Halo Current and Resistive Wall Simulations of ITER

H.R. Strauss[1],
W.Park[2], S. Jardin[2], J. Breslau[2],
A.Pletzer[2], R. Paccagnella[3], L. Sugiyama[4]

1)New York University, New York, New York,USA
2)Princeton University Plasma Physics Laboratory, Princeton, New Jersey,USA
3)Instituto Gas Ionizzati del C.N.R., Padua, Italy
4)MIT, Cambridge, MA,USA

Outline

- Halo current – nonlinear, resistive MHD with resistive wall
  - VDE
  - Disruption
  - RWM
- Resistive wall mode
  - Linear stability with resistive plasma
  - Rotational stabilization

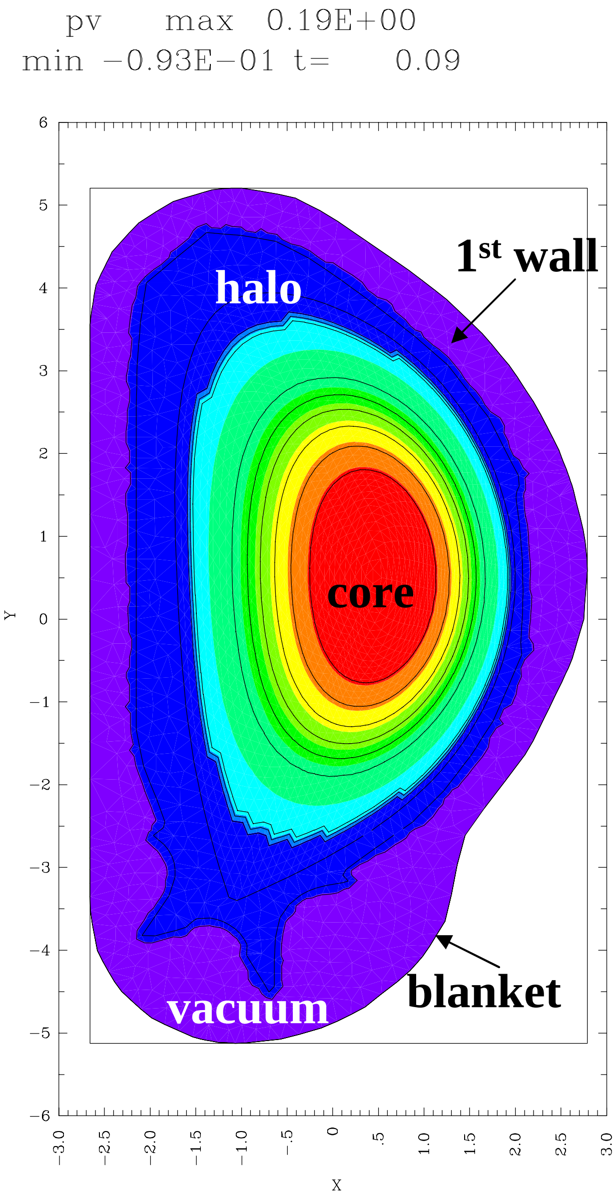
Halo Current

- Halo current:
  - Poloidal current flowing into wall
- Causes stress on walls
  - Toroidal asymmetry: TPF (toroidal peaking factor)
  - Halo current fraction
  - Want to confirm ITER database with simulation
- Occurs during:
  - VDE (vertical displacement event)
  - Major disruption
  - External kink / (RWM) Resistive wall mode
- Modeling
  - M3D code
  - Resistive wall boundary condition
    - Can apply to RWM
  - Self consistent plasma resistivity

M3D plasma – halo – vacuum model

plasma regions

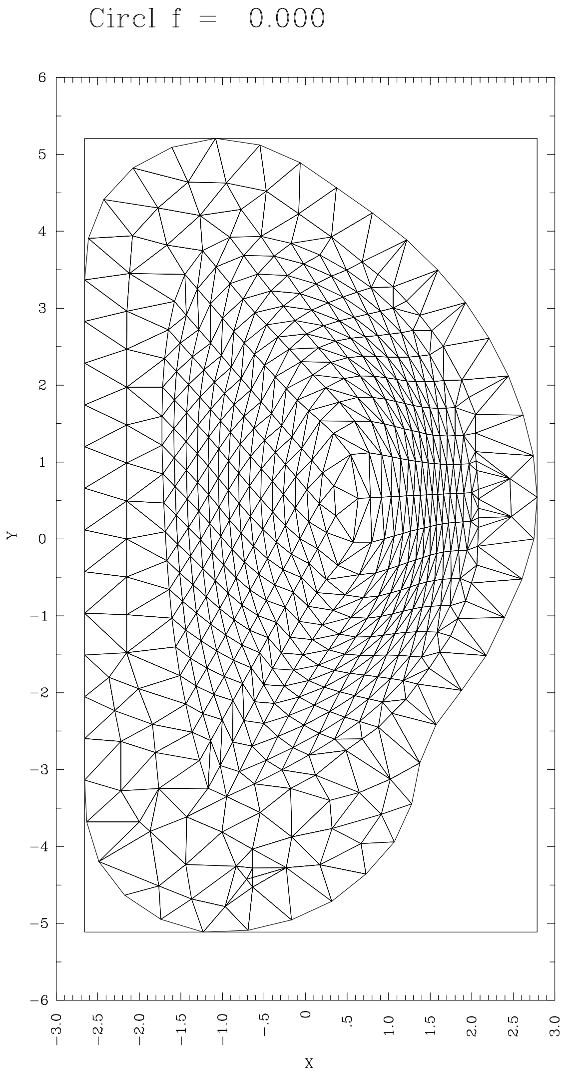
- core
- Halo
- 1^{st} wall
- inner vacuum
- Vacuum wall
- Outer vacuum

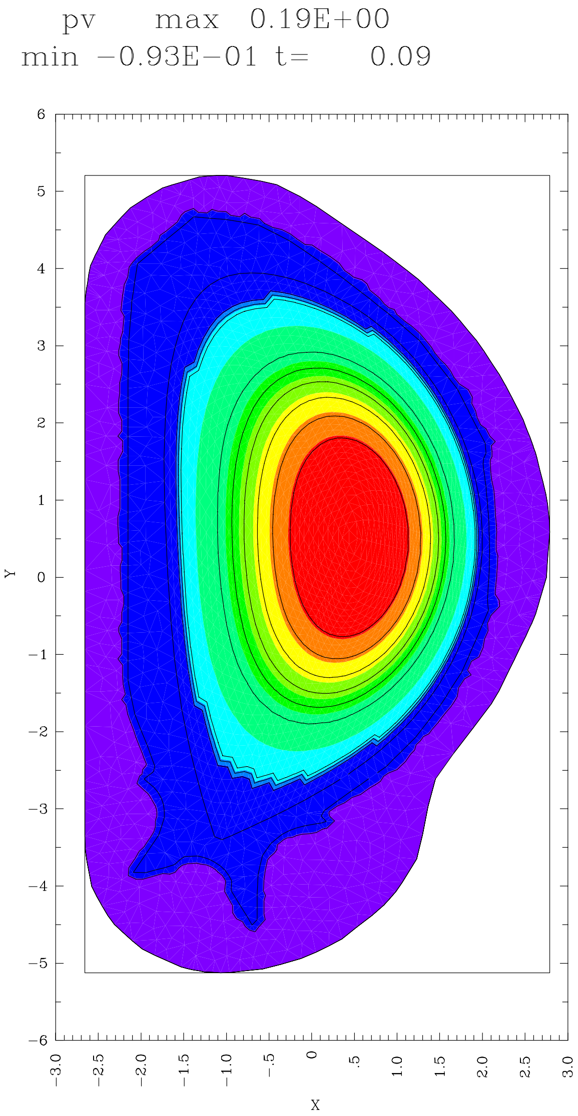


Self consistent resistivity

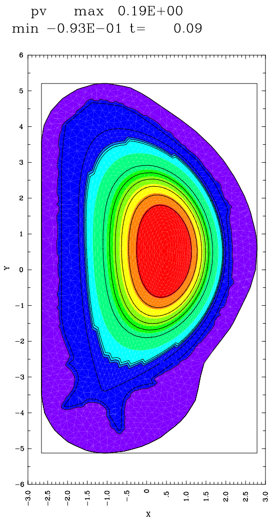
- Resistivity varies as temperature to -3/2 power
- Thermal conduction equalizes temperature on field lines
  - **2D** : **open halo field lines in thermal contact with wall**
  - **3D: disruptions cause stochastic mixing of cold plasma with core, causing thermal quench**
- Piecewise constant resistivity in some linear calculations
  - **Core: high $S = 10^6$**
  - **Halo: medium $S=10^2$**
  - **Outer vacuum: low $S = 0.1$**

Computational mesh – low resolution for clarity



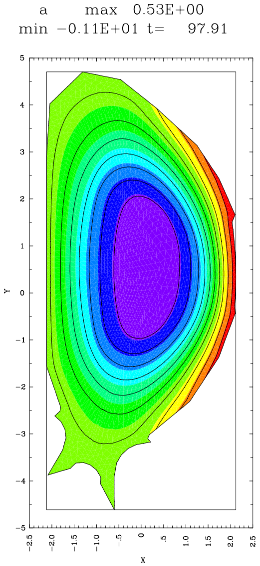


1 and 2 wall models



ITER type

- **Core – resistive MHD**
- **Halo – highly resistive MHD**
- **1^{st} wall – v = 0**
- **Inner vacuum – S < 1 resistive diffusion**
- **Resistive wall – thin wall resistive boundary**
- **Outer vacuum – GRIN Green's function**

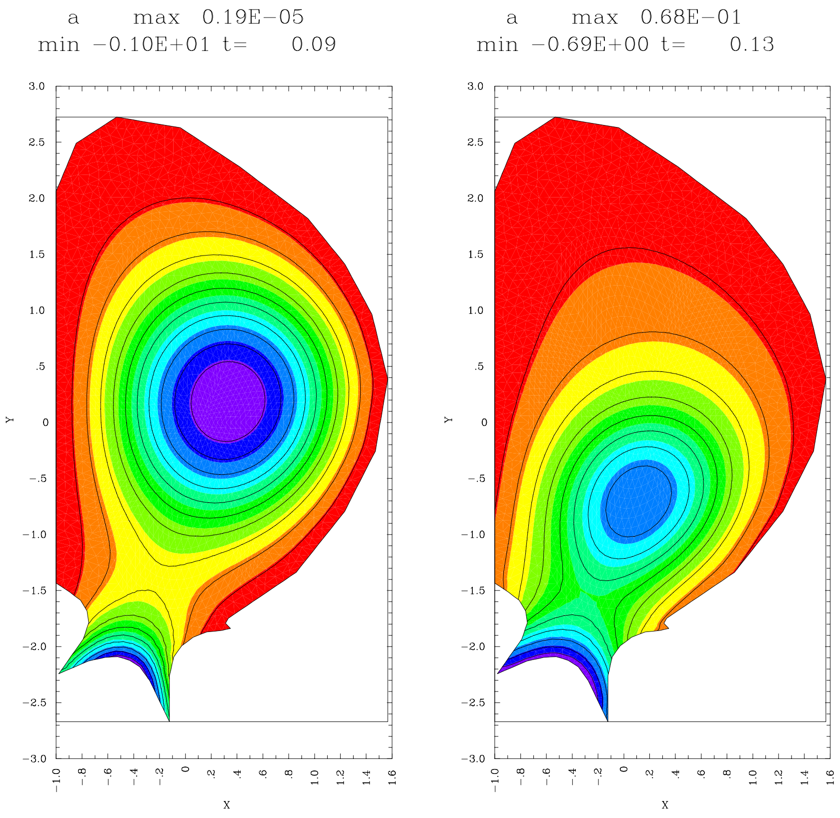


NSTX type – also used for ITER

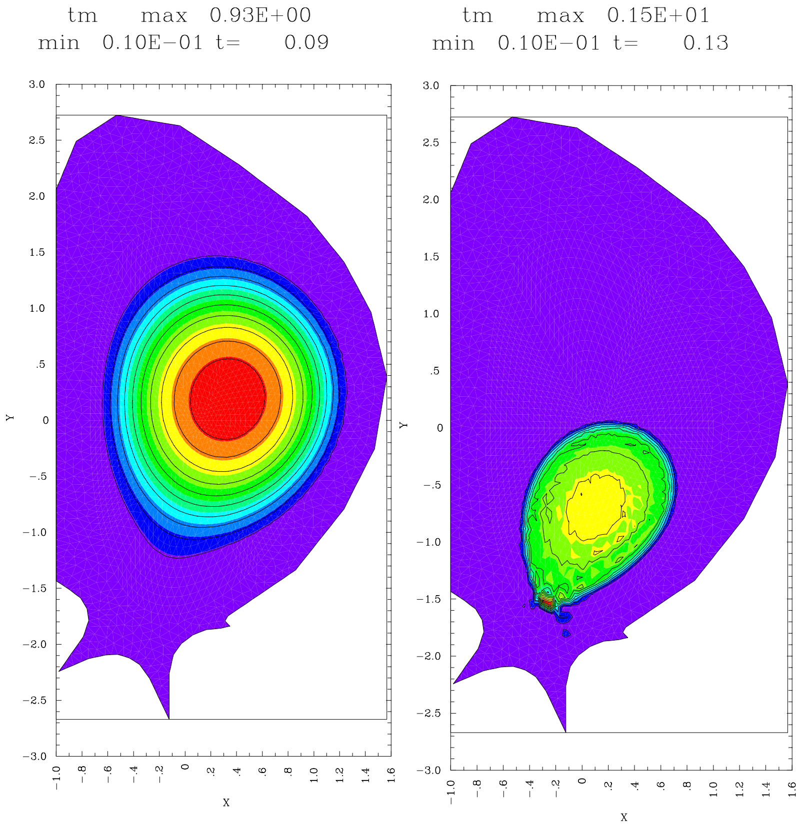
- **Core**
- **Halo**
- **Resistive wall = 1^{st} wall**
- **Outer vacuum**

VDE Instability

- **2D instability**
- **Growth rate proportional to wall resistivity**
- **1st wall is resistive**
- **Halo current flows when core near wall**



Poloidal flux function



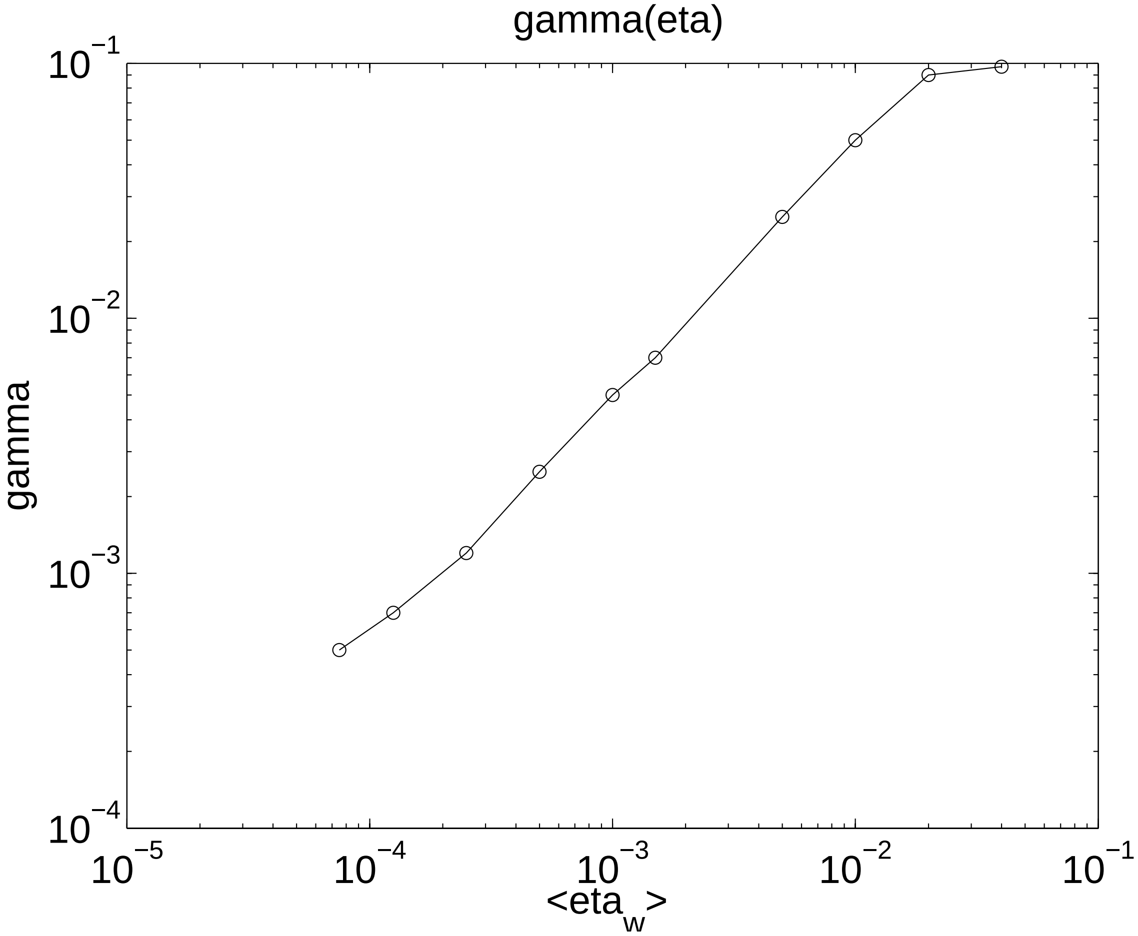
Temperature – contrast maintained

VDE growth rate is proportional to wall resistivity

- halo resistivity has to be larger than wall resistivity, which must be larger than core
- limiting case: ideal core, vacuum halo
- 2D RWM

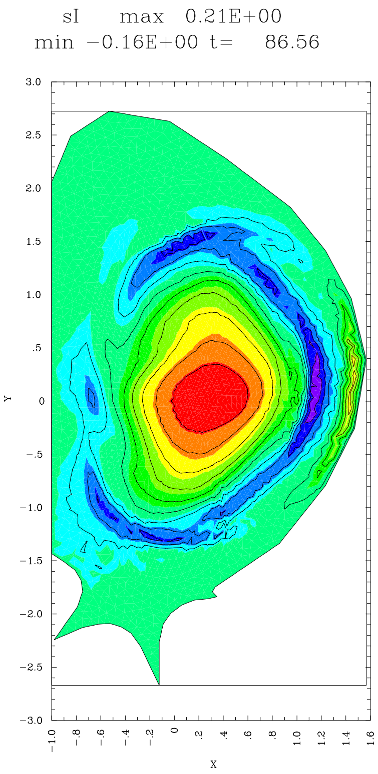
$$\eta_h > \eta_w > \eta_c$$

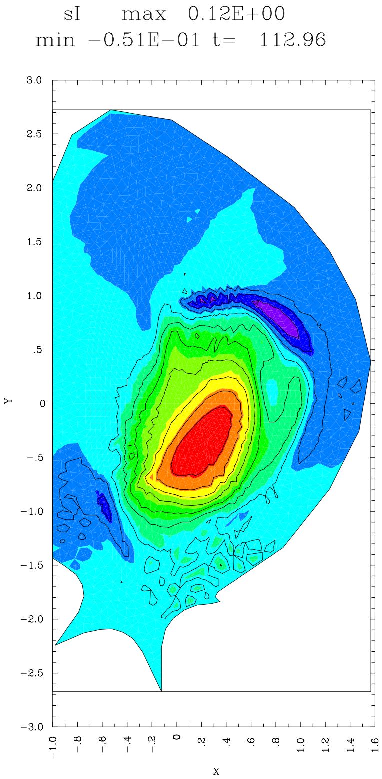
$$\gamma \sim \eta_w$$

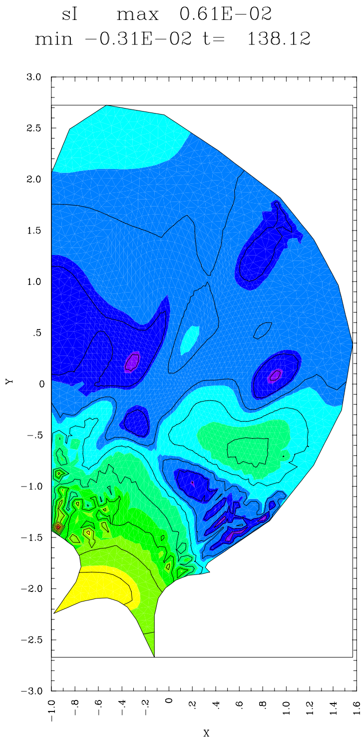


3D disruptions

- penetration of toroidal flux into wall gives halo current
- Resistive wall required
- TPF: Toroidal Peaking Factor - toroidal asymmetry of ITER halo currents
- Halo Current Fraction – measure of halo current
- Disruption can combine with VDE – increasing its growth rate
- Case of internal kink with large q=1 radius
- Contours of toroidal flux intersecting the wall are halo current

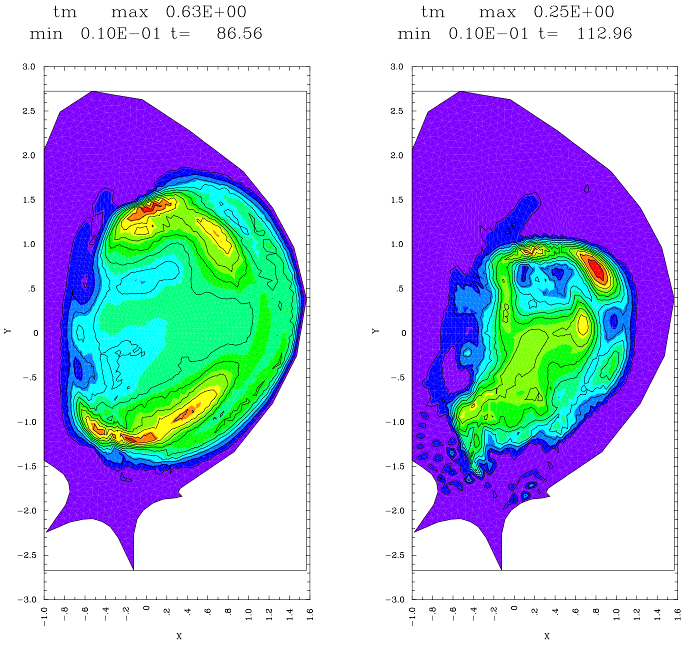

sI max 0.21E+00
min −0.16E+00 t= 86.56


sI max 0.12E+00
min −0.51E−01 t= 112.96

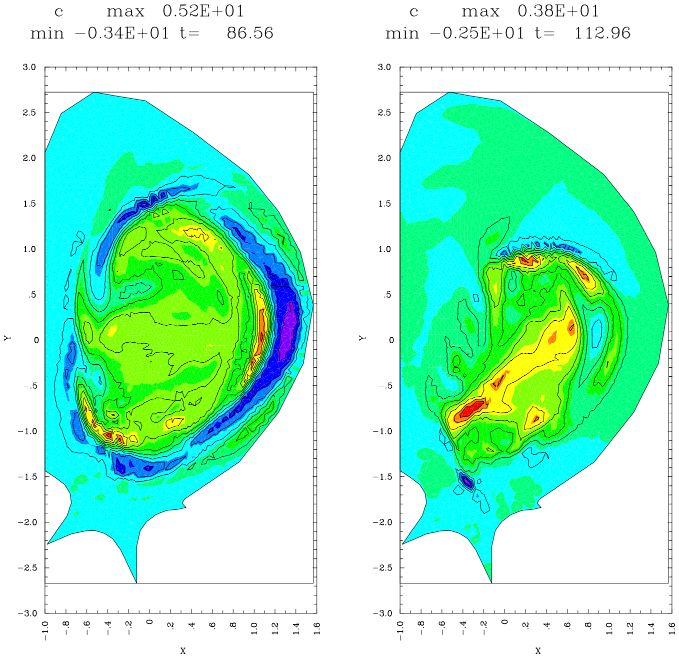

sI max 0.61E−02
min −0.31E−02 t= 138.12

Disruptions cause thermal and current quench

temperature



Toroidal current density



Thermal conduction along stochastic magnetic field cools plasma
Core not isolated from halo
High resistivity quenches current, including halo current

Halo current

Normal component of poloidal Current flowing through the boundary as function of toroidal angle

$$I_h(\phi) = \pi \oint \left| n \cdot J \right| R dl$$

Toroidal peaking factor

$$TPF = \frac{I_h(\phi)_{\max}}{< I_h >}$$

Halo current fraction of Toroidal current

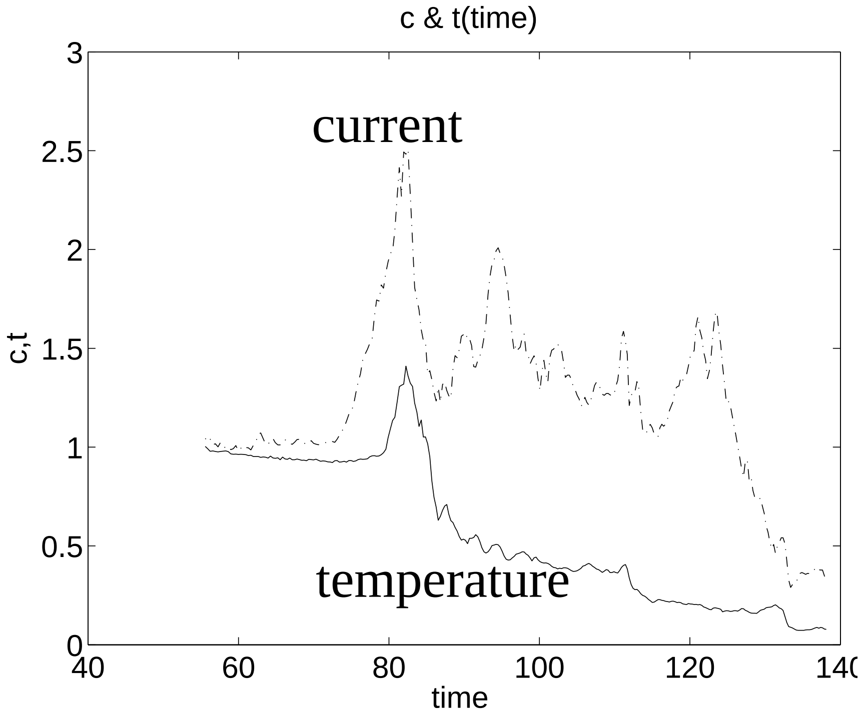
$$F_h = \frac{< I_h >}{I_\phi}$$

Inverse relation of TPF to Halo current fraction

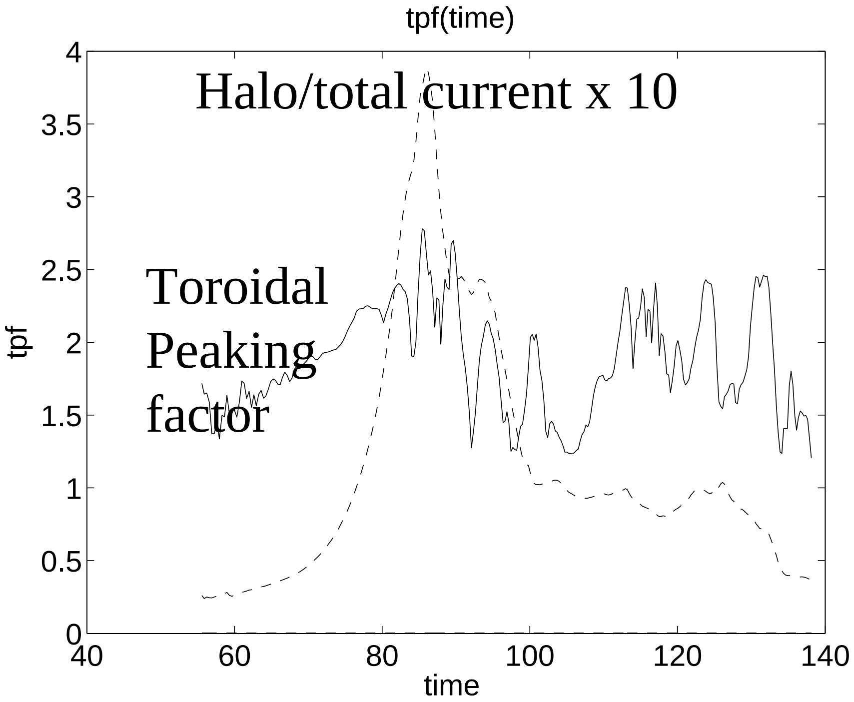
$$TPF \times F_h = \frac{I_h(\phi)_{\max}}{I_\phi}$$

toroidal peaking factor and halo current fraction

TPF = 2, F_h=.35



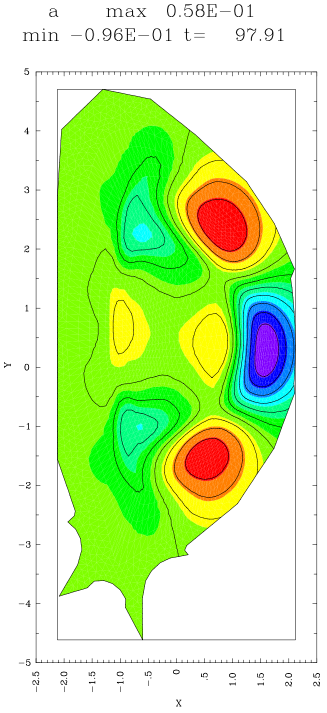
Temperature and current vs. time



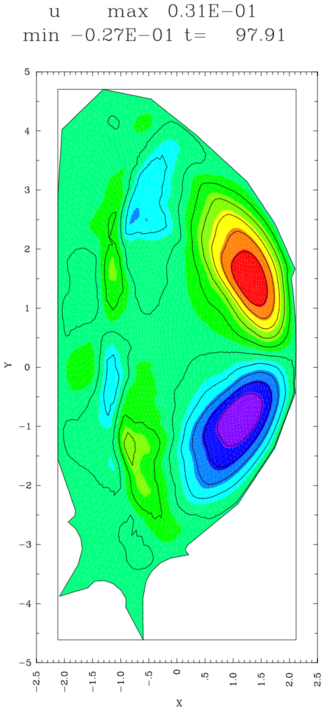
TPF and F_h vs. time

Nonlinear RW – external kink

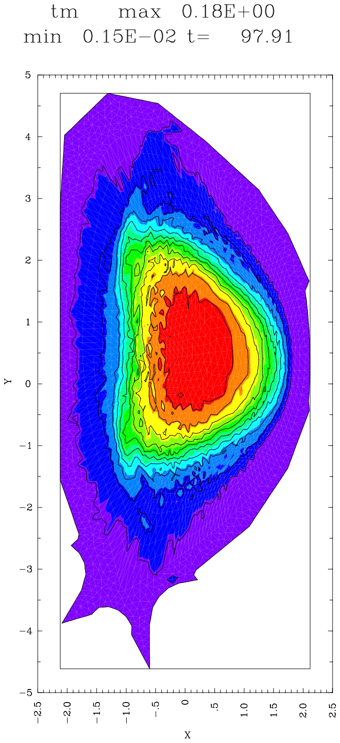
TPF = 1, F_h = .2



Poloidal flux



Electrostatic potential



temperature

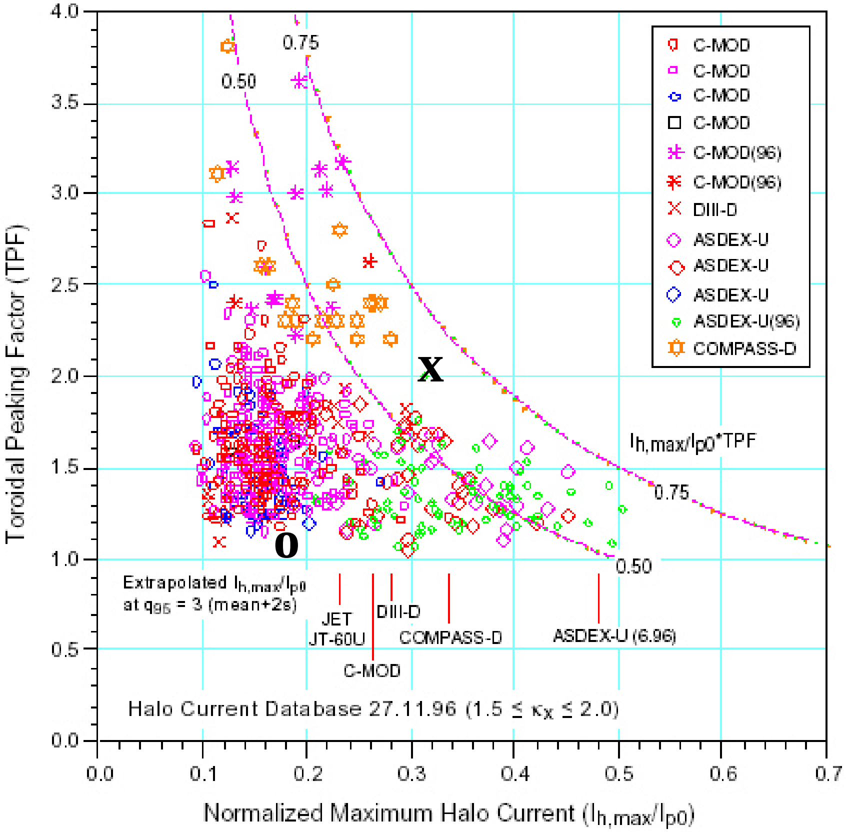
ITER AT: $q_0 = 3.6, \beta_n = 2.4$

m/n = 3/1

Results are consistent with ITER database

X – kink instability
O – resistive wall
mode

TPF



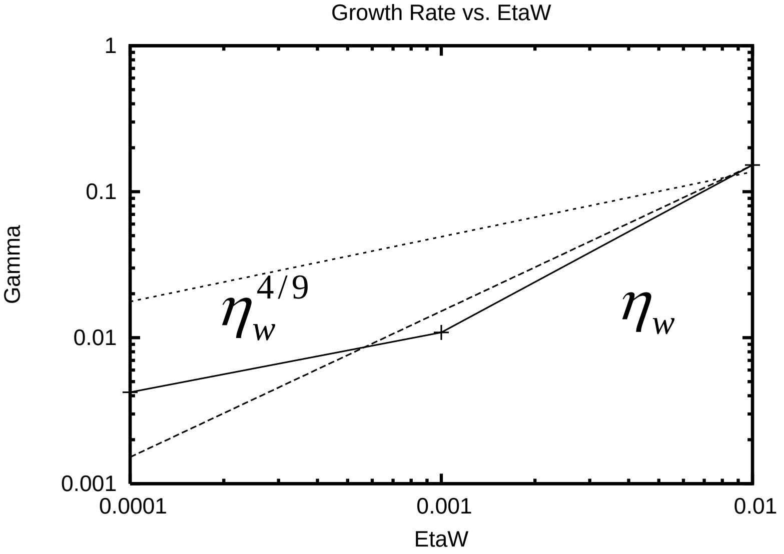
F_h

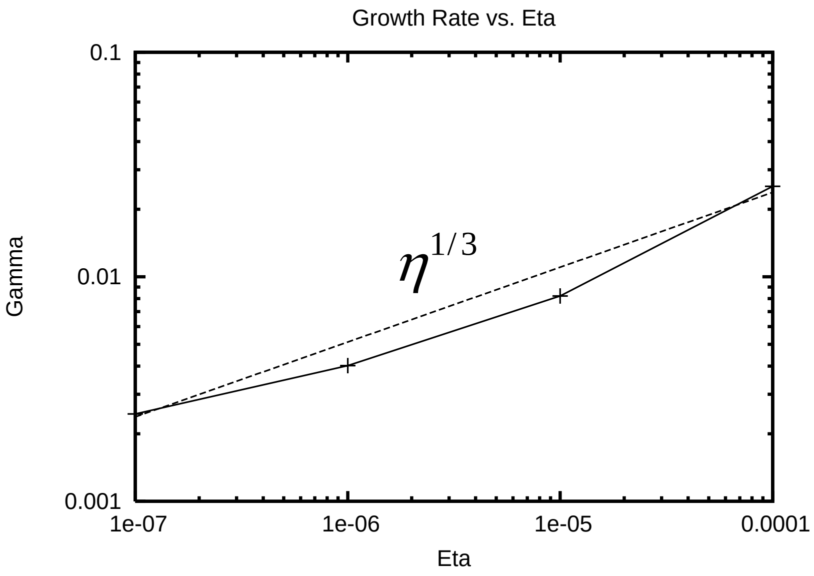
TPF x F_h = peak halo current / total current < 1

Linear Scaling of Resistive Wall mode with plasma resistivity

Simulation of RWM is complicated by plasma resistivity

Finn, 1995; Betti, 1998





$$\eta = 10^{-6}$$

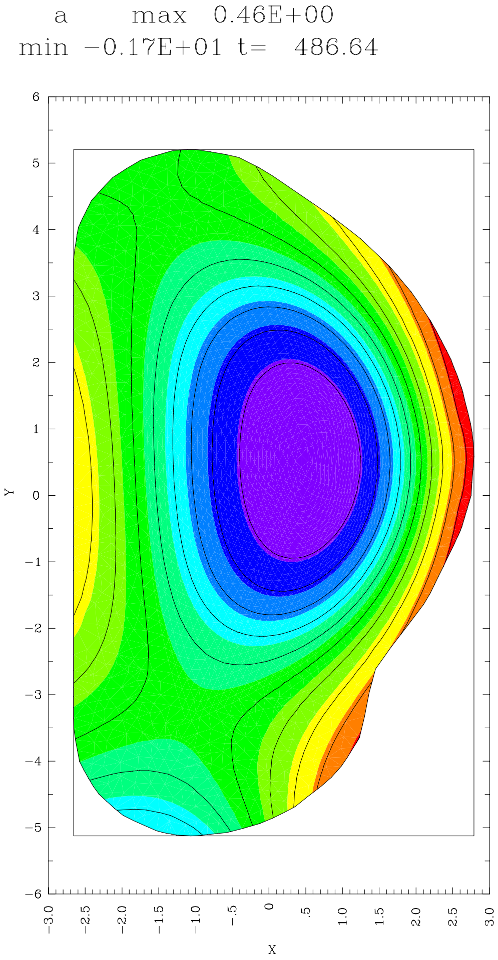
$$\gamma_t \sim \eta^{3/5} > \gamma_{RWM}$$

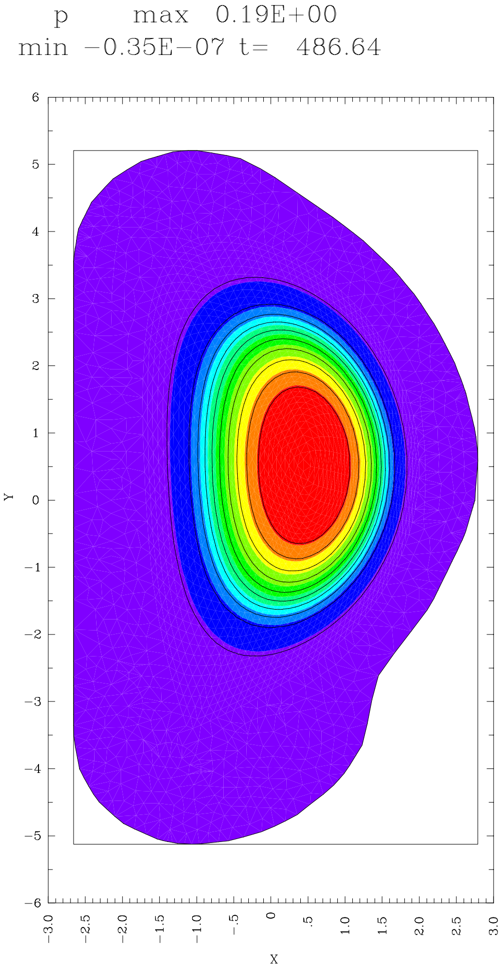
$$\eta_w = 10^{-3}$$

$$\gamma \sim \eta^{1/3} \eta^{4/9}$$

RWM interacts with tearing/electromagnetic resistive ballooning mode – RWM regime has large growth rate

ITER AT equilibrium





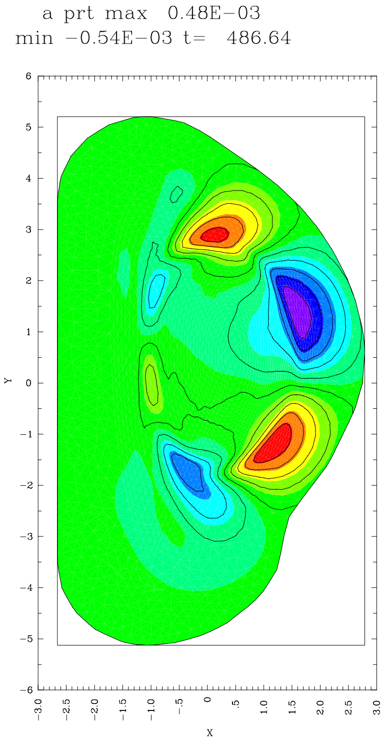
$$q_0 = 3.6$$

$$\beta_N = 2.4$$

Initialized from EQDSK – including vacuum region

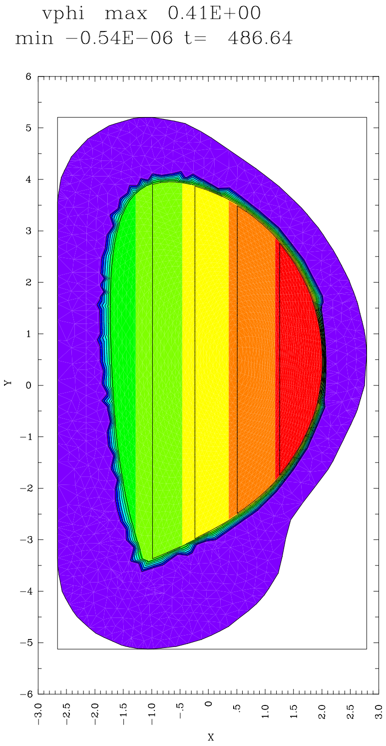
Linear stability

Poloidal flux

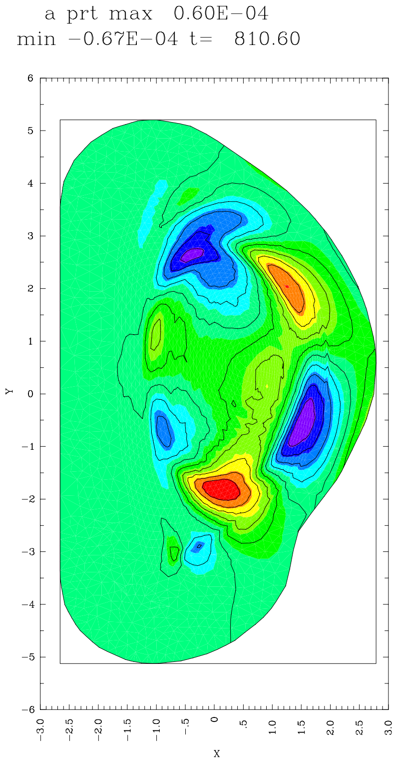


$\Omega=0$

Toroidal velocity



Poloidal flux



$$\Omega = \frac{v_\phi}{R} = 0.05\frac{v_A}{R}$$

RPRW mode is stable with ideal wall
rotation stabilized for resistive wall
Viscous damping

Summary

- Halo current in M3D simulations of disruption and RWM
- TPF consistent with ITER database
- Plasma resistivity complicates RWM
  - **Larger growth rates and lower stability boundaries**
  - **Can be stable with ideal wall**
  - **Rotational stabilization**
- **Future work**
  - **Linear stability vs. beta: need EQDSK**
  - **Nonlinear simulations with rotation and finite amplitude magnetic perturbations: disruptions**
  - **Kinetic effects: bulk ions or energetic ions**
  - **Feedback: finite amplitude modes**