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Extended MHD Effects on RMPs

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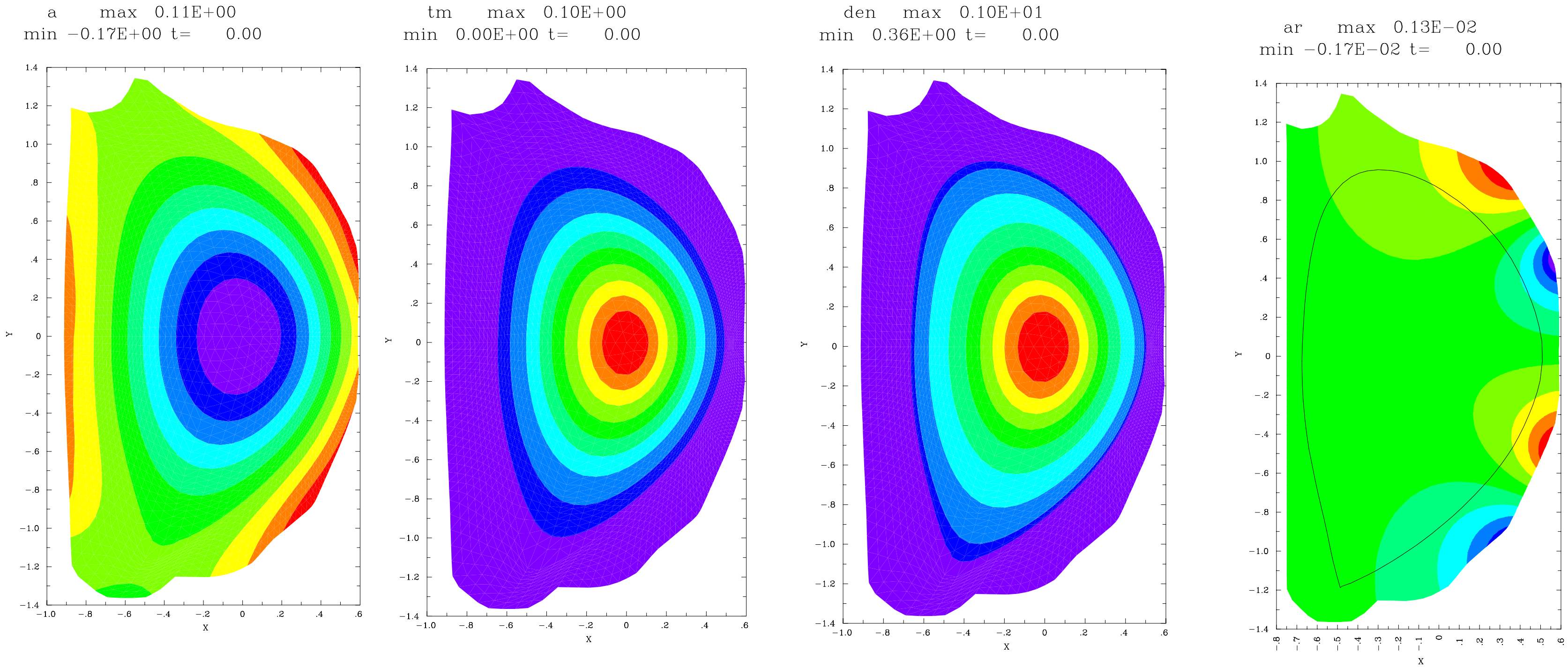
Outline

- Nonlinear MHD with RMP
- Coupling of RMP to resistive plasma mode
- Stabilization of mode and RMP screening
  - Toroidal rotation
  - 2 fluid
- Density pump out
- NSTX and collisionality

M3D MHD simulations – initial state

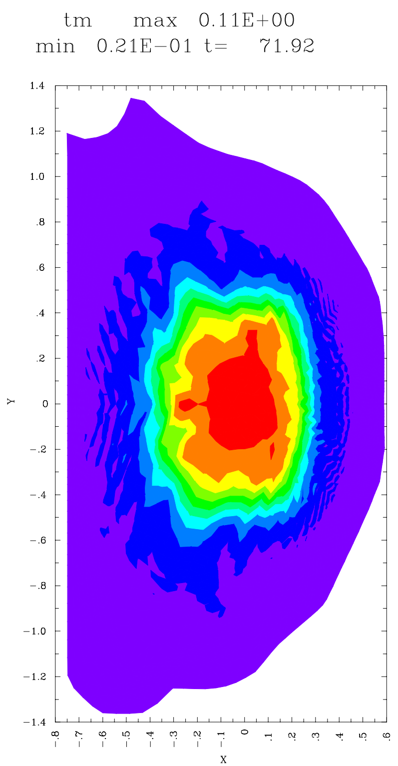
- M3D MHD simulations
  - Initialized from DIII-D eqdsk file of equilibrium reconstruction g126006



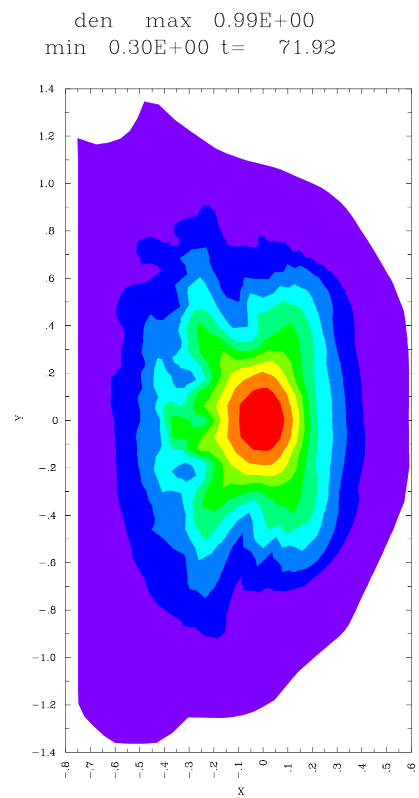
Magnetic flux temperature density N=3 flux

Effect of “vacuum” RMP

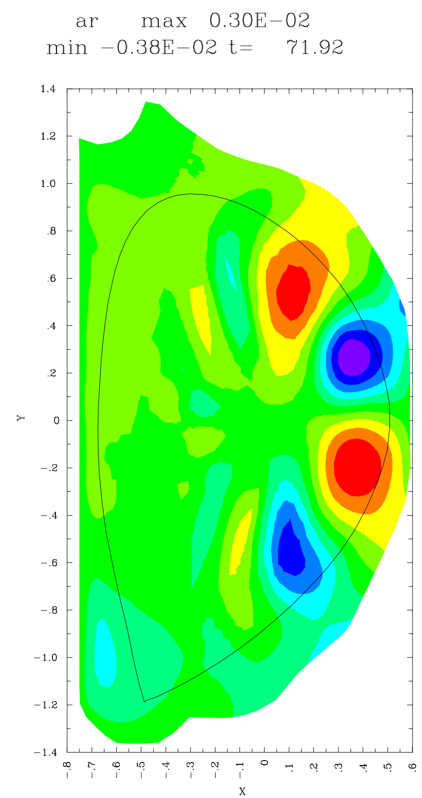
- MHD evolution of RMP is quite different from experiment
  - Initial state evolved until t=72 $\tau_A = R / v_A$
  - Rapid cooling due to large parallel thermal conduction
  - Slow density loss on stochastic magnetic field lines
  - RMP flux extends inward (plasma response)



Temperature



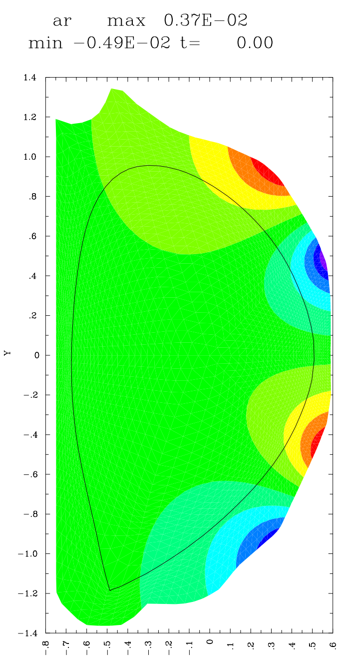
density



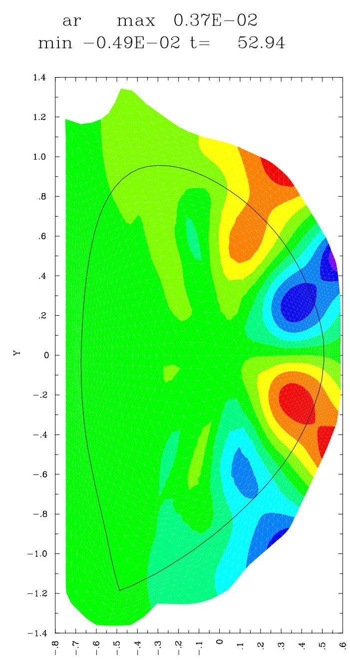
N=3 flux

Coupling of RMP to resistive MHD mode

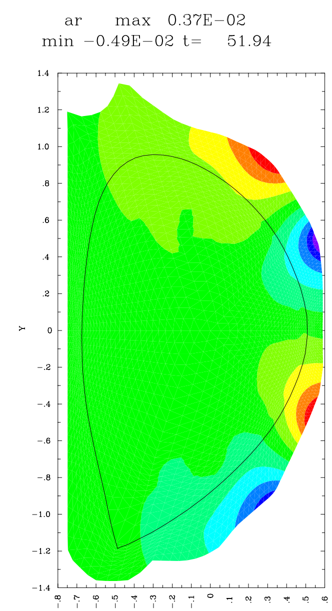
- the RMP appears to couple to a resistive MHD mode
  - RMP gets a helical component
  - Rotation and/or 2 fluid drifts suppress the mode, as well as screening the RMP



Vacuum RMP
N=3 Poloidal flux



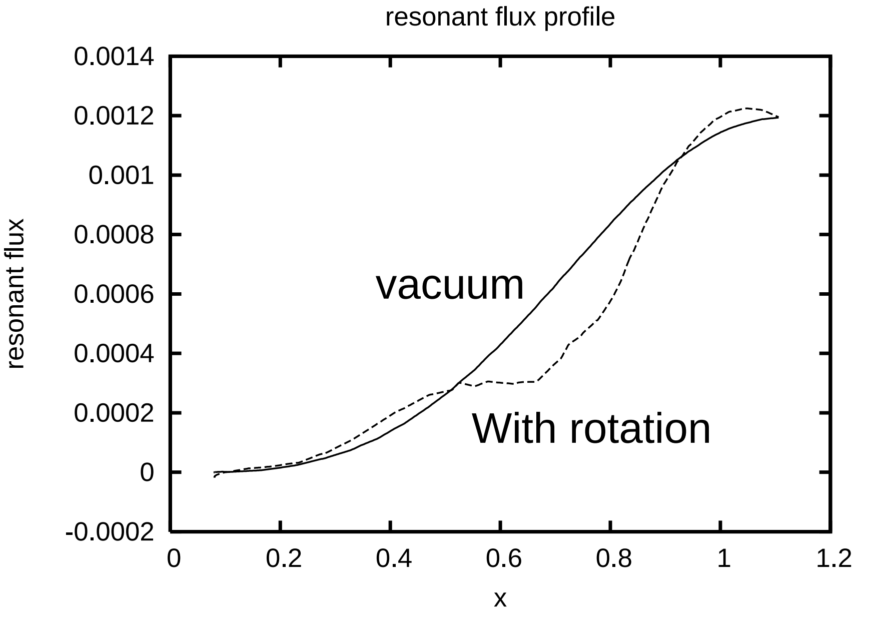
No rotation
Poloidal flux



Rotation suppresses
Mode and screens RMP

Effect of rotation on flux penetration profile

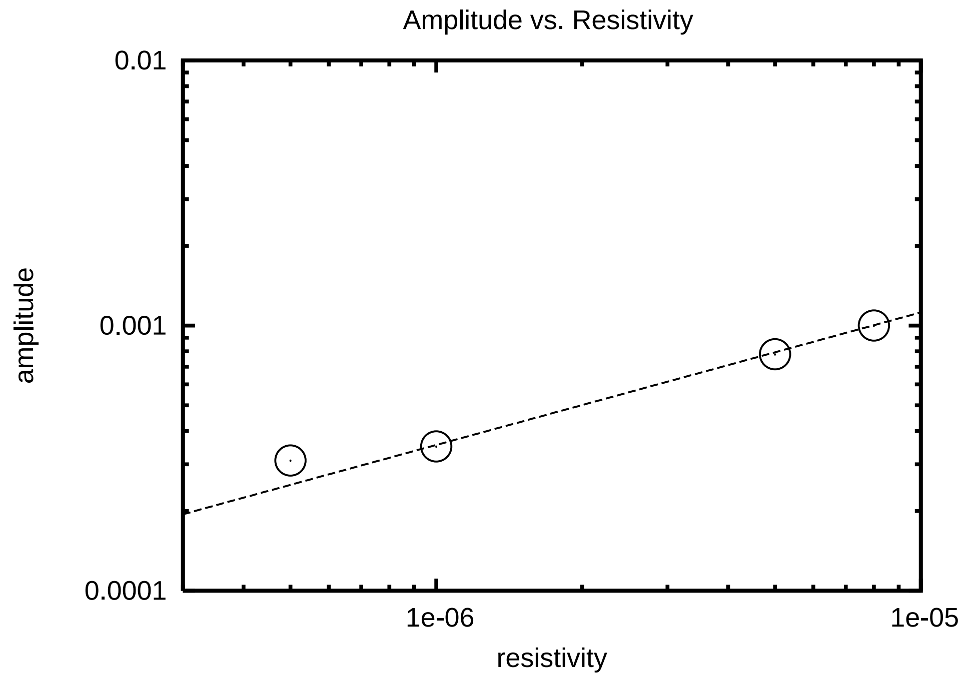
- Rotation excludes perturbed flux from the plasma
  - Profiles of perturbed flux along a ray from the magnetic axis to a point on the boundary where the flux is maximum
  - Solid curve: initial RMP flux, dashed curve: flux at t=52 with rotationl
- Flux penetration profile depends on rotation



Perturbed poloidal n=3 flux along a ray

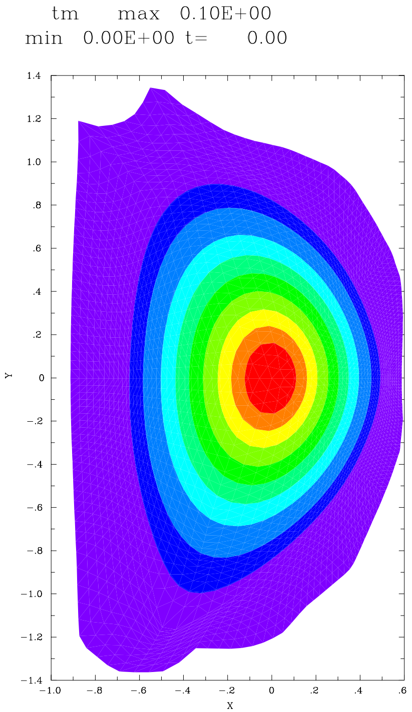
Mode growth depends on resistivity

- The mode growth rate appears to scale as the ½-1/3 power of resistivity
  - In the simulations a Spitzer – like self consistent resistivity is used which varies at temperature to the -3/2 power
  - Starting from the same initial state, the maximum amplitude of the n=3 perturbation out of phase with the vacuum RMP is measured at t=52

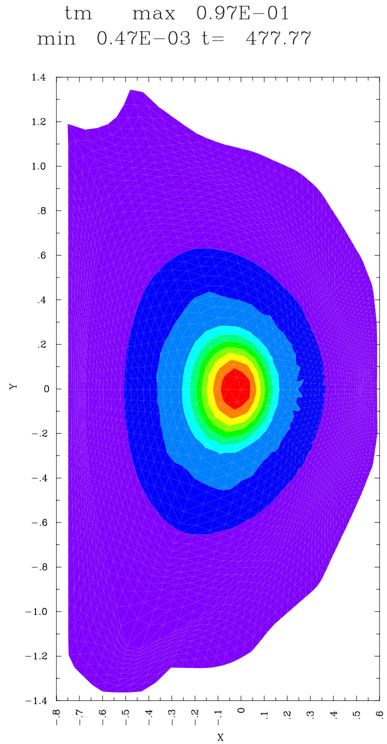


Resistive mode can be excited without RMP

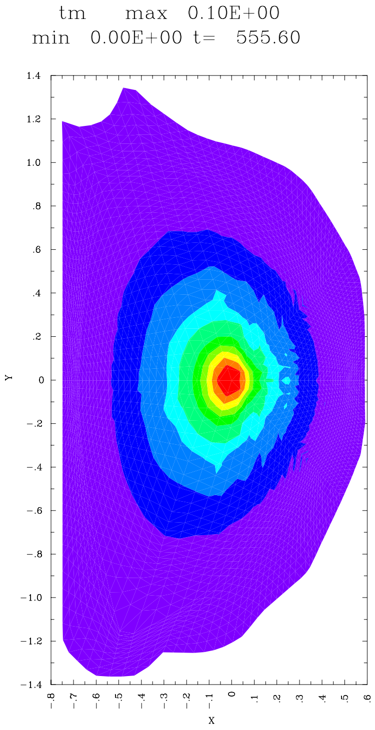
- Resistive mode is excited by the RMP, or by initial perturbation with no RMP
- Long time simulations show relaxation to saturated state
- Nonlinearly it has a similar effect to the RMP



Temperature
T=0

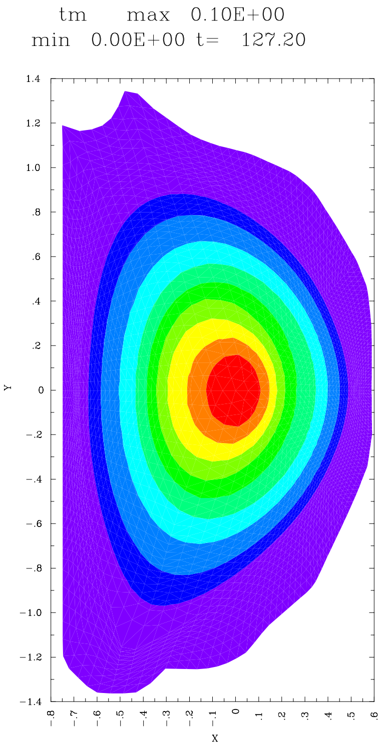


Temperature
Mode excited by
RMP t=478

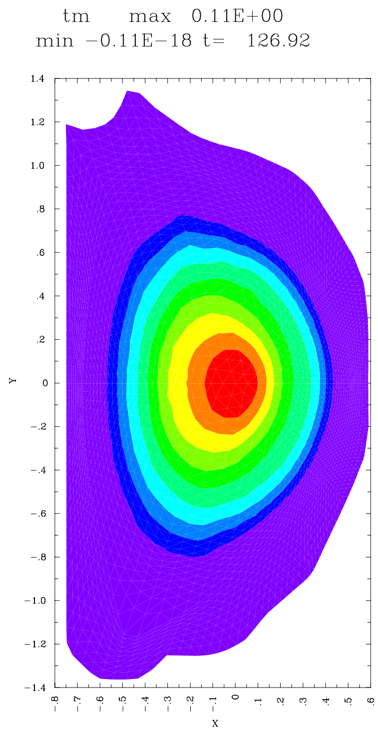


Temperature
Mode excited by
initial perturbation
T=555

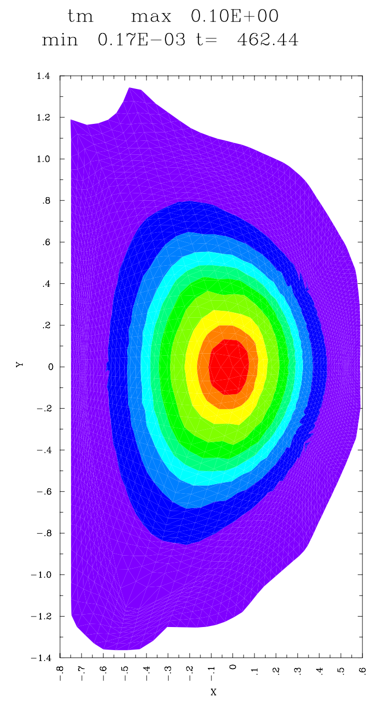
rotation and/or two fluid drifts suppress mode and screen RMP



Temperature,
Rotation, no RMP



Temperature,
Rotation, RMP



Temperature,
Two fluid, RMP
No toroidal rotation

rotation: about 3X DIII-D experiment

2 fluid: $H = c/(\omega_{pi} R)$ = 0.1 = 5X DIII-D experiment, η = 100Xexperiment
Equal ion and electron temperatures

$$\omega_* \approx \gamma \sim \eta^{1/3}$$

Collisionality effect on resistive instability

- The resistive mode growth rate / drift frequency is the collisionality. Assume for simplicity the growth rate scales as ½ power of resistivity

$$\gamma_r = \Delta' \eta^{1/2} k \left(\frac{v_A}{R} \right)^{1/2}$$

$$\omega_* = k \rho_s \frac{c_s}{L}$$

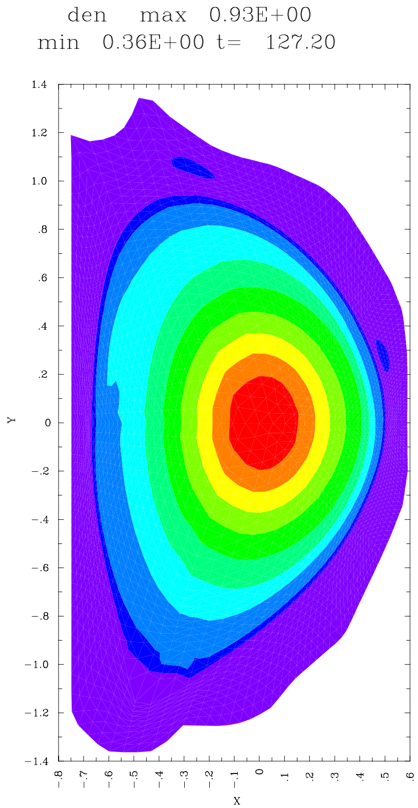
$$\frac{\gamma_r}{\omega_*} = \nu_*^{1/2} \frac{\Delta' L}{\beta_e^{3/4} R} \approx \nu_*^{1/2}$$

Resistive modes are stable for $\nu_* < 1$

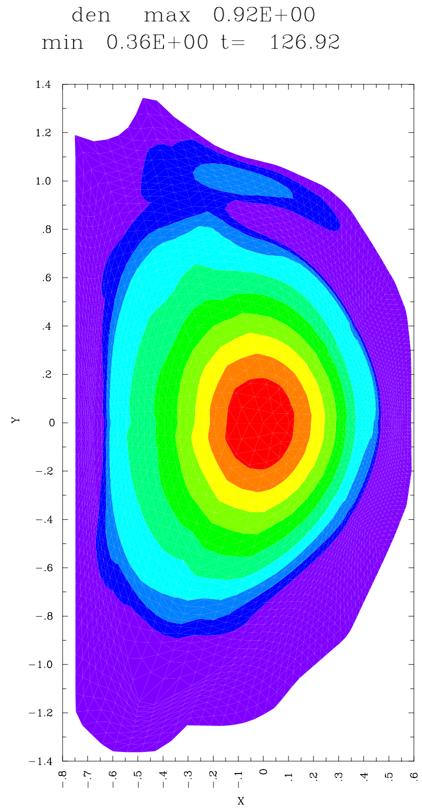
Collisional regime ELMs could be resistive modes
- no sharp threshold
- stabilized by two fluid drifts

Density pumpout with toroidal rotation or two fluid drifts, and RMP

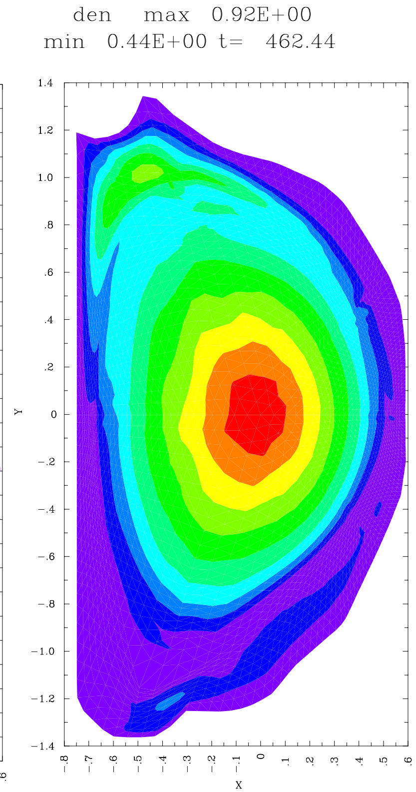
- With toroidal rotation or two fluid drifts there is density loss even without the RMP. With the RMP the loss is enhanced. Density perturbations on open field lines tend to flow to an x-point
  - In this case there is an x-point at the top, outside the boundary, as well as at the bottom
  - There is also density loss because of (screened) RMP stochastic layer, as with no rotation



Density with rotation but no RMP



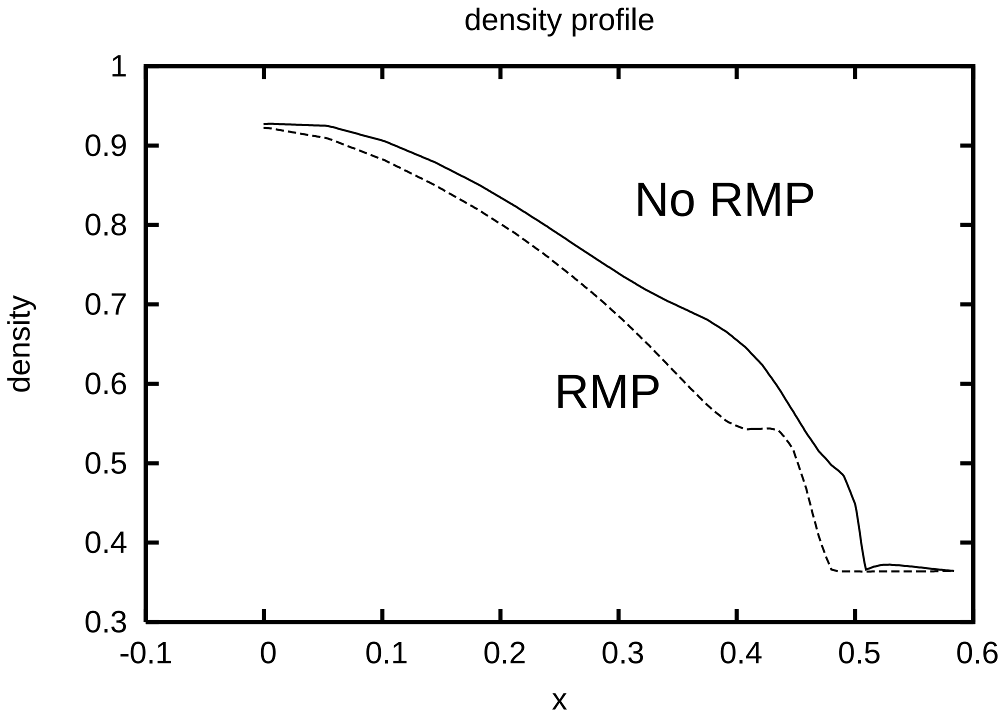
Density with Rotation and RMP



Density with 2 fluid and RMP

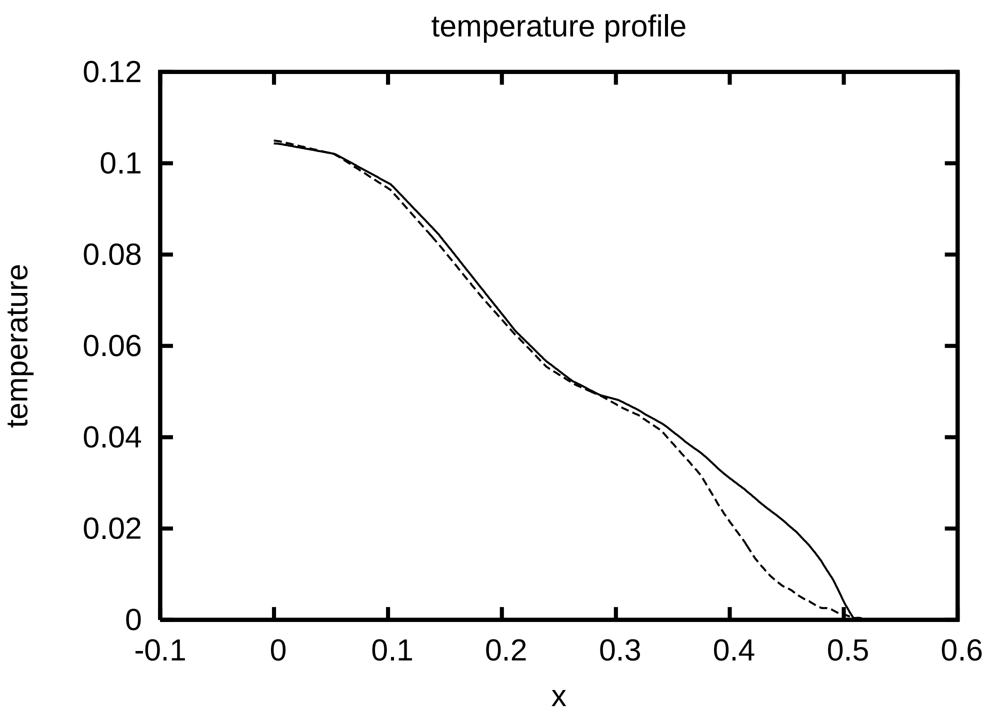
Density profiles with toroidal rotation and RMP

- Density profiles along the midplane are compared with toroidal rotation with and without the RMP. In comparison to the temperature perturbations, the density perturbations extend into the plasma core
- The core density loss is small compared with experiment



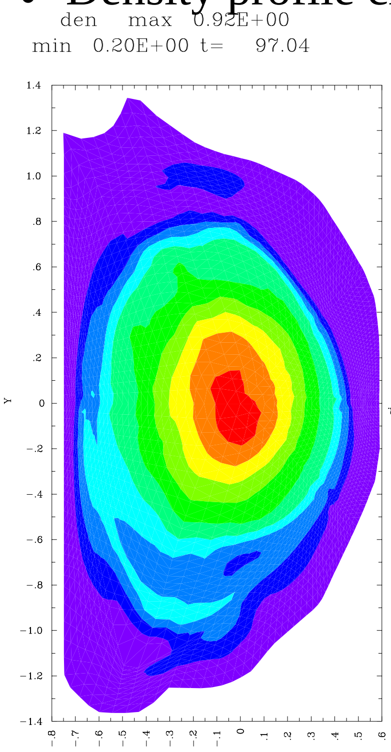
Effect of RMP and rotation on temperature profile

- The cooling region penetrates into the plasma
  - Profiles of temperature along midplane as a function of $R - R_{axis}$
  - Solid line: no RMP, dashed line: with RMP
  - small effect on the plasma core
  - Note region of steepening
  - Gradient is less at separatrix

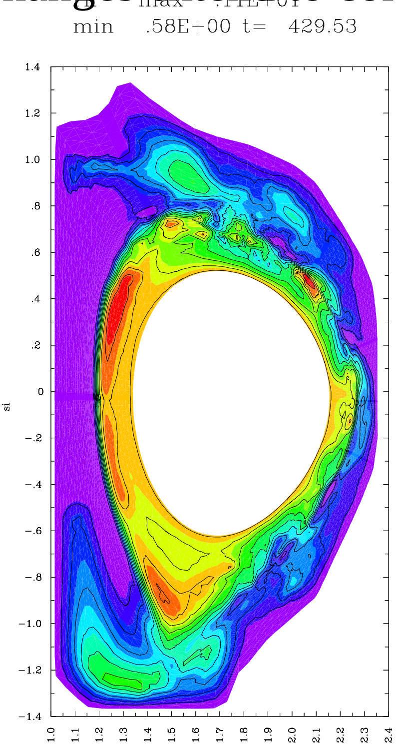


ELM - RMP

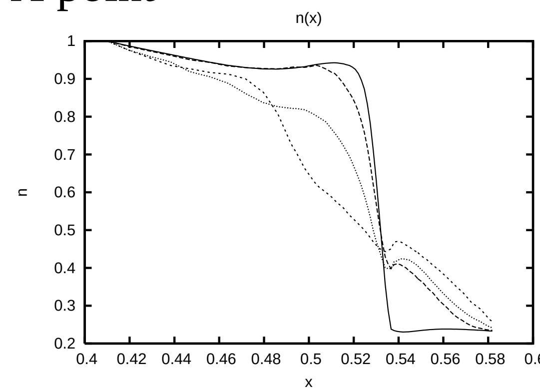
- ELMs and RMPs have similarities
  - Density expelled onto open magnetic field lines
  - Poloidal flow carries excess density to magnetic X point
  - Temperature profiles relax in edge layer
  - Density profile changes extend to core



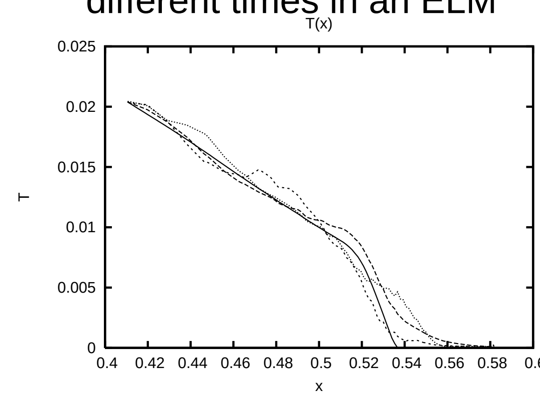
RMP



ELM at long time



Density profiles at different times in an ELM



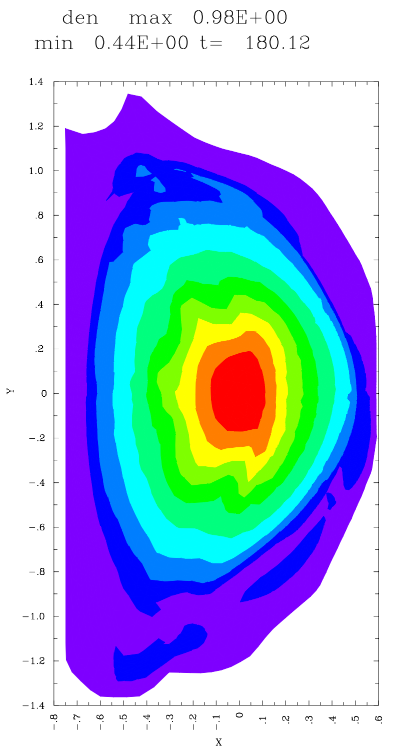
Temperature profiles at different times in an ELM

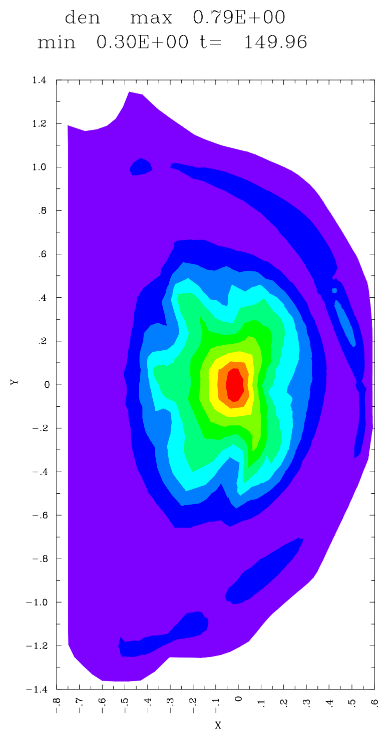
Effect of rotation and two fluid drifts on density pumpout

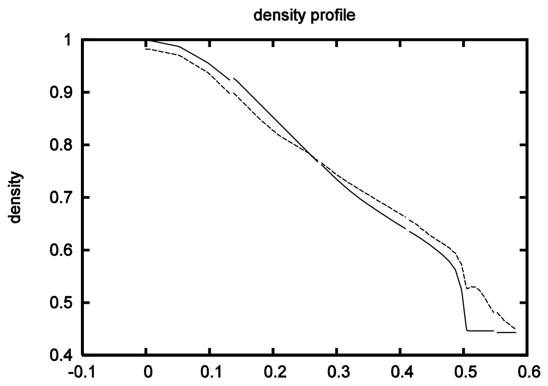
- Toroidal rotation and density pump out
  - Rotation causes density and pressure to deviate from magnetic flux surfaces
  - Pressure loss at edge causes decompression, which affects density even on axis
  - Temperature is a flux function because of high parallel thermal conduction
  - Toroidal rotation is more straightforward
- poloidal rotation
  - Two fluid drifts, as well as radial electric field, cause poloidal rotation
  - Poloidal rotation can cause a density pedestal (MHD H mode) and shocks (Betti and Friedberg, 2000)
    - Flux surface averaged sound speed vanishes at separatrix, so poloidal rotation at the separatrix is supersonic
    - G – S solver with poloidal / toroidal rotation and free boundary in progress (R. Schmitt, G. Y. Park, L. Guazzotto)

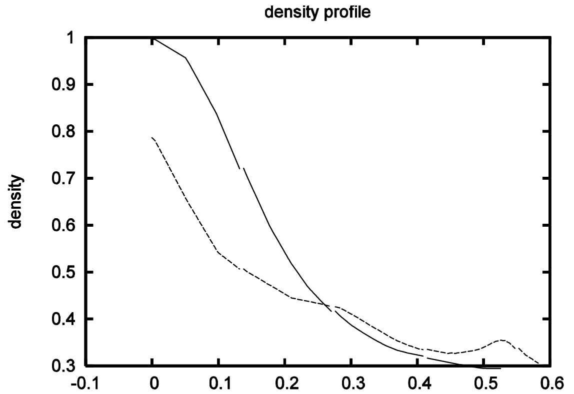
Profile effect on MHD density pump out

- The density profile has a big effect on the density pump out by rotation and RMP
- Broad density profile: a small effect
- Narrow profile: large effect





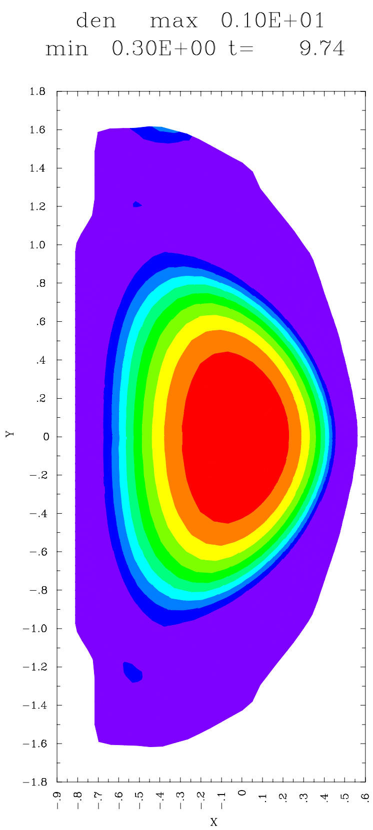




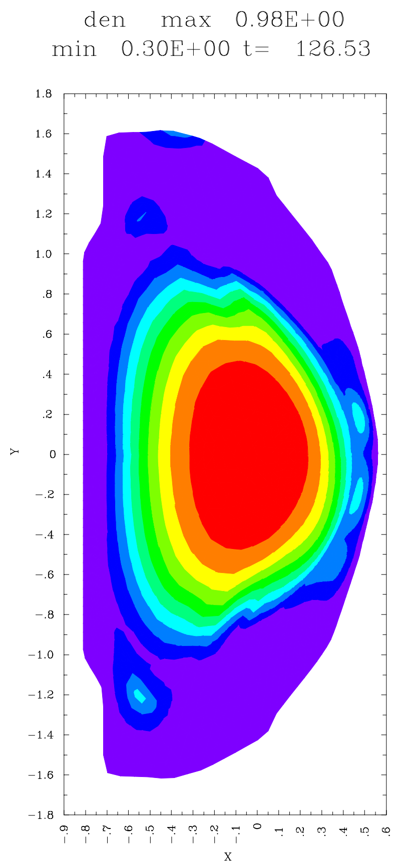
NSTX ELMs

- RMP “doesn’t work” for NSTX
- RMP makes an ELM free discharge unstable to ELMs!
- Perhaps the NSTX ELMs are resistive modes
- RMP changes collisionality, or damps toroidal flow, causing an ELM
- Only ELM simulations without RMP, so far

Density evolution –NSTX g124347 “small ELM”



T=9



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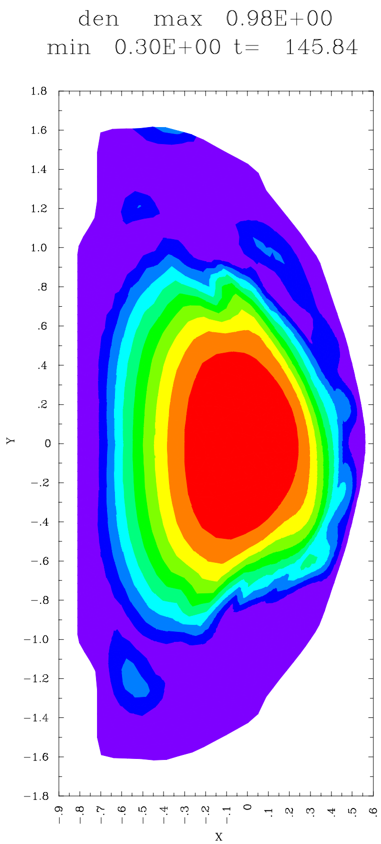

T=146

summary

- Nonlinear evolution with RMP but no rotation
  - Temperature and density loss in wide stochastic layer
- Resistive mode has similar effect as vacuum RMP
- Plasma rotation or two fluid effects
  - Stabilize the resistive mode
  - screen the RMP from the plasma
- Toroidal rotation is not necessary for RMP screening!
- Rotation and RMP cause some density pump out
  - Depends strongly on density profile
  - Poloidal rotation: free boundary G-S solver with flow
- Similarlities between RMPs and ELMs
- RMP does not work in NSTX
  - RMP destabilizes an ELM free discharge
  - ELM may be a resistive mode destabilized by change in collisionality or toroidal rotation damping