Studies of Stellarators and MPP Simulations with M3D

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M3D Stellarator Equilibrium and Stability

The M3D [1] code is capable of using a 3D mesh, suitable for stellarator studies. A finite element discretization [2] is used in poloidal planes and a finite difference mesh is used in the toroidal direction. Simulations can be initialized with Vmec [3] equilibrium data. M3D is run with resistive dissipation, as well as cross field thermal conduction.

M3D can be run with a coarse grain parallelization, with poloidal planes of data assigned to different processors. The following examples of W7AS and a quasi - axisymmetric (QAS) design were calculated with SGI and Sun shared memory multiprocessor computers. The code now has the option of massively parallel distributed memory computation.

Relaxation of M3D Equilibrium from VMEC

Vmec provides a parameterization of magnetic surfaces which is used to construct the M3D grid. The Vmec magnetic field data is interpolated onto the M3D mesh, and the toroidal current and magnetic field are found. Along with the pressure profile, this is sufficient to initialize M3D.

Source terms are included to maintain the toroidal current and pressure.

Parallel thermal conduction is simulated with the "artificial sound" method [4]. Kinetic energy is removed by viscous damping.

Pressure is advanced by both advection and "artificial sound"

$$\frac{\partial p}{\partial t} = -\mathbf{v} \cdot \nabla \mathbf{p} - (\gamma - 1)\mathbf{p}\nabla \cdot \mathbf{v} - \nabla_{\|}\mathbf{v}_{\mathbf{a}\|} + \kappa_{\perp}\nabla_{\perp}^{\mathbf{2}}(\mathbf{p} - \mathbf{p_0})$$

$$\frac{\partial v_{a\|}}{\partial t} = -c_a^2\nabla_{\|}p + D_a\nabla_{\perp}^2 v_{a\|}$$

to relax towards a state with

$$\nabla_{\|} p = 0.$$

A new option is to turn off the pressure advection (in green) This technique has been useful to slow down or suppress resistive ballooning modes, which interfere with study of resistive equilibrium. This method is expected to be useful only for sufficiently small $S < 10^4$. At high S, the advection terms have the same effect as the artificial sound terms, except in resistive "tearing layers" where the pressure is unimportant.

Symmetry:

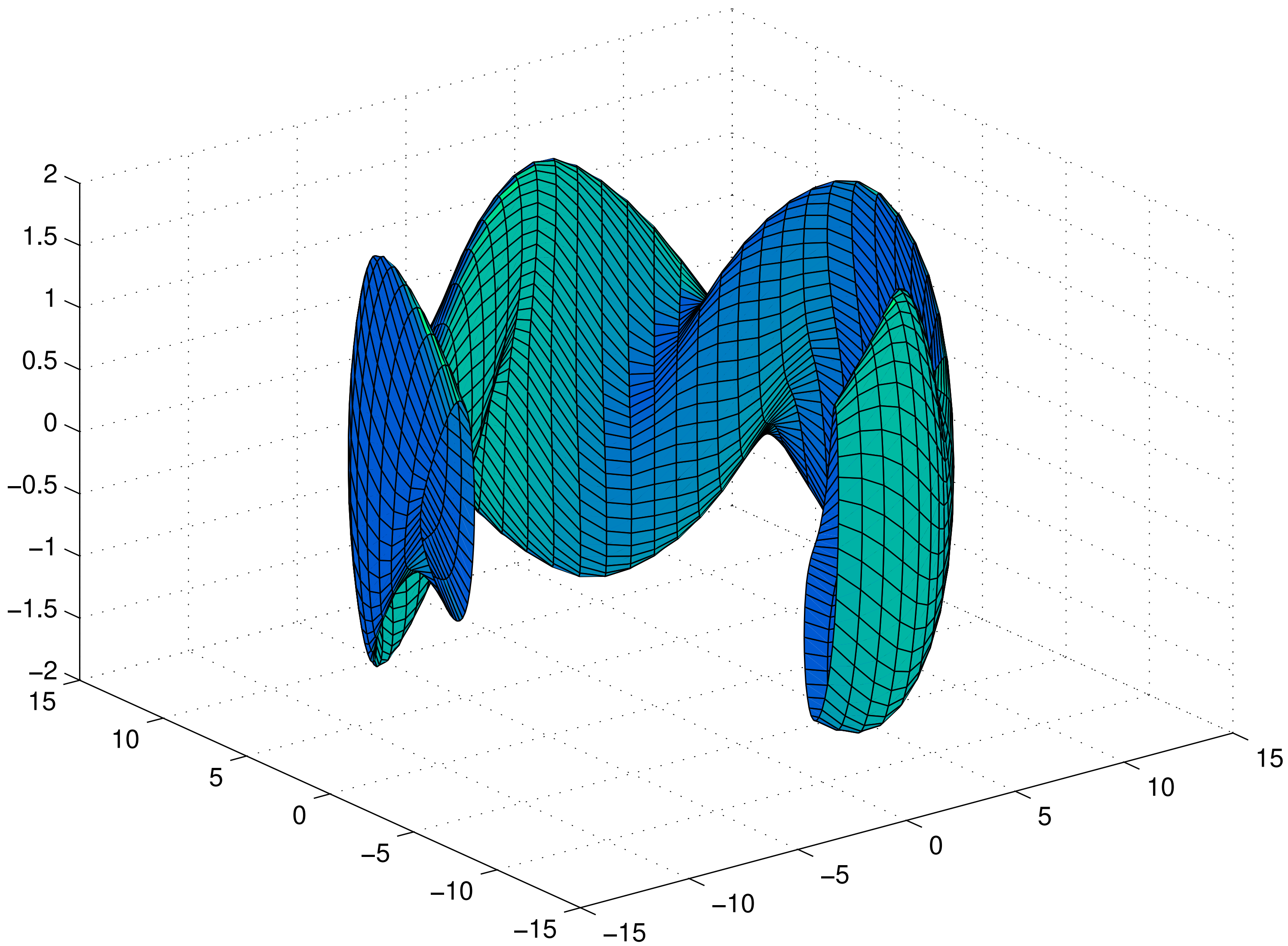
Calculate 1/2 field period π/N_F.

$$F(R, Z, \phi) = \pm F(R, Z, -\phi)$$

$$F(R, Z, \pi/N_F + \phi) = \pm F(R, Z, \pi/N_F - \phi)$$

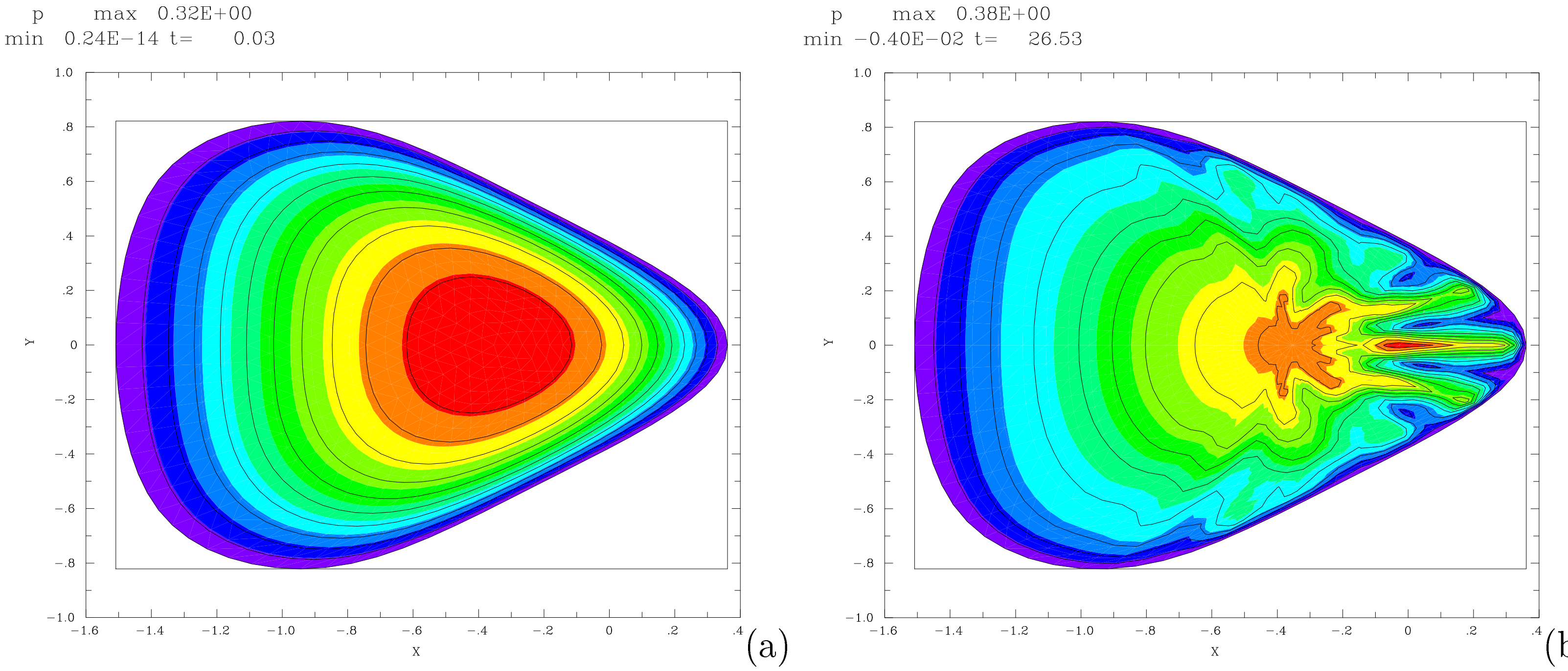
Resistive Ballooning in W7AS

Recently simulations have been done of W7AS. The following shows the outer flux surface boundary of the W7AS period 5 stellarator.



Outer boundary of a 5 field period W7AS stellarator, with 1/4 cut away to show cross section shape.

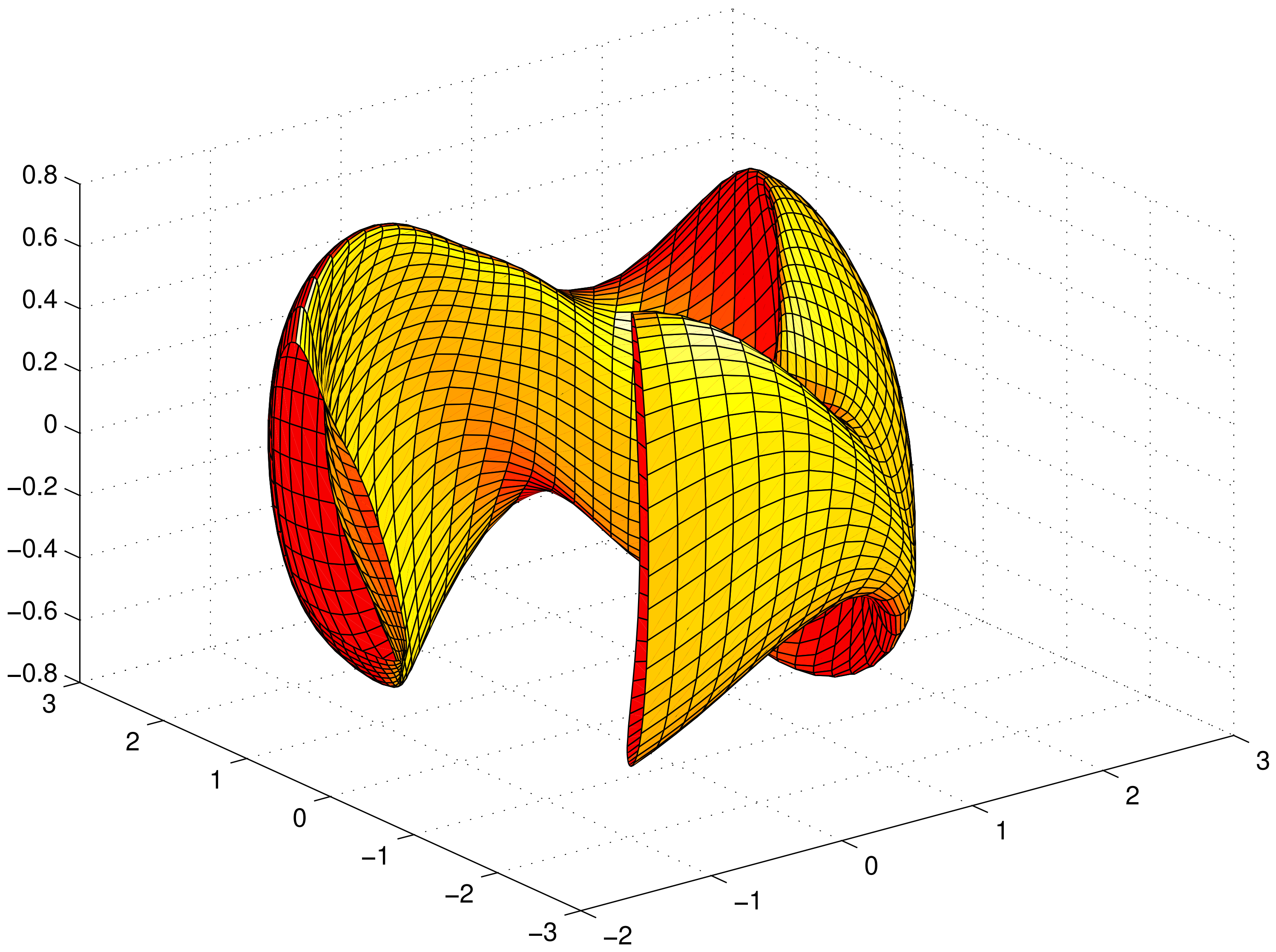
This example has high $< \beta >= 3\%$. It is ideally stable, but is unstable to resistive ballooning.



(a) pressure $t = 0$. (b) pressure at $t = 26.5$

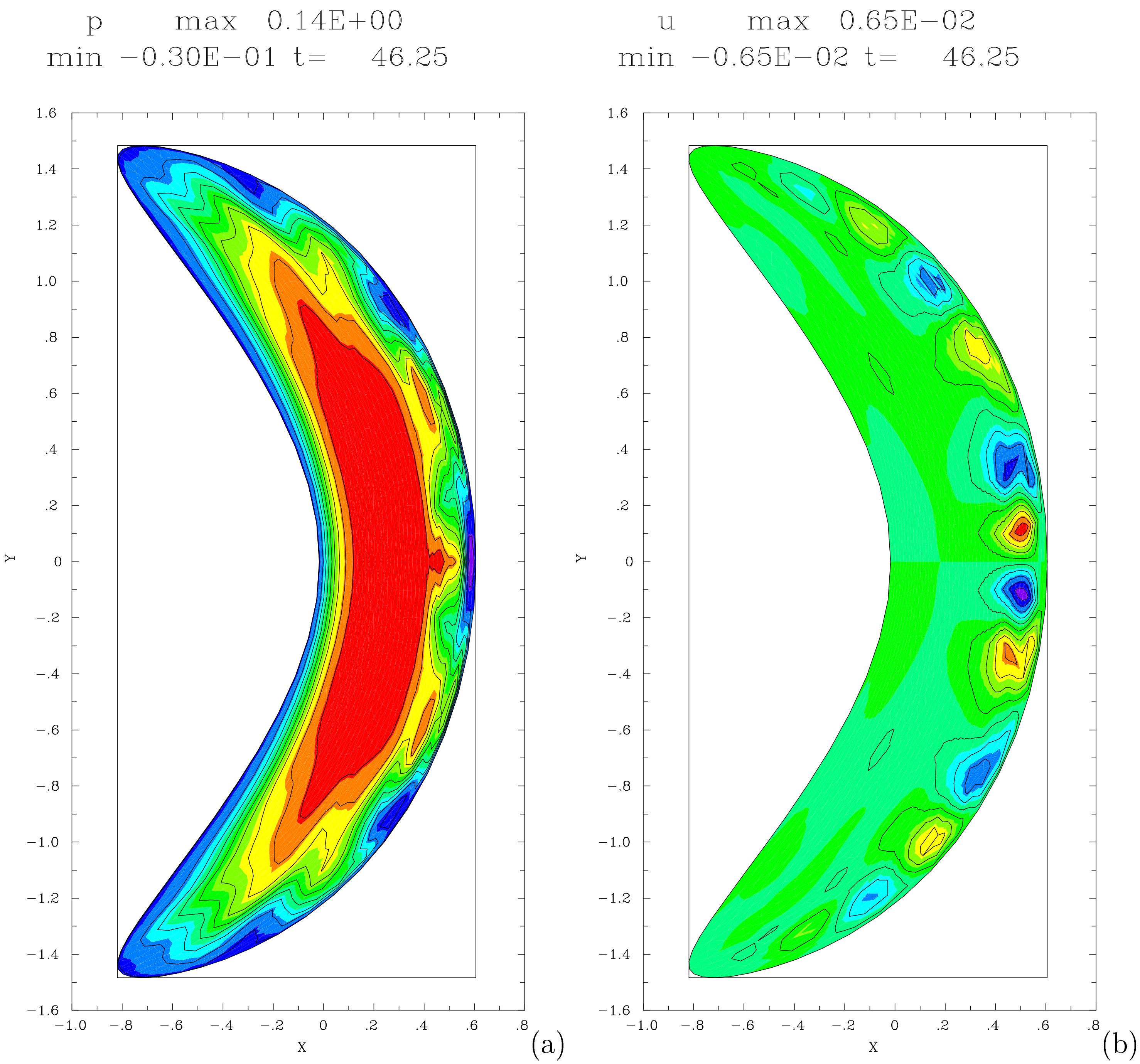
Equilibrium & Stability of NCSX

The following example is initialized with a QAS li383 equilibrium, a possible design for the NCSX experiment.



Outer boundary of a 3 field period QAS stellarator equilibrium (li383), with 1/4 cut away to show cross section shape.

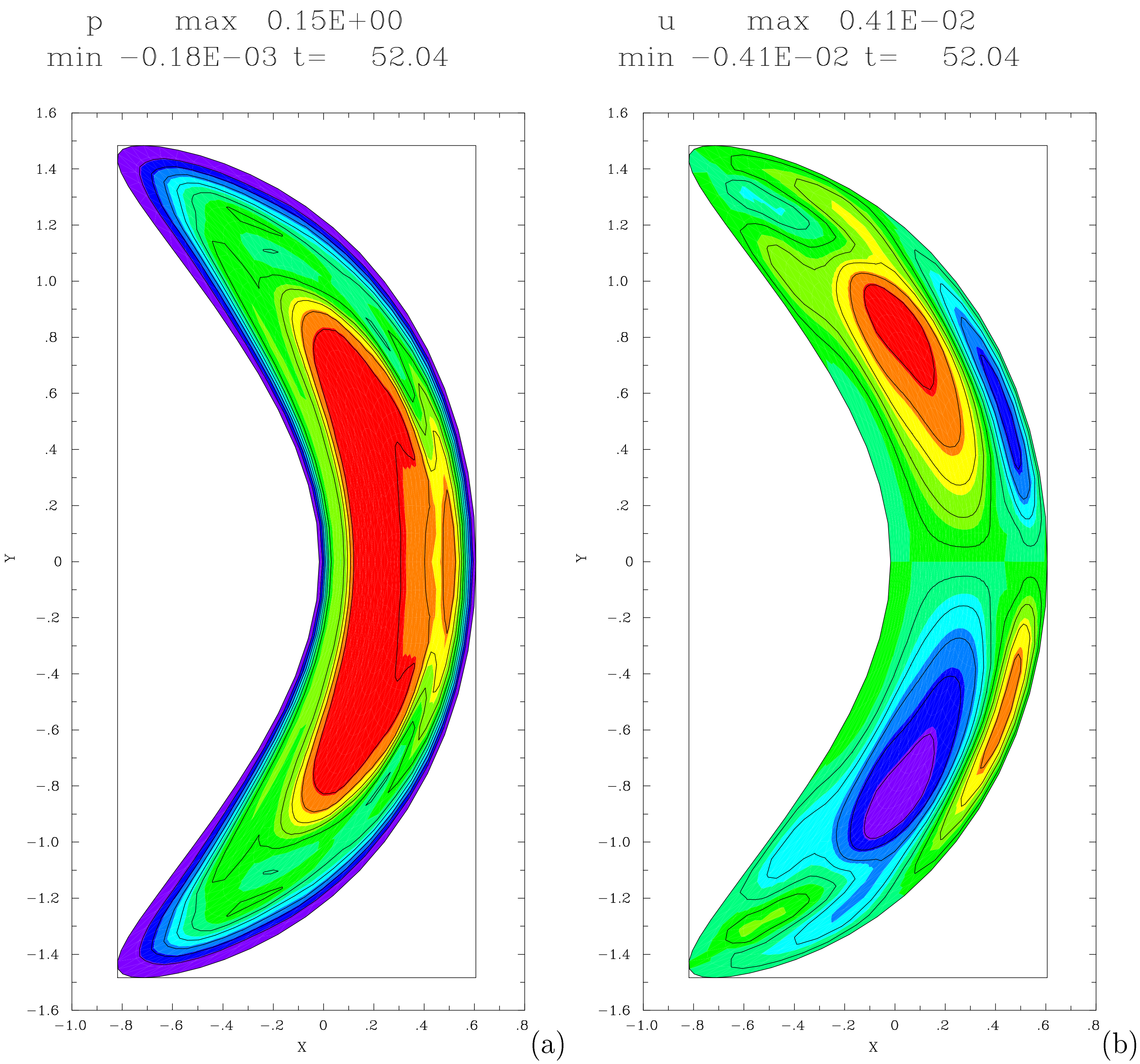
This example has high $<\beta>= 4\%$. It is ideally stable, but is unstable to resistive ballooning.



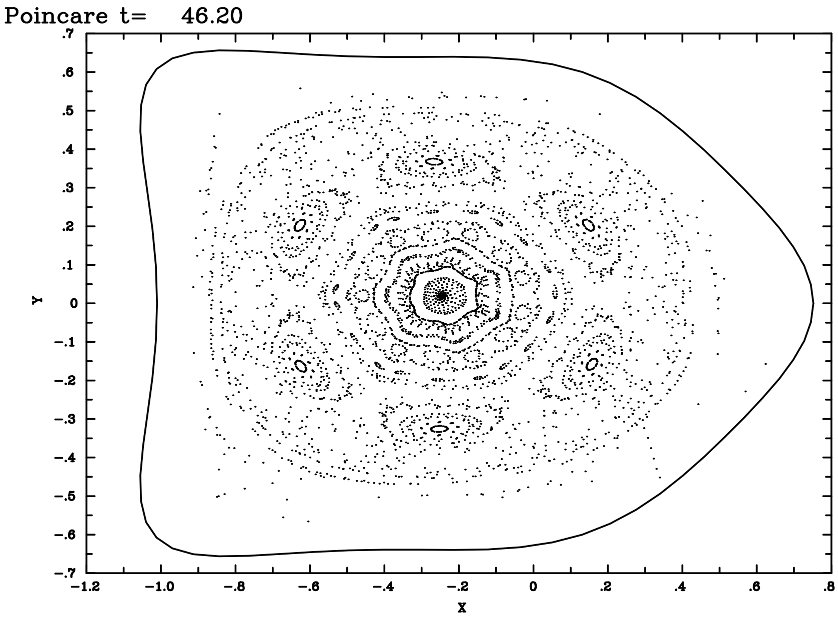
(a) (b)

(a) pressure at $t = 46$. (b) electrostatic potential at $t = 46$.

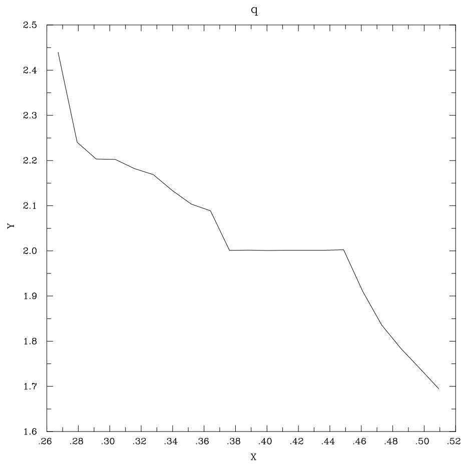
It is possible to suppress these modes by turning off pressure advection, while retaining the "artificial sound." The pressure flattening is associated by a $(6, 3)$ island.



(a) pressure at $t = 52$. (b) electrostatic potential at $t = 52$.



(a)



(b)

(a) Poincaré plot at $t = 46$ (b) q profile at $t = 46$

The conclusion is that a method has been found to distinguish between p' and $J'_{||}$ driven resistive evolution, which makes it possible to study island evolution in stellarators.

Higher resolution studies will be performed using the MPP version of M3D.

Acknowledgments

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