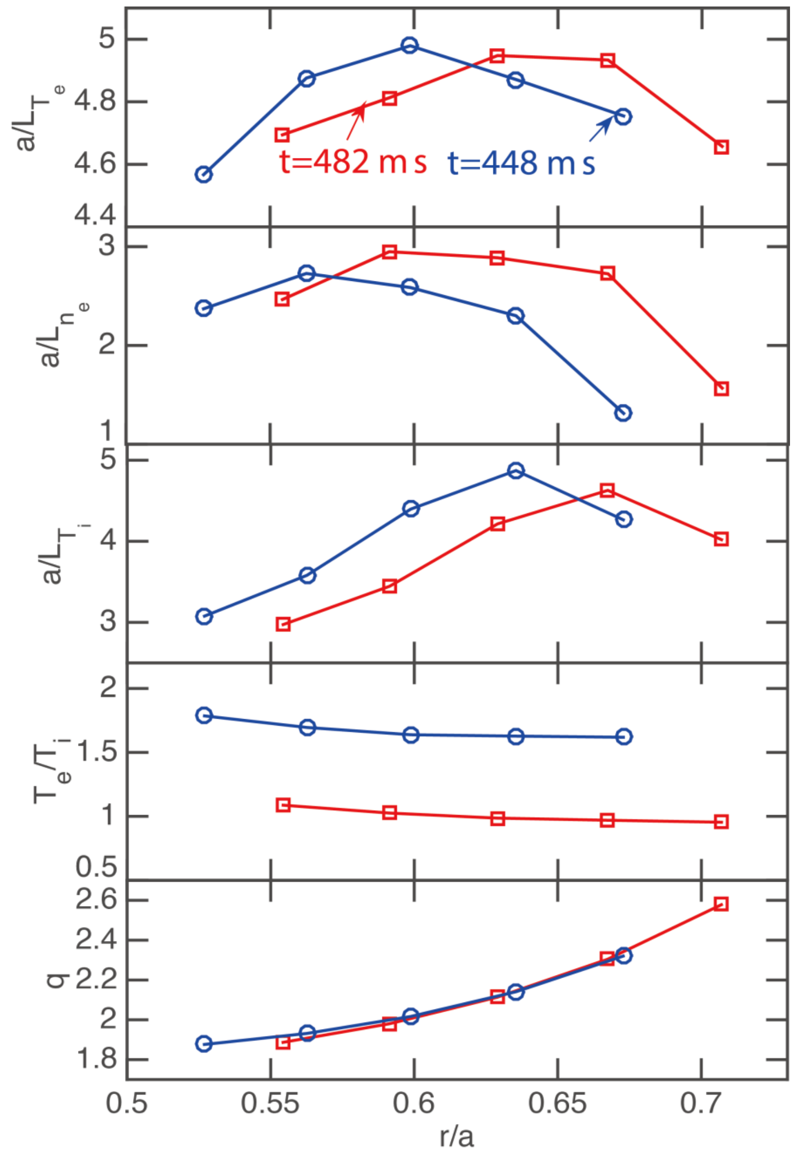
# RF-heated Shot 141805 Shows Large Discrepancy between GS2 and Jenko ETG Thresholds at t=448 ms

- At t=482 ms, linear ETG threshold radial profiles are qualitatively similar to shot 140301
- Good agreement between GS2 and Jenko ETG thresholds at t=482 ms, in contrast to the t=448 ms case

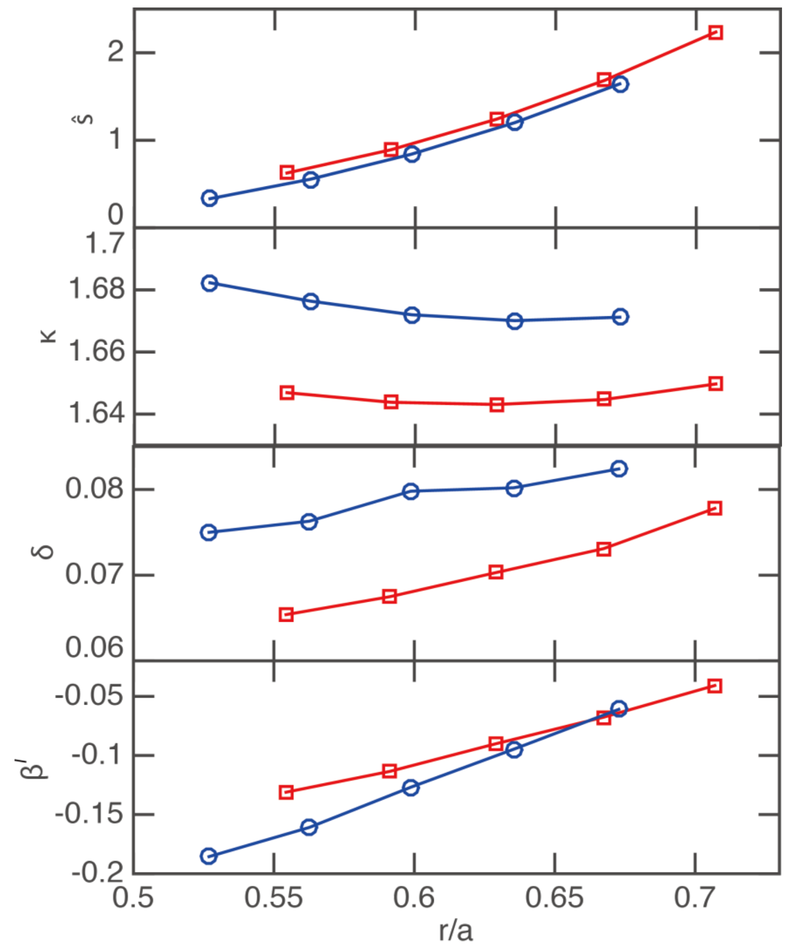


# Equilibrium profiles of Shot 141805 at the Two Time Points Show the Largest difference in $T_e/T_i$

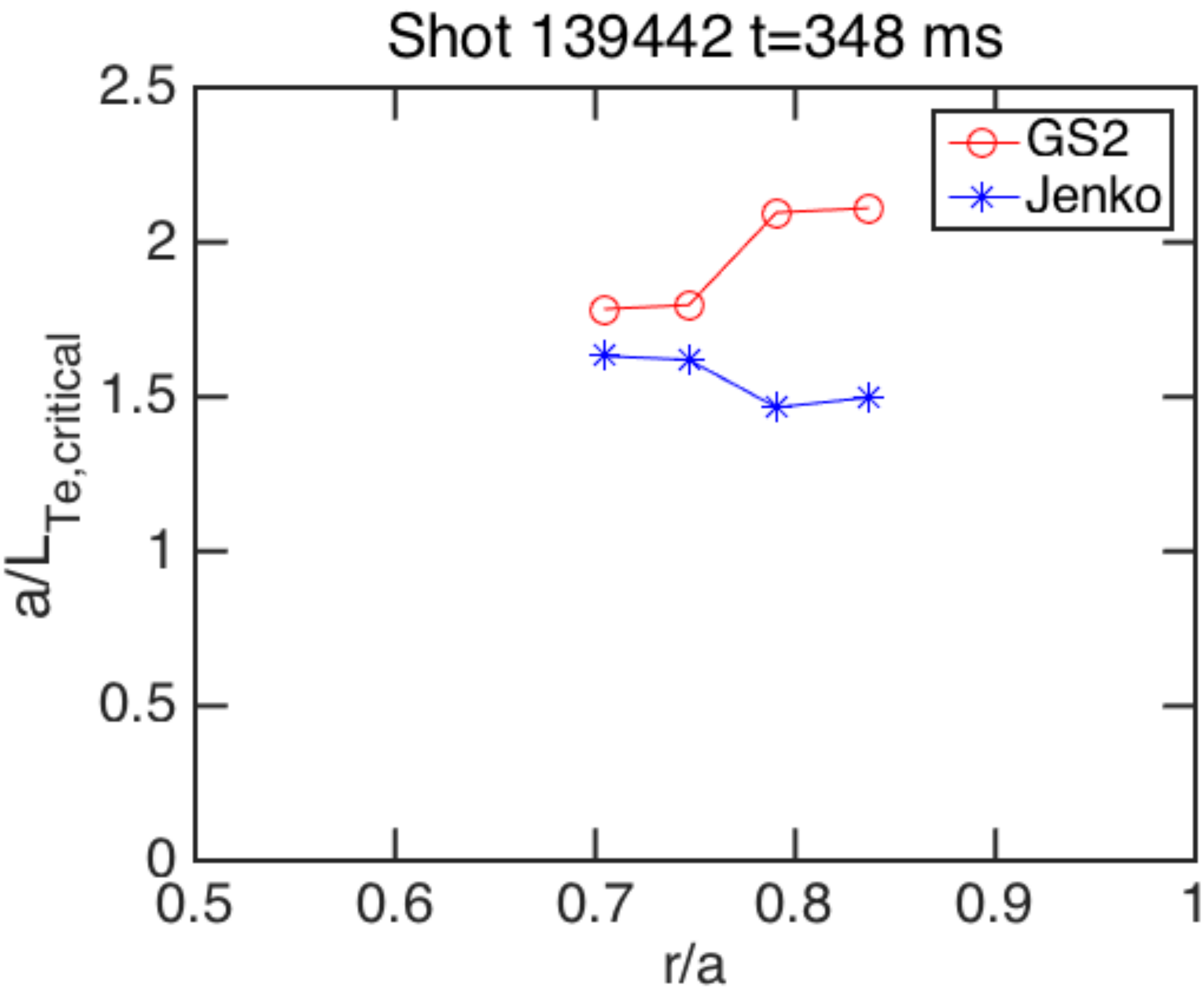



- Density gradient difference is also large at larger radius
- Both $T_e/T_i$ and $a/L_{ne}$ may be important



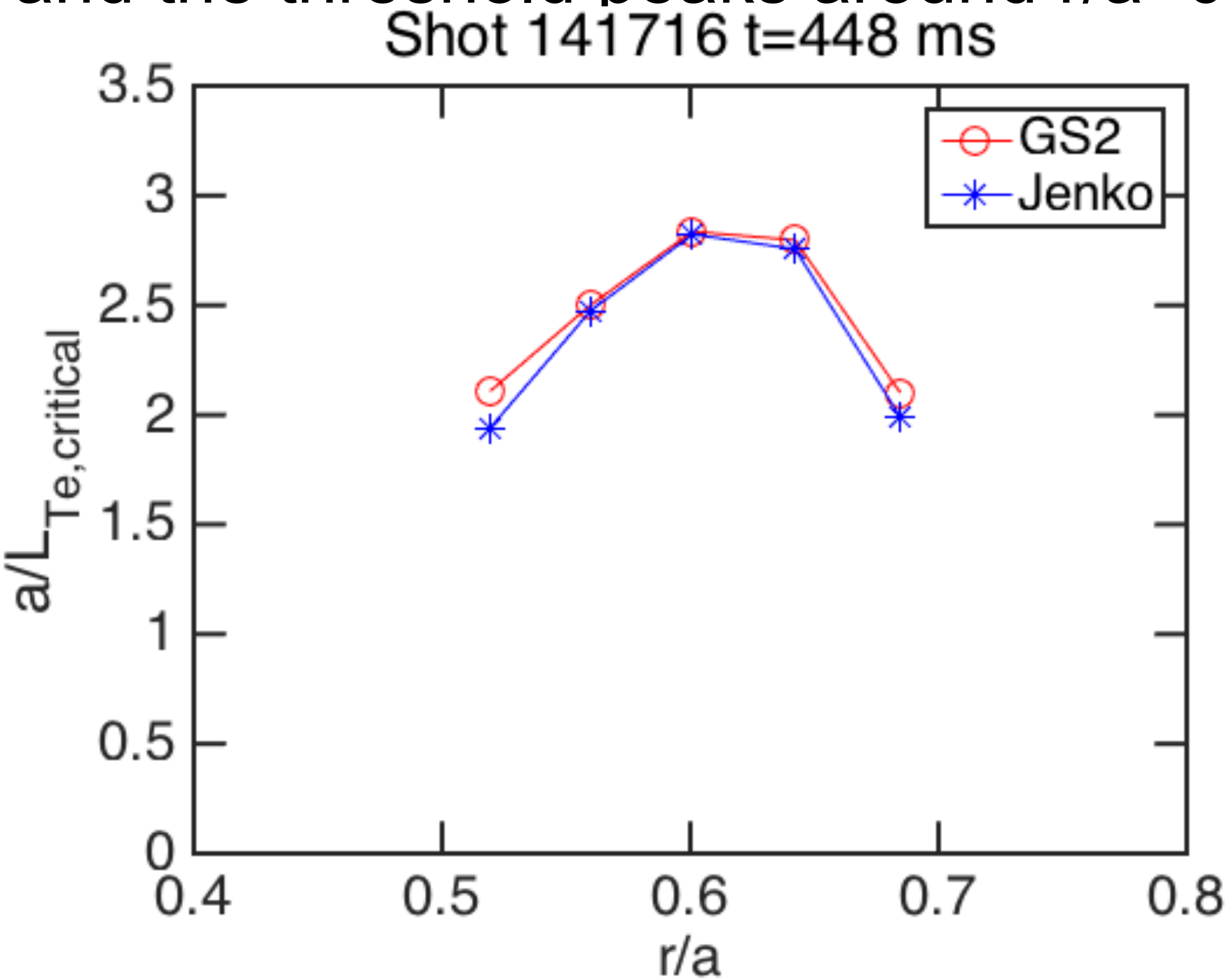
# Larger Difference between GS2 and Jenko ETG Thresholds is Seen at Larger Radius for NBI-heated shot 139442

- Magnetic shear may play a role in this discrepancy



# Jenko ETG Linear Threshold Works Nicely for NBI-heated Shot 141716

- Very small difference between the two linear threshold is seen and the threshold peaks around r/a=0.6



# Summary

- We have carried out about 1160 linear stability analyses for a variety of NSTX L-mode plasmas with both RF and NBI heating using the GS2 gyrokinetic code. The chosen L-mode plasmas are of a wide range of equilibrium parameters, which is important for mapping linear stability in parametric space for NSTX
- The analyses have shown some common features and differences in radial profiles of linear stability for different L-mode plasmas
- ETG linear threshold has been calculated using standard linear fitting method with the GS2 code for all radial locations
  - A peak in ETG linear threshold around r/a~0.5-0.6 is a quite common feature
  - Good agreement with Jenko ETG threshold is seen in many cases
  - Larger discrepancy with Jenko threshold is also seen, which may be due to different $T_e/T_i$, $a/L_{ne}$ or magnetic shear values
- Future work is to increase the parametric coverage of linear stability analysis, which is paving the way to derive an ETG threshold formula more suitable for low-aspect ratio ST parameters