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Tearing Parity Microturbulent Drift Modes on NSTX

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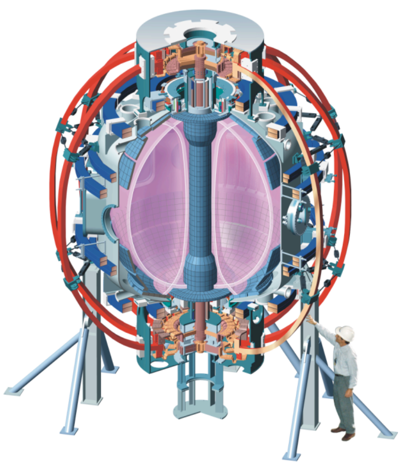

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Outline

I. **Microstability analysis of High density H-mode 108730 shows robust tearing parity drift mode in plasma core**

- Mode subdominant to twisting parity mode in collisionless limit

II. **Experiments on NSTX at low density have lower electron losses (Stutman, IAEA-2004, APS-2004 invited, NI-1.001)**

- Microstability calculations of six NSTX plasma conditions
- Find tearing parity modes at high density, with high electron losses
- Find absence of tearing parity modes at low density and low electron losses

I. Microstability Analysis of High Density H-mode 108730

NSTX: NBI in MHD Quiescent Discharge: $T_i > T_e$, Resilient Te Profiles

NSTX

$I_p = 0.8$ MA

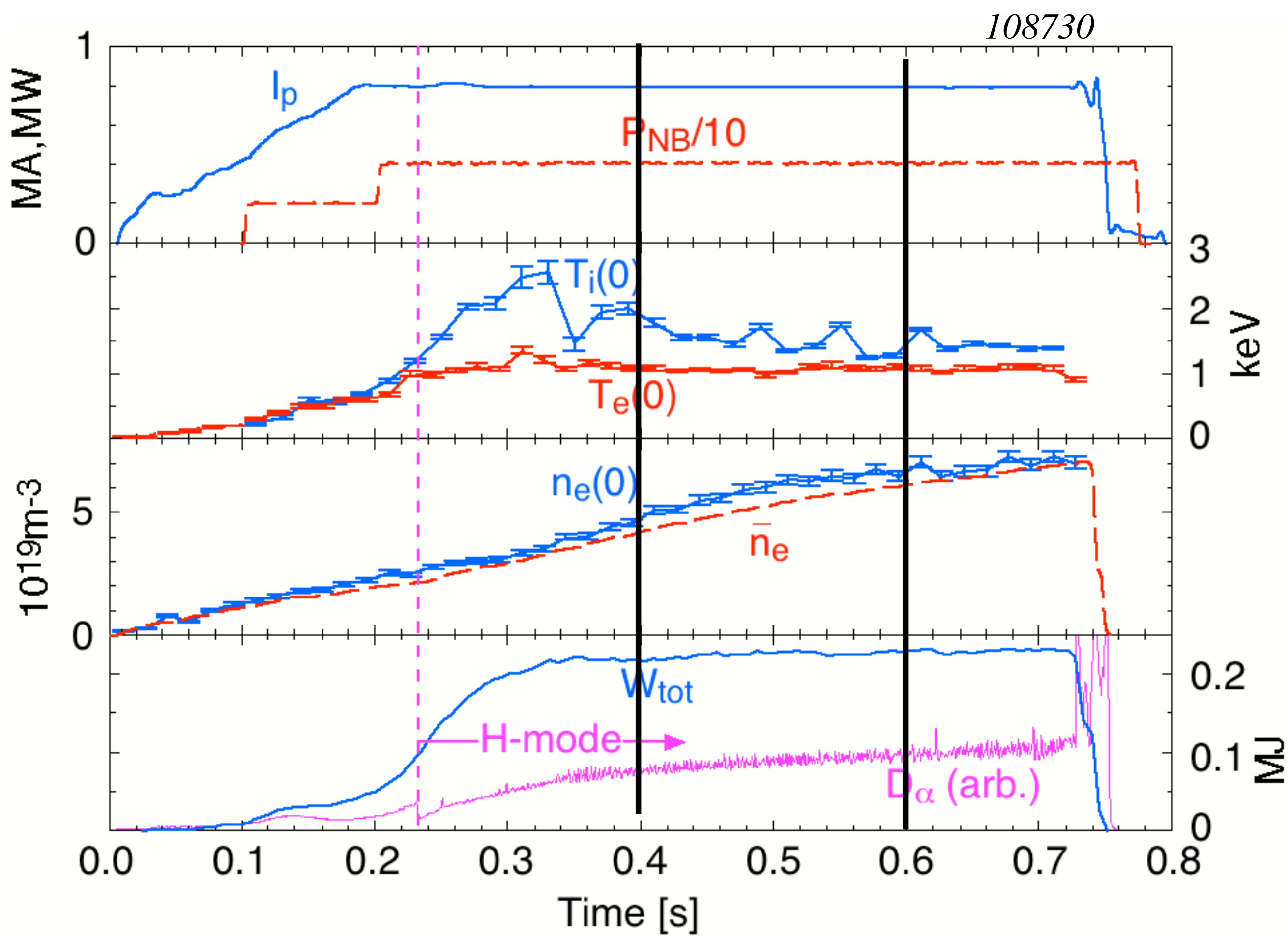
$B_T = 0.5$ T

$P_{NBI} = 4$ MW

$E_{NBI} = 90$ keV

$b_T = 16\%$

W = 0.23 MJ



LeBlanc-EPS-03

NSTX H-mode: Te(r) Resiliency

During H-mode

$T_e(r)$ remains resilient
electron density increases
ion temperature decreases

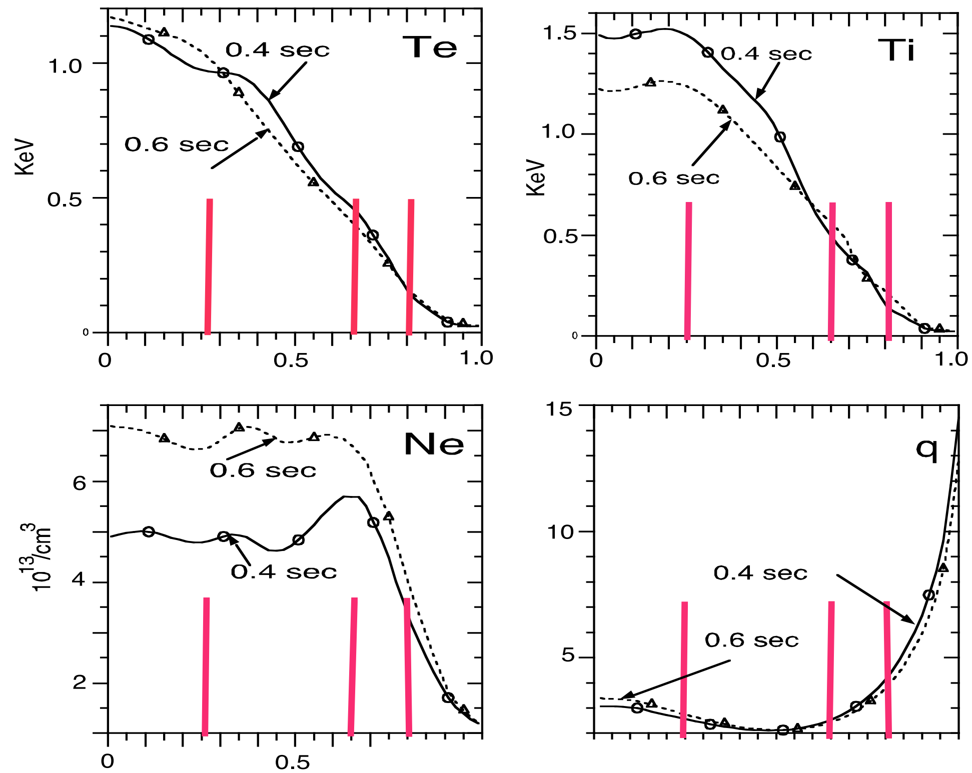
What clamps
Electron temperature profile?

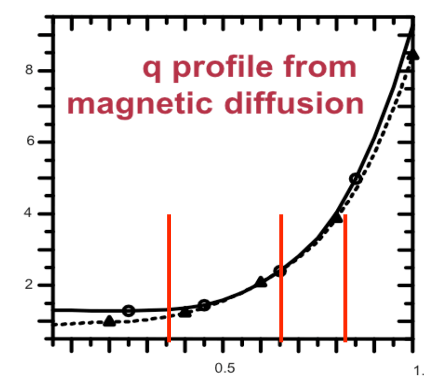
Examine microinstability
Growth rates at 3 zones

q profile: fit to external magnetic data

a) partial kinetic EFIT model
b) magnetic diffusion model

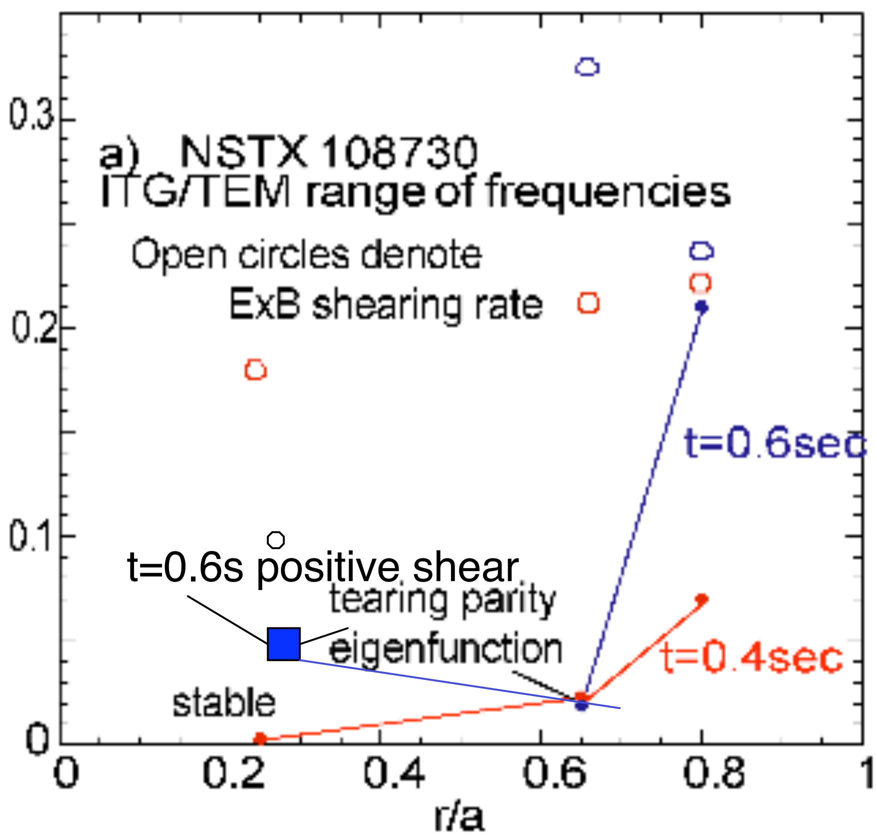
Need MSE measurement

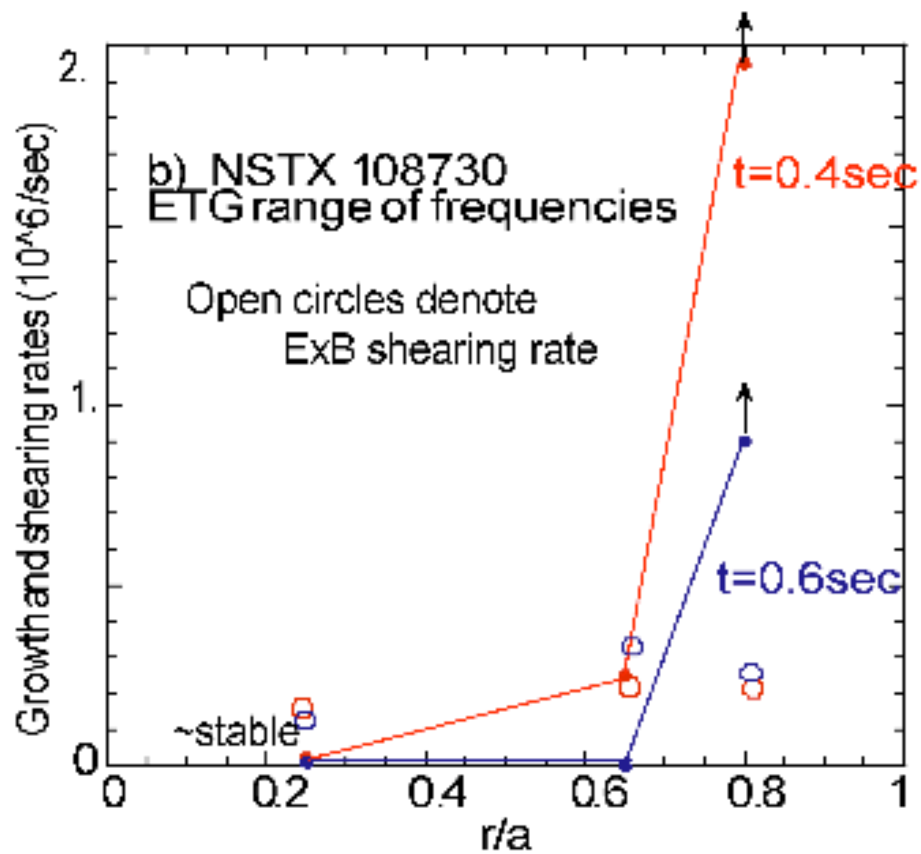




NSTX: Examine ITG and ETG Microstability

Find: tearing parity eigenfunction, with broad wave vector spectrum $\gamma(k_\perp r_i)$
ITG instabilities, with symmetric eigenfunctions and parabolic $\gamma(k_\perp r_i)$





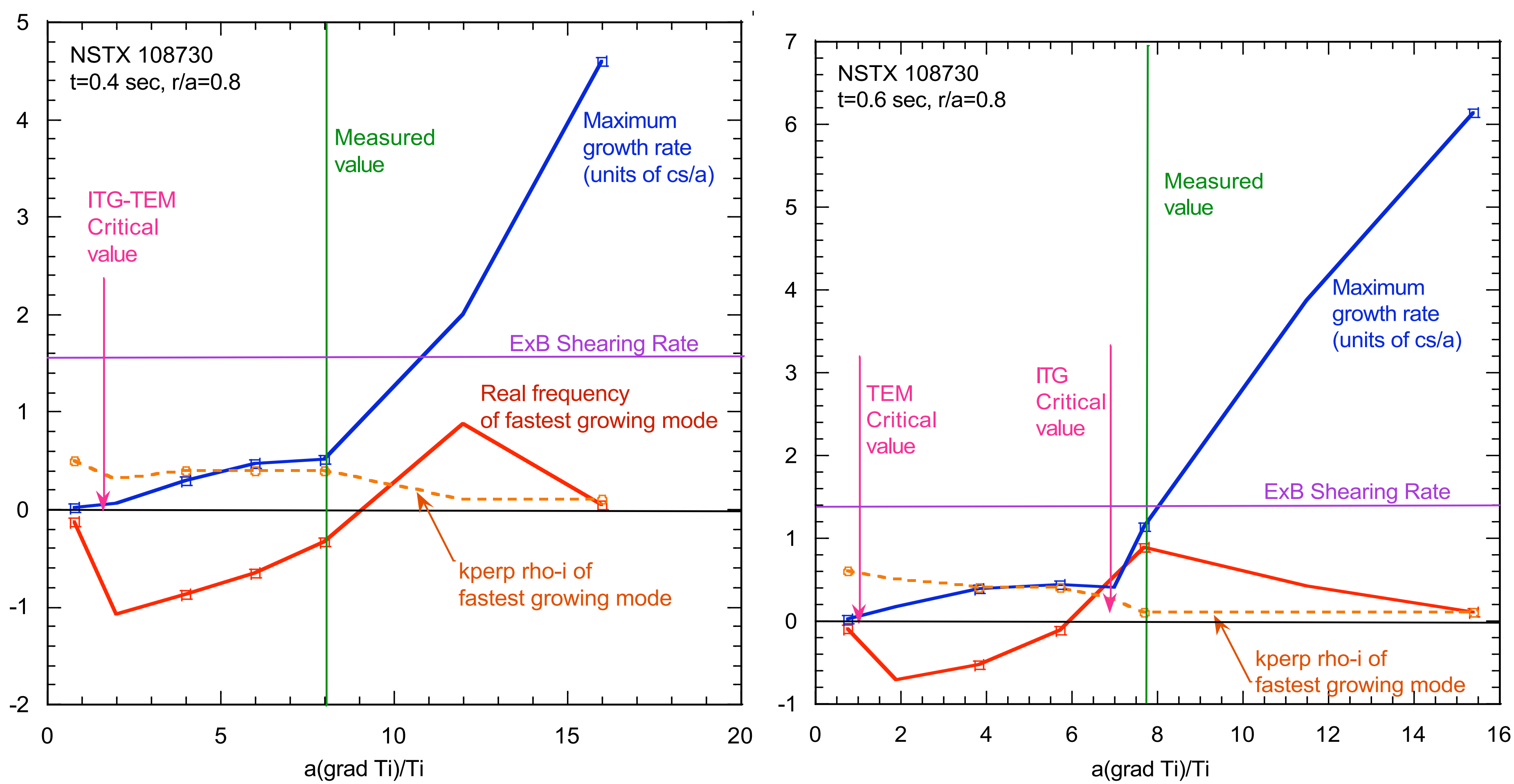
NSTX ITG Near Marginal Stability at 0.8r/a

With 25% error bars on shearing rate, ITG possibly stable with $2\text{–}3\gamma^{ITG} > \omega_{ExB}$ criterion

What should be the criterion for ITG stability?

Dimits (PoP 2001) requires $4\gamma^{ITG} > \omega_{ExB}$

Nonlinear Calculations including ExB shear would resolve this

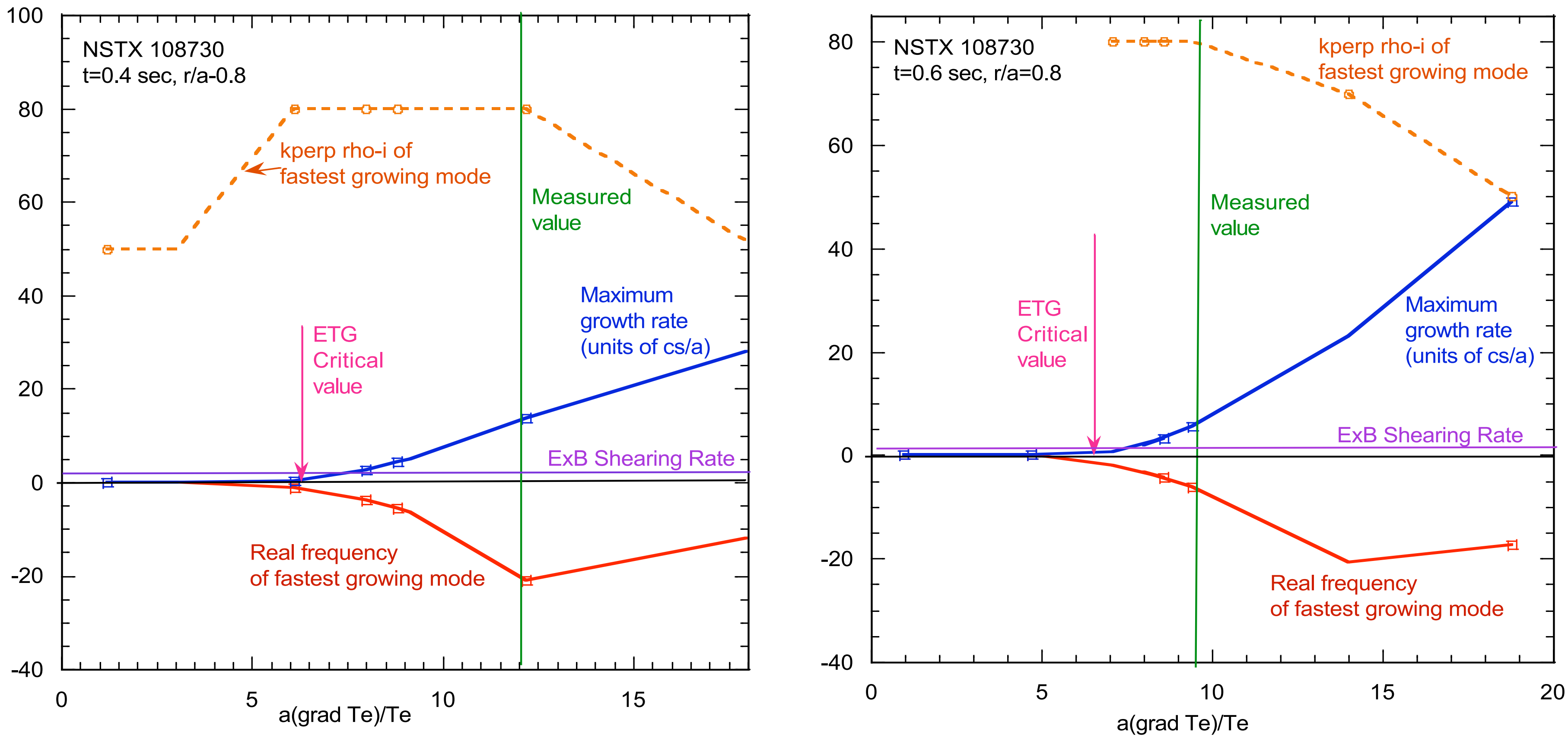


NSTX: ETG Instrinsically above Marginal Stability

At Plasma Edge: $\omega_{ExB} < 2\gamma^{ITG}$

Fastest Growing ETG Drift Mode Wavelengths and Growth Rates Decrease as $a(\nabla T_e)/T_e$ is Reduced

Higher Critical Gradient for ETG than TEM, Similar to ITG



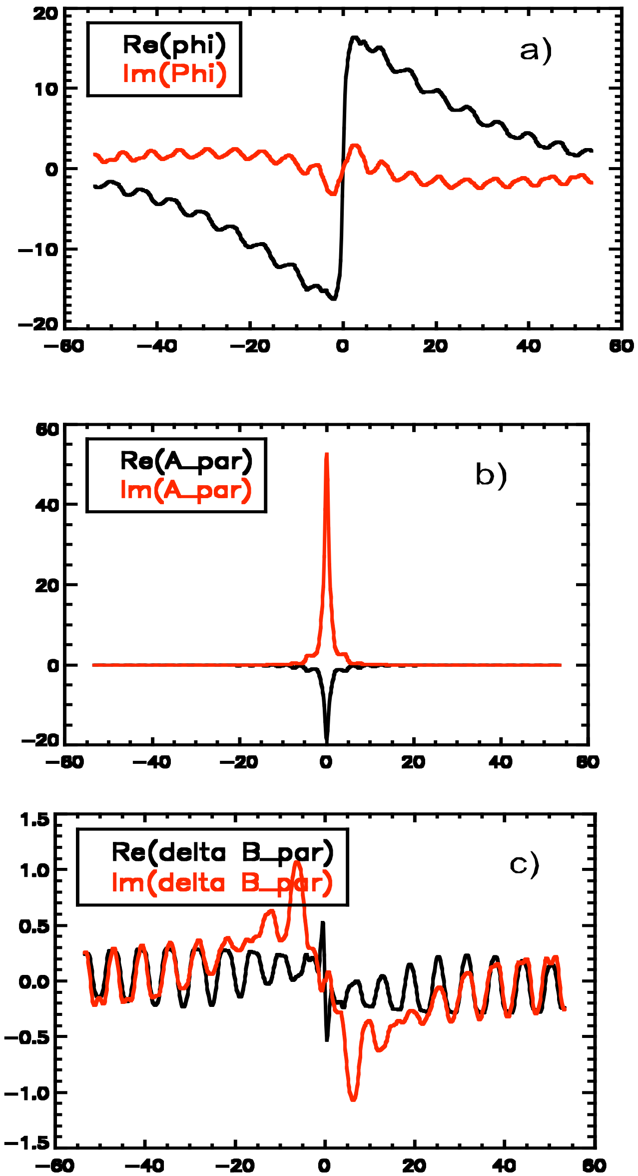
Convergence tests

Eigenfunctions of electrostatic
and electromagnetic fields
for 0.6 sec and r/a= 0.25
at $k_{\perp}\rho_s$=0.5

Seventeen 2π extent
of field line length needed
to confine eigenfunctions

Corresponds to a very large
radial width in the
simplest approximation
width of $A_{//}=\Delta\theta \sim 1$radian

Resonant trapped particle instability
at each field period

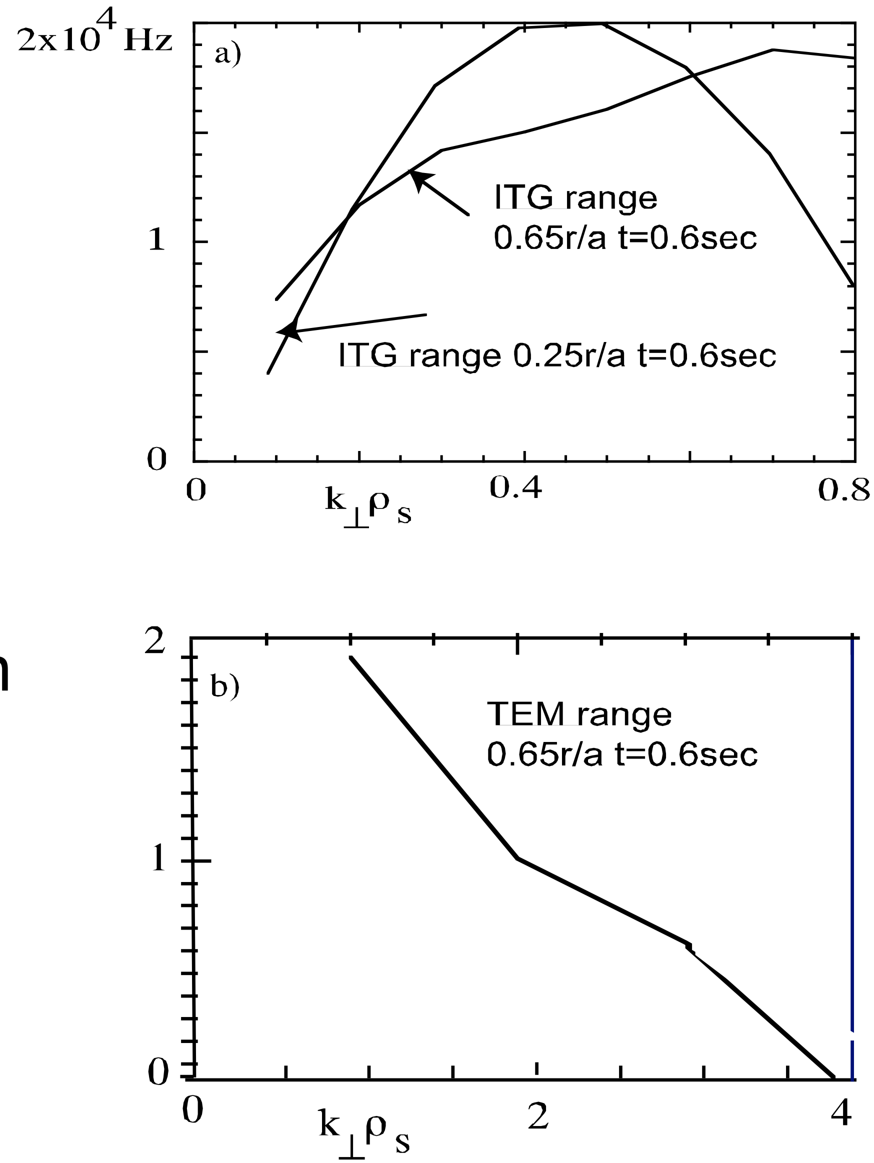


Broad spectrum of unstable modes

What causes
high electron diffusivity?

Plasma core:
Find only long wavelength
microstabilities:
neither ITG nor ETG,
exhibit tearing parity,
rotate in electron drift direction

At 0.65r/a modes extend
To smaller wavelengths than
At 0.25r/a



Connor Condition Satisfied for Linear Instabilities

Connor, Cowley, Hastie (1990) examined linear instability conditions

for tokamak microtearing mode in the intermediate collisionality regime

For $\eta_e,\eta_i=\infty$, instability occurs only if $\partial_r T_i > \partial_r T_e$. Dispersion relation:

$$\frac{\gamma}{(\omega_{*e}^{T})} = -\hat{C}_1 \lambda \ell n \lambda + \hat{C}_2 \sqrt{\frac{\varepsilon \nu_e}{\omega_{*e}^{T}}} - \hat{C}_3 \frac{\nu_e}{\omega_{*e}^{T}} - \hat{C}_4 \frac{\omega_{*e}^{T}}{\nu_e}$$

Broad spectrum: weak, well converged modes with tearing parity

$k_\perp\rho$=0.1 to 0.8 at r/a =0.25 at 0.6 sec and

$k_\perp\rho$= 0.1 to 1.0 at r/a=0.65 at both 0.4 sec and 0.6 sec.

Well converged, unstable modes with mixed parity

at higher wavevectors, up to $k_\perp\rho_s<2\text{–}3$ at r/a =0.65 at 0.4 and 0.6 sec.

At 0.4 sec, unstable growth rates at r/a =0.25 are smaller

and the modes, aside from $k_\perp\rho_s=0.1$, do not have tearing parity.

Connor condition is satisfied in NSTX core,

except r/a =0.25 at 0.4 sec, where no tearing parity mode was found.

What is the radial width of the μtearing mode?

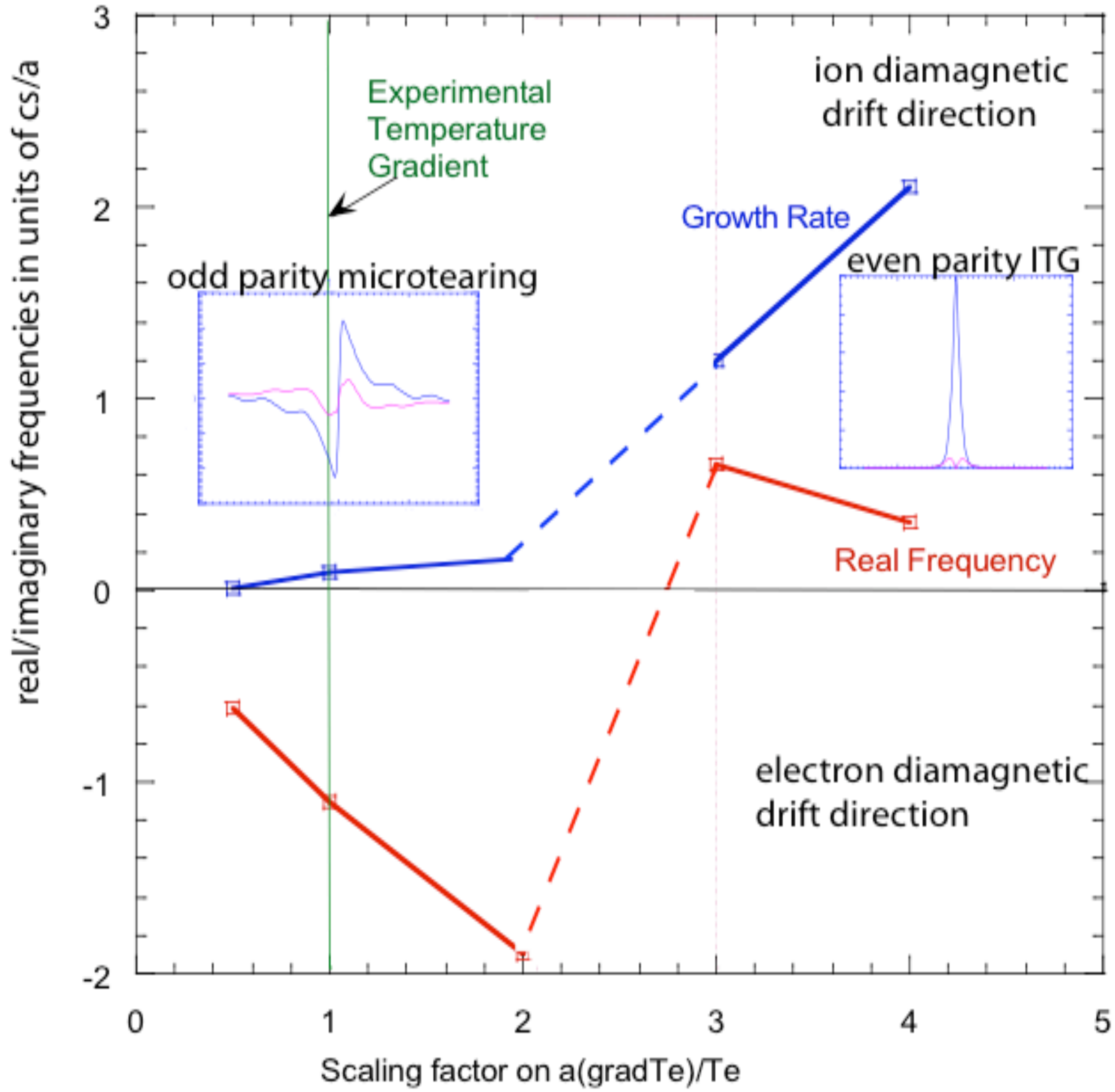
- Corresponds to a very large radial width in the simplest approximation

- Width of $A_{//}=\Delta\theta$ ~1radian. Estimate $<k_x>=<k_y>\cdot rq'/q\cdot\Delta\theta$.
  With $<k_y> = 0.5/\rho_s$, rq'/q = 0.15, $\Delta\theta$ = 1.2 radians,
  Then $\Delta x=2\pi/<k_x>=84\rho_s\sim 84\rho_i$.

- Near the plasma core ρ_i = 0.017 m,
  leading to the radial width of the tearing mode:
  $\Delta r_{tearing}$~1.4 m > a_{mid}=1.2 m, the plasma minor radius.

- More detailed calculations are needed
  to properly answer this question.

Microtearing Instablity at 0.65r/a: effect on NSTX transport?



Without collisions,
the twisting parity,
electrostatic mode
becomes dominant.

NSTX: 108730 Good ion confinement correlated with ITG stability

Poor electron confinement: core μtearing, edge ETG
Resilient Te profiles: likely due to unchanged
μtearing, ETG core driving forces ($a\nabla N_e/N_e$, $a\nabla T_e/T_e$)

If 2-3$\gamma_{lin} < \omega_{ExB}$ stabilizes ITG, ITG may be stable everywhere.
ω_{ExB} suppression of ETG and microtearing modes not yet known
Need MSE for q profile data.

t=0.4/0.6s	χ_i	χ_e	ITG,μtearing	ETG
r/a=0.25	$< \chi^{neo}$	$>> \chi_i$	stable/ unstable μtearing 0.02MHz	stable/ stable
r/a=0.65	$< \chi^{neo}$	$>> \chi_i$	unstable μtearing0.02MHz/ unstable μtearing 0.02MHz	unstable(0.36MHz)/ stable
r/a=0.80	$< \chi^{neo}$	$>> \chi_i$	unstable 0.07MHz/ unstable 0.22 MHz (ExB stabilized)	unstable 1.9MHz/0.9 MHz

Does ExB shear suppress microtearing instability?

II. Microstability Analysis of Five NSTX Plasma Conditions

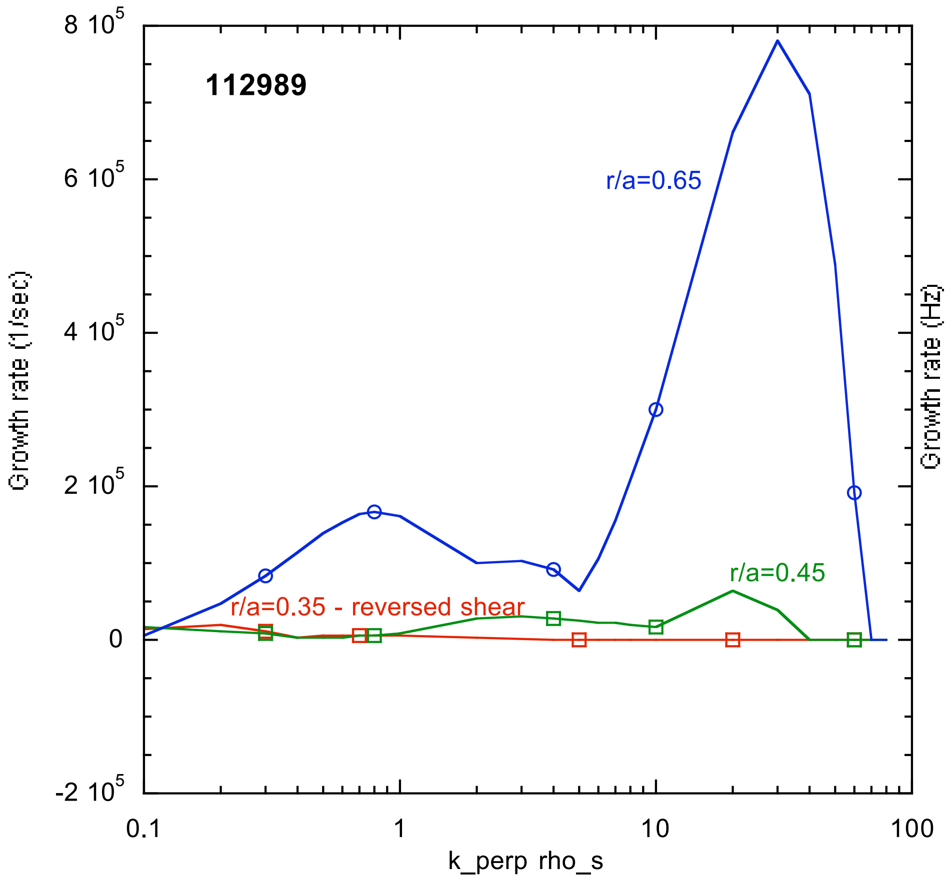
- Preliminary calculations

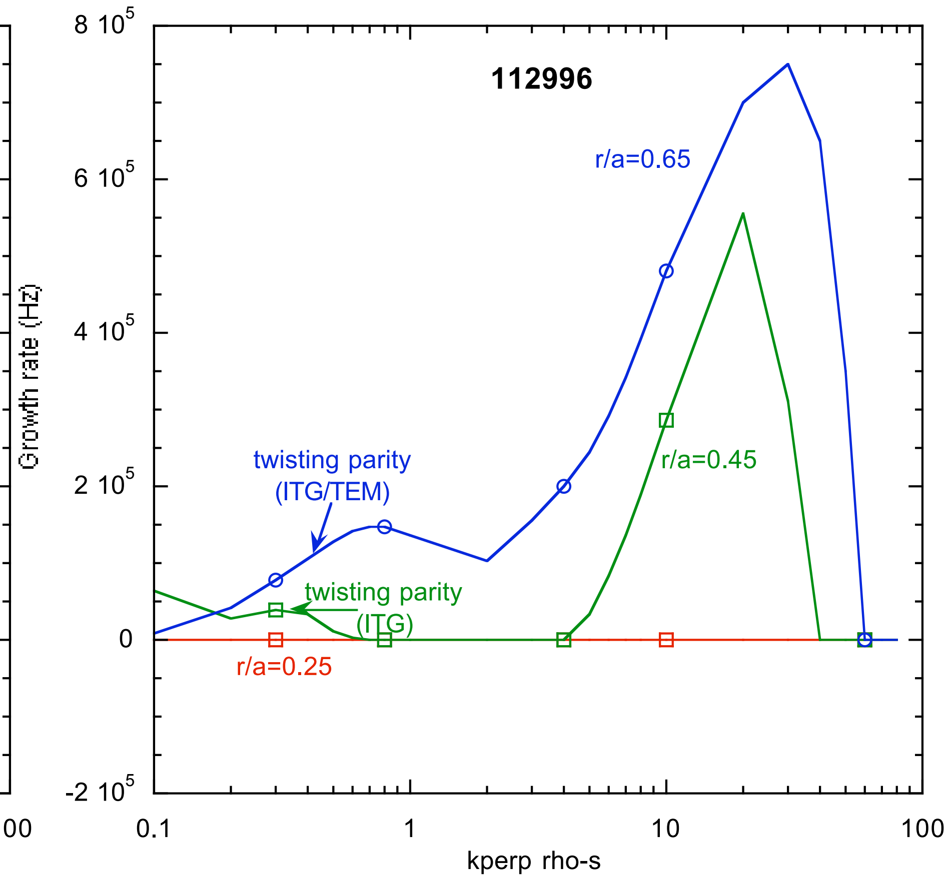
- Additional convergence studies needed

- q profile measurements needed

Low density L-mode

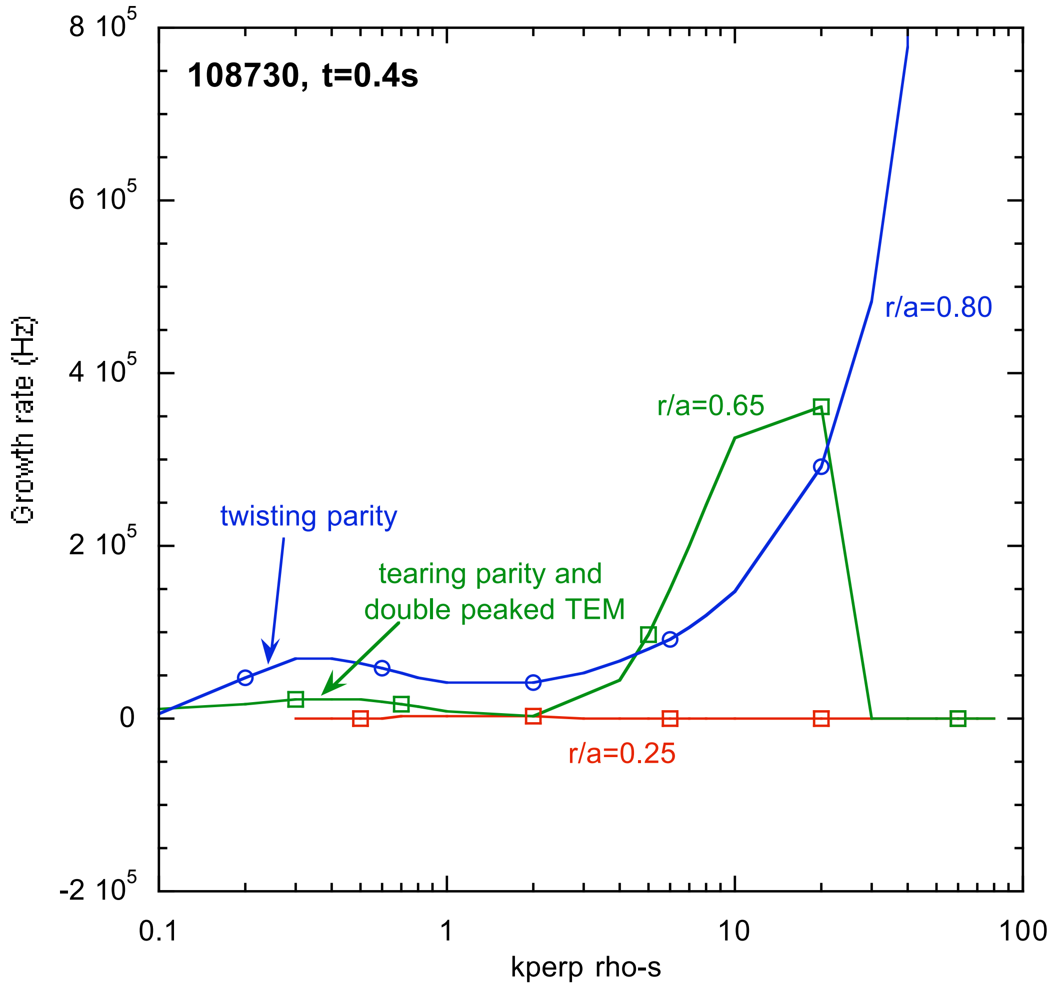
Fast ramp: TEM, ETG stabilized by q'<0 at r/a=0.35
μtearing stabilized, ETG weakened at r/a=0.45
Slow ramp: ITG-TEM, ETG unstable at r/a=0.45 for higher χ_e case





Non-elming, MHD quiescent, mid-density H-mode

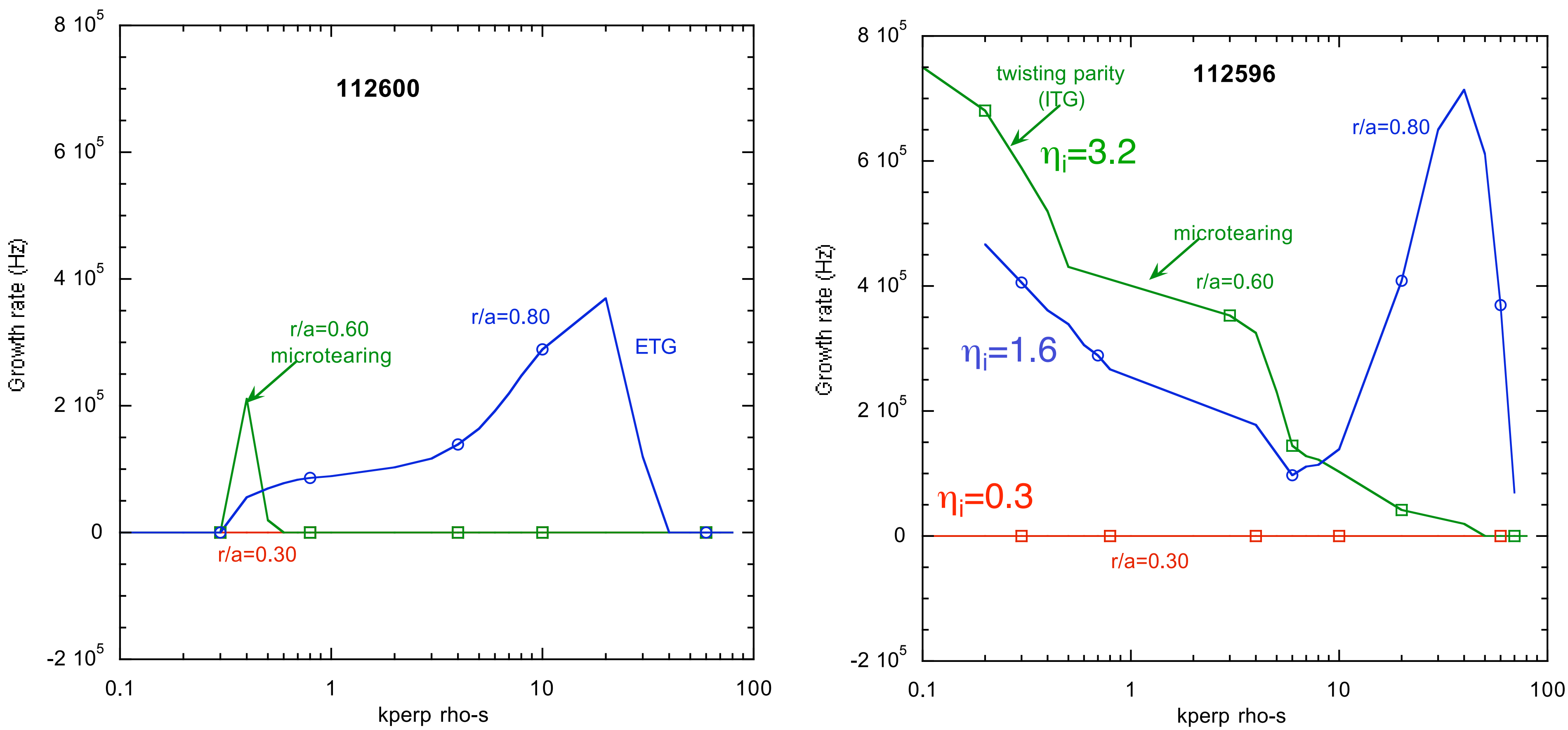
Microtearing unstable at midradius
ETG unstable at midradius and 0.8r/a,



High density H-mode

Midradius: Long λ microtearing unstable, ETG not strongly growing

At r/a=0.80 ETG unstable



Nonlinear Simulations are in Progress

NSTX

- Nonlinear simulations are in progress on
  NERSC's IBM SP RS/6000 supercomputer,
  using 336 processors on 42 nodes, with 4MB memory
  per processor and GS2 compiled for 64 bit addressing

- Computational domain: 758 million meshpoints
  in a rectangular box (at the outside plasma midplane)
  with 15 ρ in the x direction and 63 ρ in the y direction.

- Nonlinear terms evaluated on a grid with
  243 points in x and 27 points in y
  for 9 k_y modes ≤ 0, 161 k_x modes, after dealiasing.

- Generalize rule for determining the number of k_x modes:
  $N_x \leq (2\pi r q'/q) \bullet N_y \bullet (L_x/L_y) \bullet (N_p - 1)/2$
  when more than one field period for necessary
  eigenfunction connections. N_p=number of 2π field periods

CONCLUSIONS

NSTX

- Linear microstability analysis of ST experiments at high density show tearing parity electrostatic eigenfunctions (Redi, EPS-2004)
  - For decades μtearing modes were suggested to lead to high χ_e
  - μtearing consistent with Connor, Cowley, Hastie PPCF 32 (1990) 799.

- Calculations: μtearing mode is subdominant to twisting parity under collisionless conditions (Redi, EPS-2003)
  - NSTX experiments: low density ST plasmas
    > have reduced electron losses (Stutman, IAEA-2004, APS invited)
    > microstability calculations: μtearing weaker, ETG unstable
  - "Edge" modes r/a>0.5 on NSTX are tokamak-like, twisting parity
  - High density H-mode: high χ_e, strong μtearing mode

- η_i fluctuations <0 in H-mode experiment
  - Microstability η_i scan suggests tearing microstabilities present

- Nonlinear calculations require considerable resources; are in progress.