M3D linear ELM benchmark with ELITE and NIMROD

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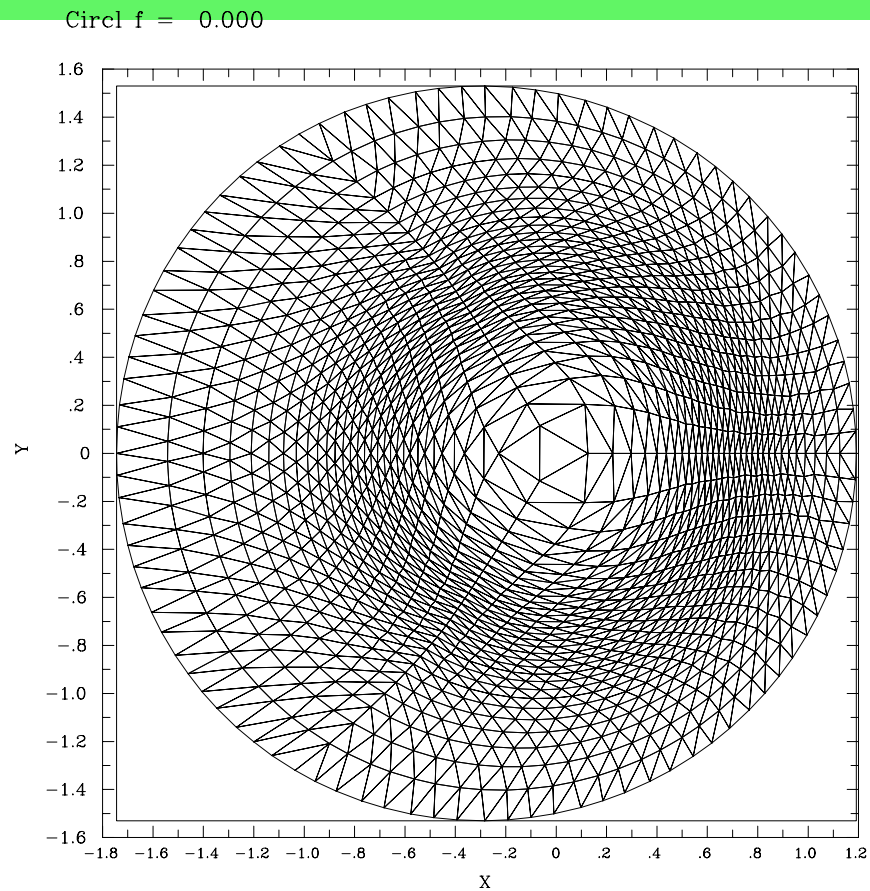
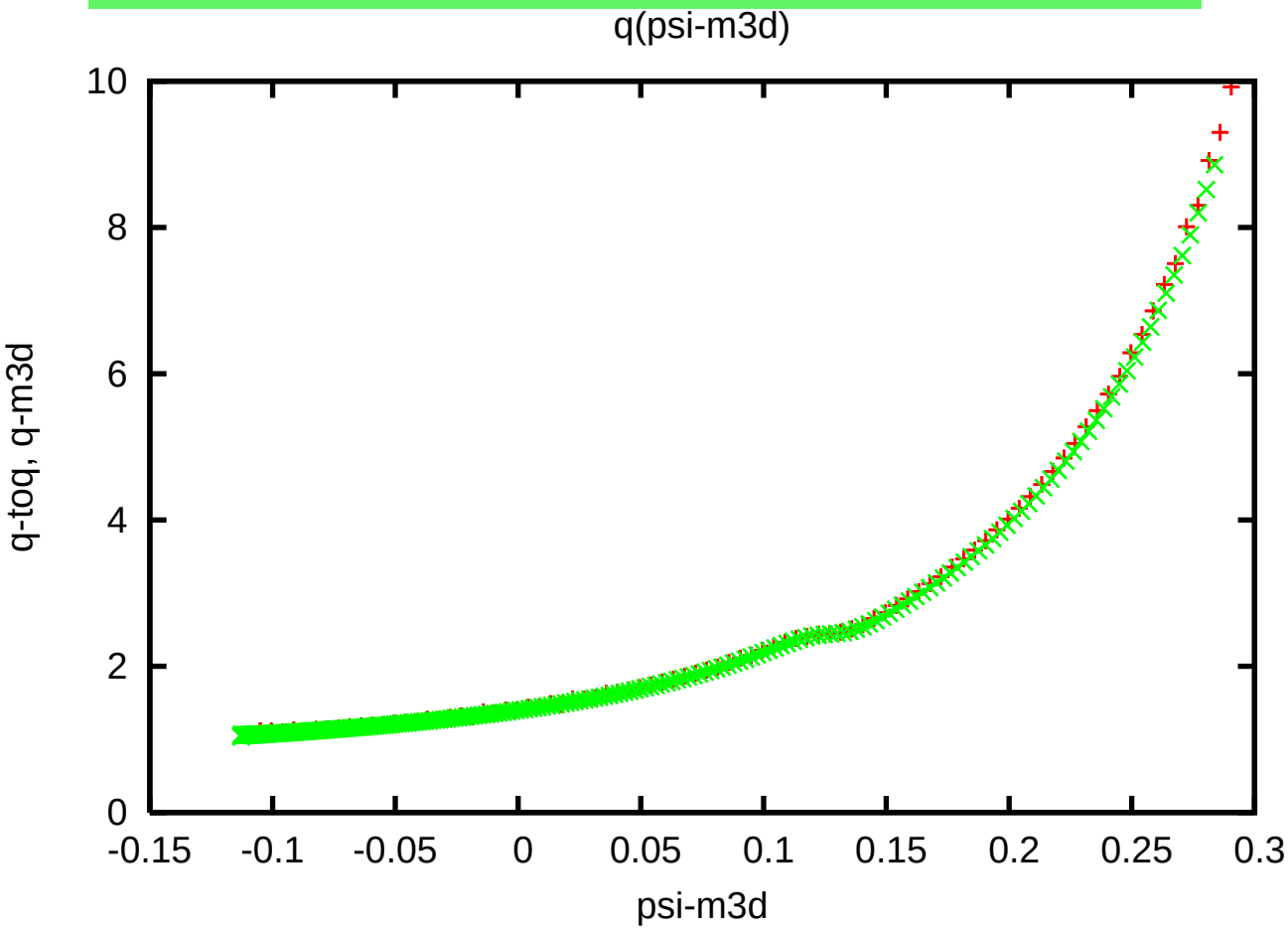
TOQ equilibrium

- TOQ equilibrium krbm1.dskdcon provided by P. Snyder, S. Kruger
- Interpolate from TOQ asc file
  - M3d mesh interpolated from TOQ mesh (shown at low resolution)
  - Transform to M3D units
  - verify M3D equilibrium

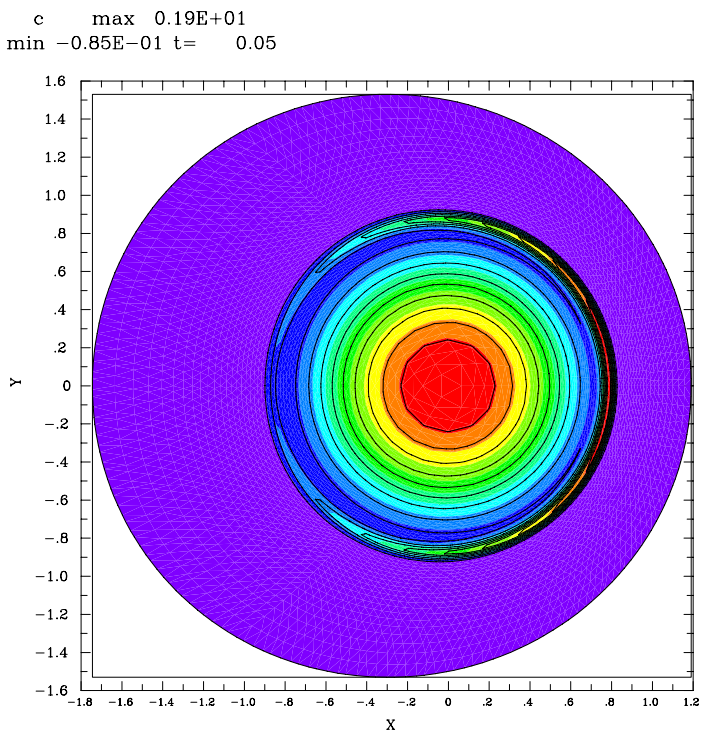


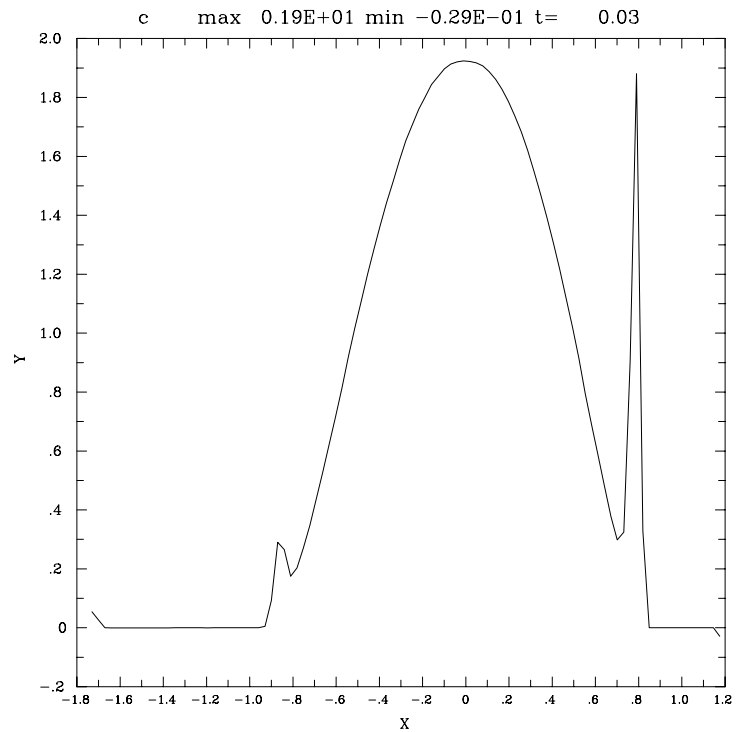
Q profile



- Toq and M3D q profiles agree
- Need to check beta agreement

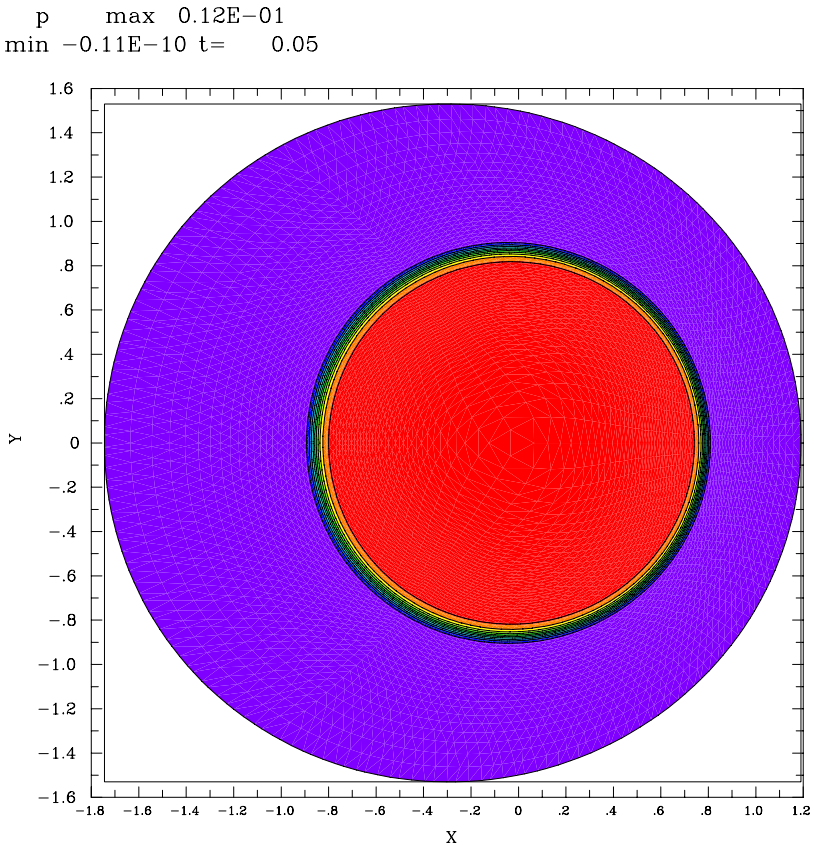
Toq equilibrium
Current and current profile

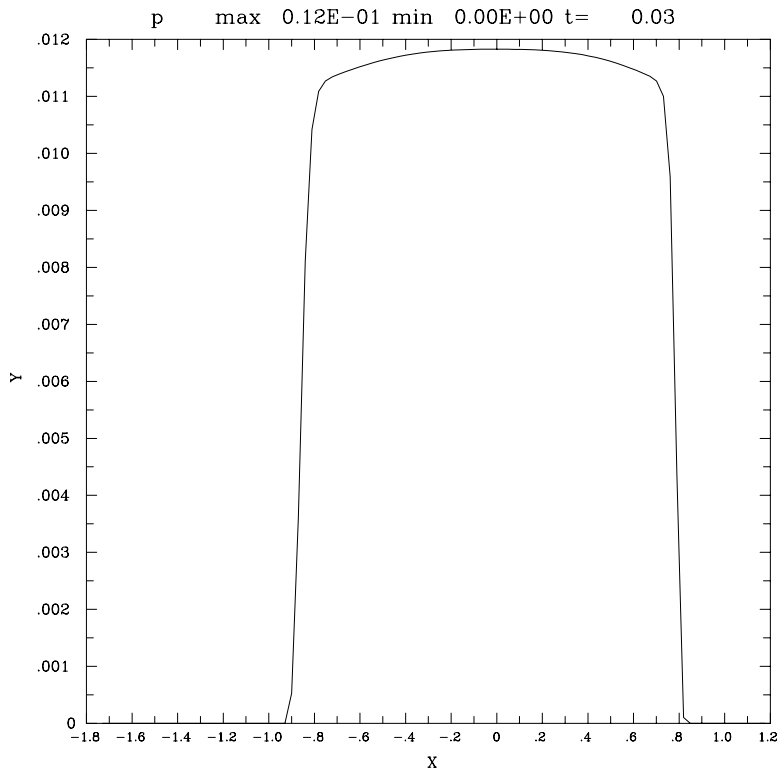




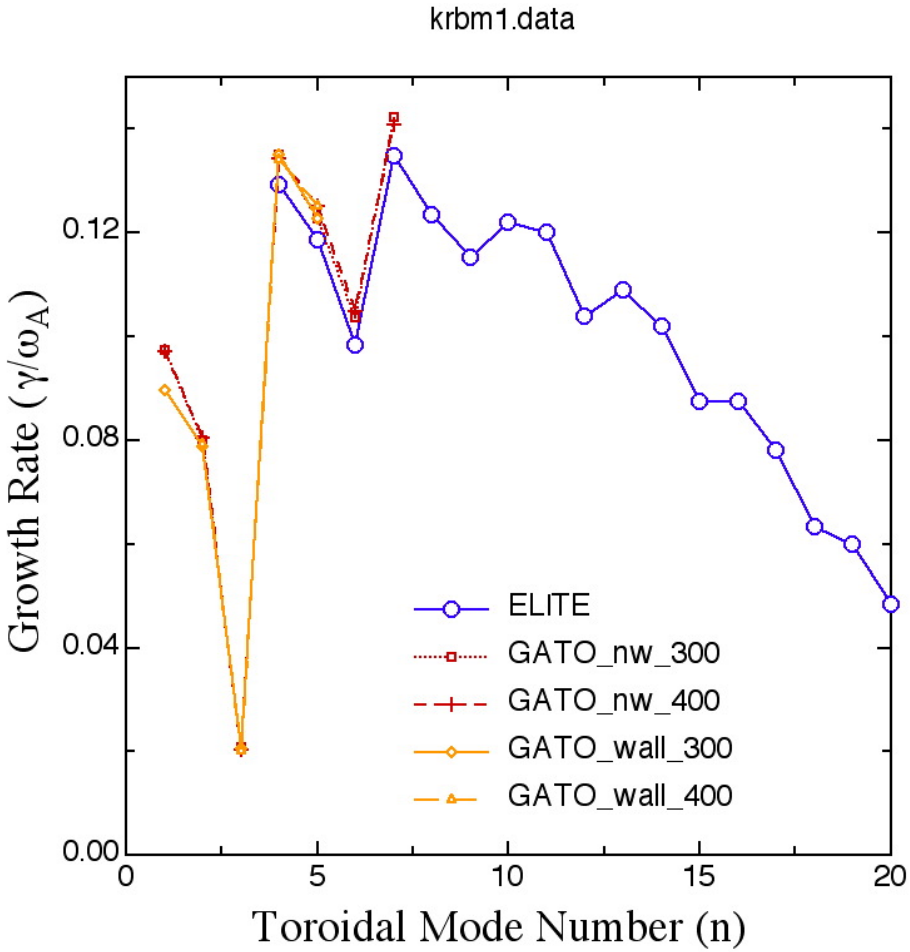
Toq equilibrium

pressure and pressure profile





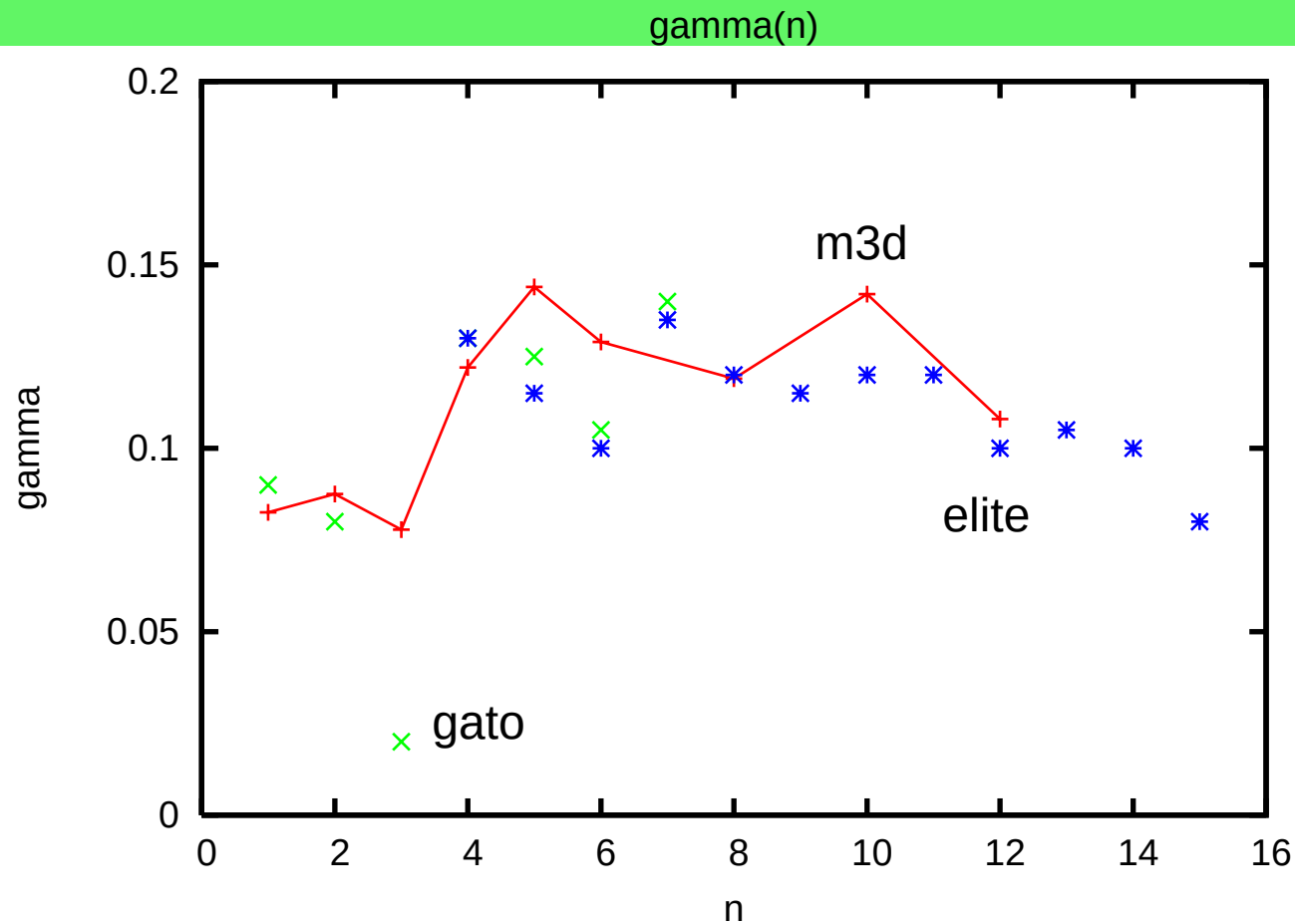
Benchmark case: ELITE linear growth rates



M3d linear stability

- Resistivity profile is important
  - Used a step function resistivity with step very close to the bottom of the pressure (temperature) pedestal
  - Growth rates are sensitive to
    - Outer (“vacuum”) resistivity
    - Resistivity profile (location of the step)
- Higher resolution needed
  - In progress

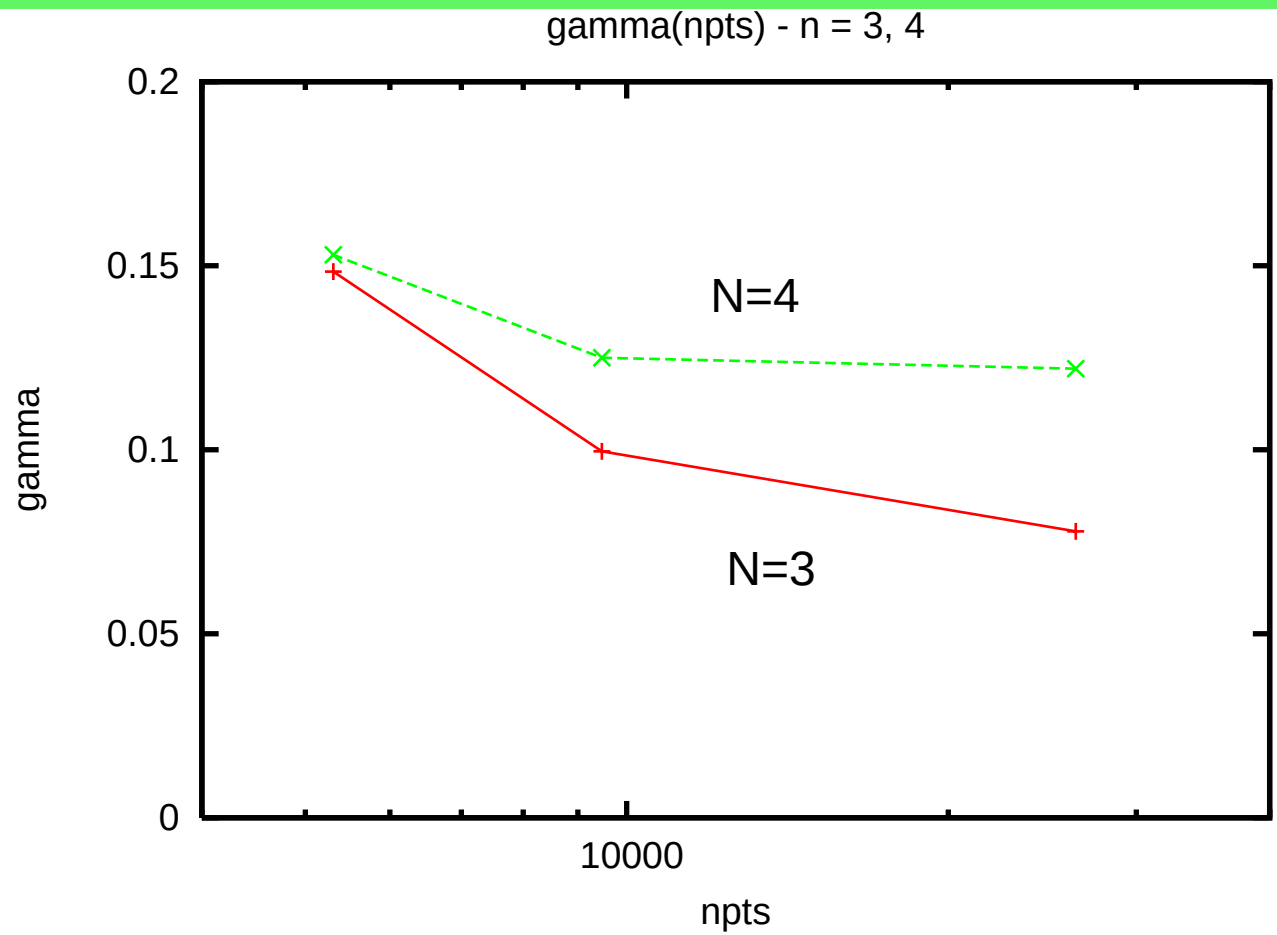
Benchmark: M3D growth rates



Comparable, but larger disagreement for low n(?) eg n = 3.

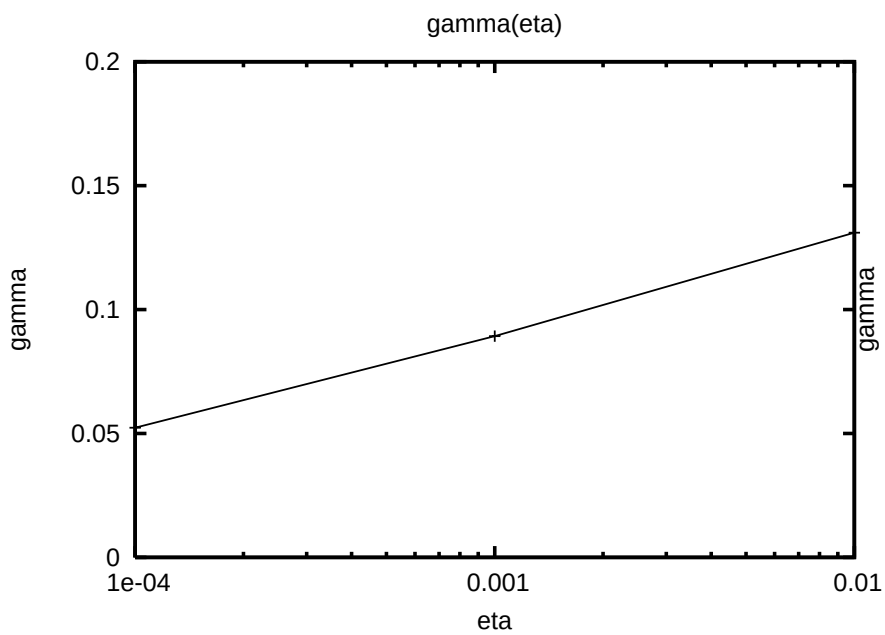
$$\eta_{inner} = 10^{-6}, \eta_{outer} = 10^{-2}$$

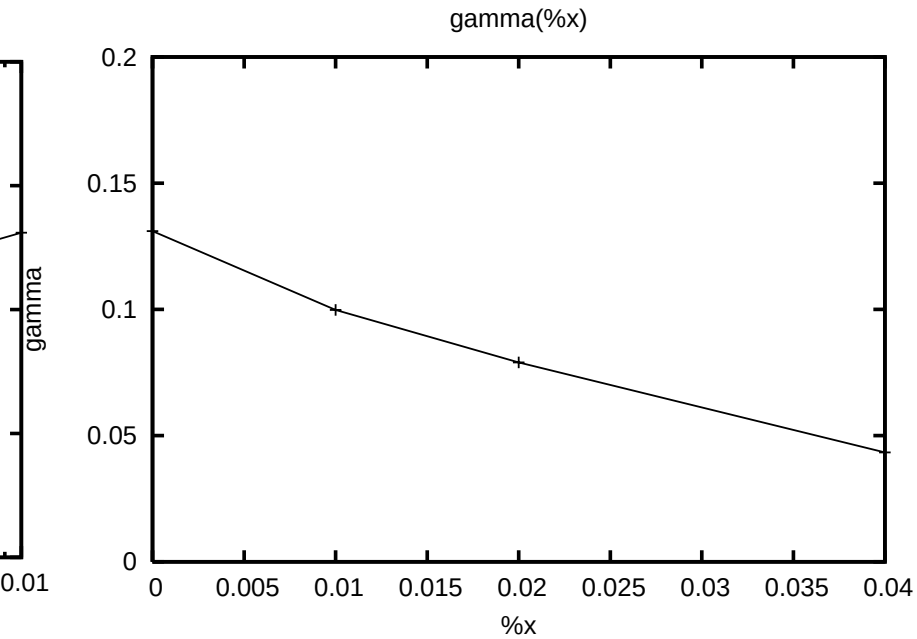
Convergence of n=3 growth rate



N=3 is sensitive to resolution
N=4 converges much better
Resistivity profile kept fixed

Effect of resistivity profile on n=3 mode growth rate





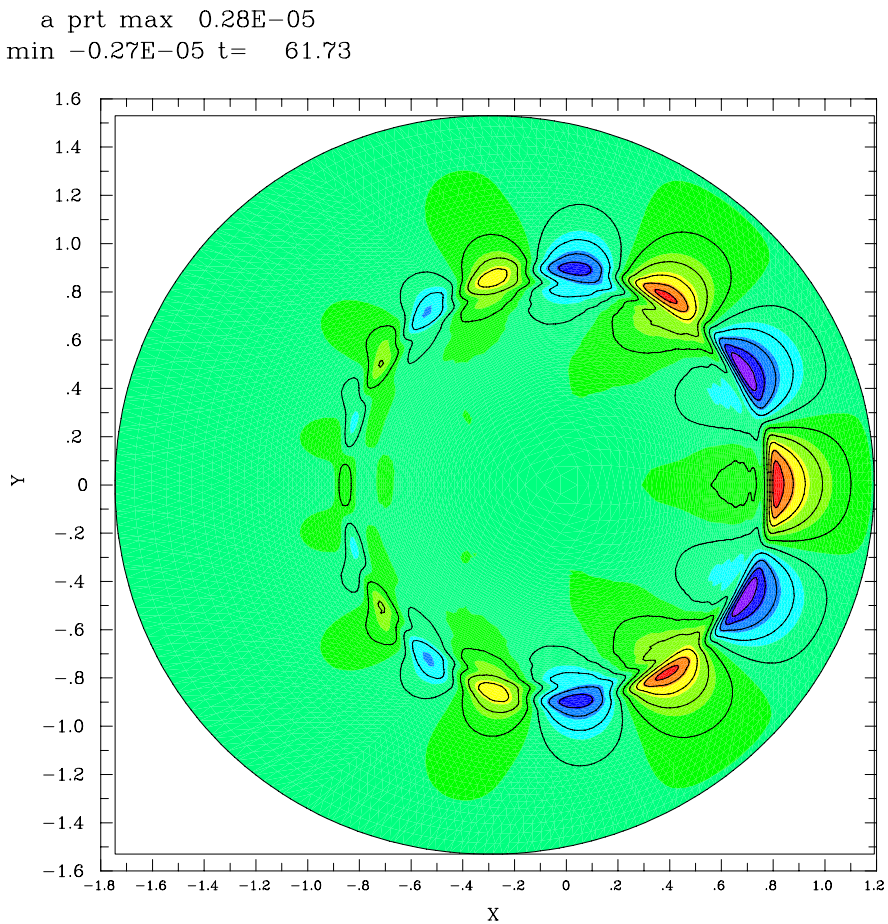
Vacuum resistivity

Vacuum position displacement

Resistivity profile has a large effect on growth rate

Mode structure, n=3

- **Changing resistivity and resolution has some effect on mode structure**
- **Shown: perturbed poloidal flux function psi**

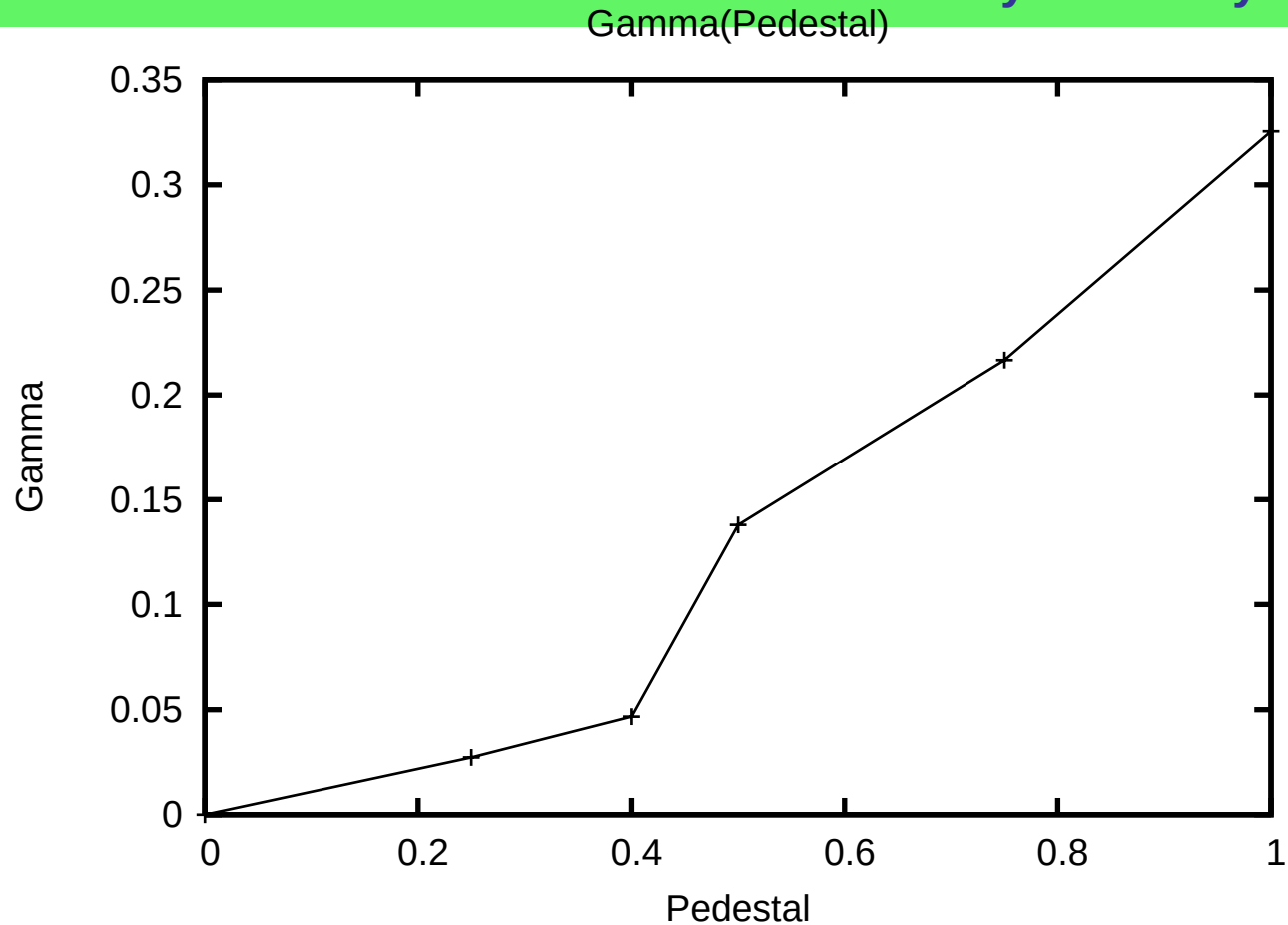


Stability boundary

- Growth rates of ideal unstable modes are comparable to resistive modes (for low to medium n)
- Stability of ideal and resistive modes differ
  - Resistive tearing and ballooning modes have a different stability boundary from ideal modes
    - can be unstable for all beta
  - Ideal and resistive modes can be stabilized differently
    - ideal modes can be stabilized by gyroviscosity
    - Resistive modes can be stabilized by electron pressure and flow

Example of resistive stability

Growth rate of n = 9 mode in a sequence of equilibria
break in curve indicates ideal stability boundary



Fraction of XGC pedestal is varied from 0 to 1 in M3D
Calculate linear stability, resistive MHD model
$S = 10^6$ at top of pedestal, $S = 10^2$ at bottom of pedestal

Drift effects can lower resistive mode growth rates

- Two fluid drifts affect both ideal and resistive modes
  - Ideal MHD
  - Tearing / electromagnetic resistive ballooning (low n)
  - Electrostatic resistive ballooning (high n)
- Dispersion relations
  - Ideal modes stable at high n
  - Tearing / ballooning: can grow linearly in resistivity
  - Electrostatic RBM: can grow linearly in resistivity
- Stabilize resistive but not ideal:
  - Cold ions

$$\omega(\omega - \omega_{i*}) = -\gamma_{MHD}^2$$

$$\omega(\omega - \omega_{i*})^2(\omega - \omega_{e*})^3 = -i\Delta'\eta^3 k^6 \left(\frac{v_A}{qR}\right)^2$$

$$\omega(\omega - \omega_{i*})(\omega - \omega_{e*}) = i\Delta\eta k^2 \left(\frac{v_A}{qR}\right)^2$$

$$\omega_{i*} = 0$$

summary

- M3D benchmark is in “reasonable” agreement with ELITE
- Higher resolution needed for better agreement
- N=3 disagreement with GATO is puzzling
- Need to compare marginal stability with ELITE
  - Prepare a sequence of equilibria with varying pedestal gradient
  - Compare growth rate for, eg, n = 10
  - Stabilize resistive modes with two fluid and/or flow