REACTORS WITH STELLARATOR STABILITY AND TOKAMAK TRANSPORT

P.R. Garabedian

Because the W7-AS and LHD experiments exceeded theoretical β limits, the ARIES-CS study has been considering more realistic predictions from runs of the NSTAB code. Force balance and stability may be lost across islands when the equilibrium equations are not in conservation form.

There are compact stellarators with either two or three field periods that have good properties for a reactor. The coils for two periods look better primarily because their distance from the separatrix is smaller in units of the plasma radius. The most economical size for the reactor has not yet been determined.

Maxwell stress tensor

$$\mathbf{T} = \mathbf{B}\,\mathbf{B} - (B^2/2 + p)\,\mathbf{I}$$

MHD force balance in conservation form

$$\nabla \cdot \mathbf{T} = 0\,, \quad \nabla \cdot \mathbf{B} = 0$$

force on a closed control surface

$$\int\!\!\int \mathbf{T} \cdot \mathbf{N}\, dS = 0$$

example of Burgers equation in slab geometry

$$2\Psi_x\,\Psi_{xx} = (\Psi_x^2)_x = \eta\,\Psi_{xxx}$$

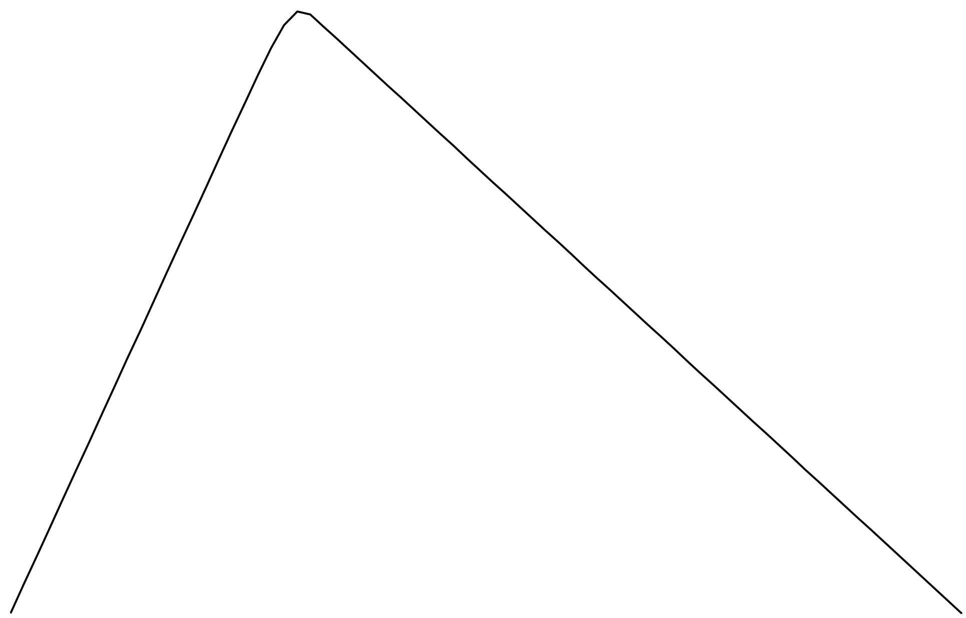
three RFP boundary conditions

$$\Psi(-1) = \Psi(1) = 0\,, \quad \Psi_x(-1) = 1$$

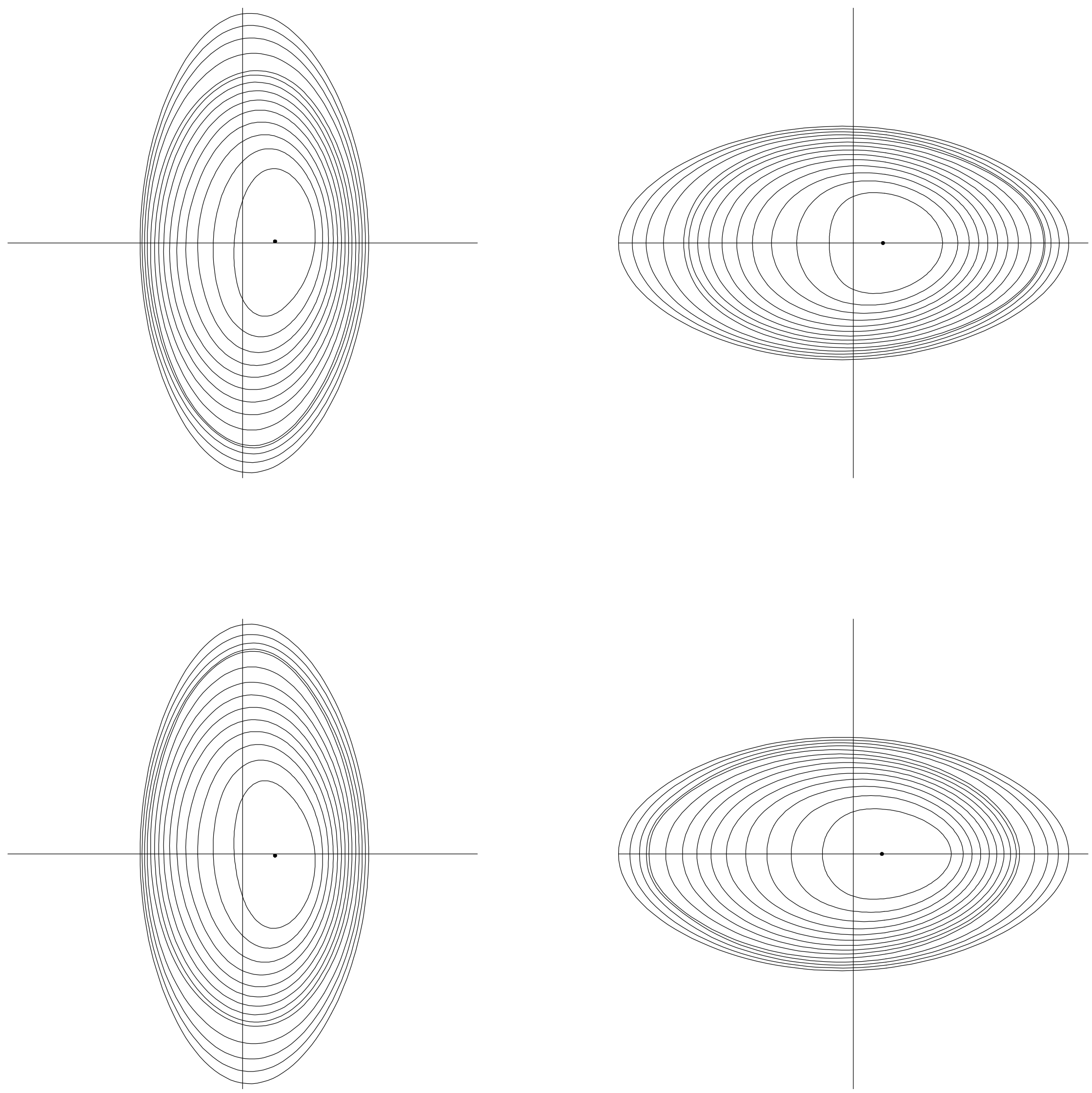
conservative scheme calculates jumps correctly

$$(\Psi_{n+1} - \Psi_n)^2 - (\Psi_n - \Psi_{n-1})^2 =$$

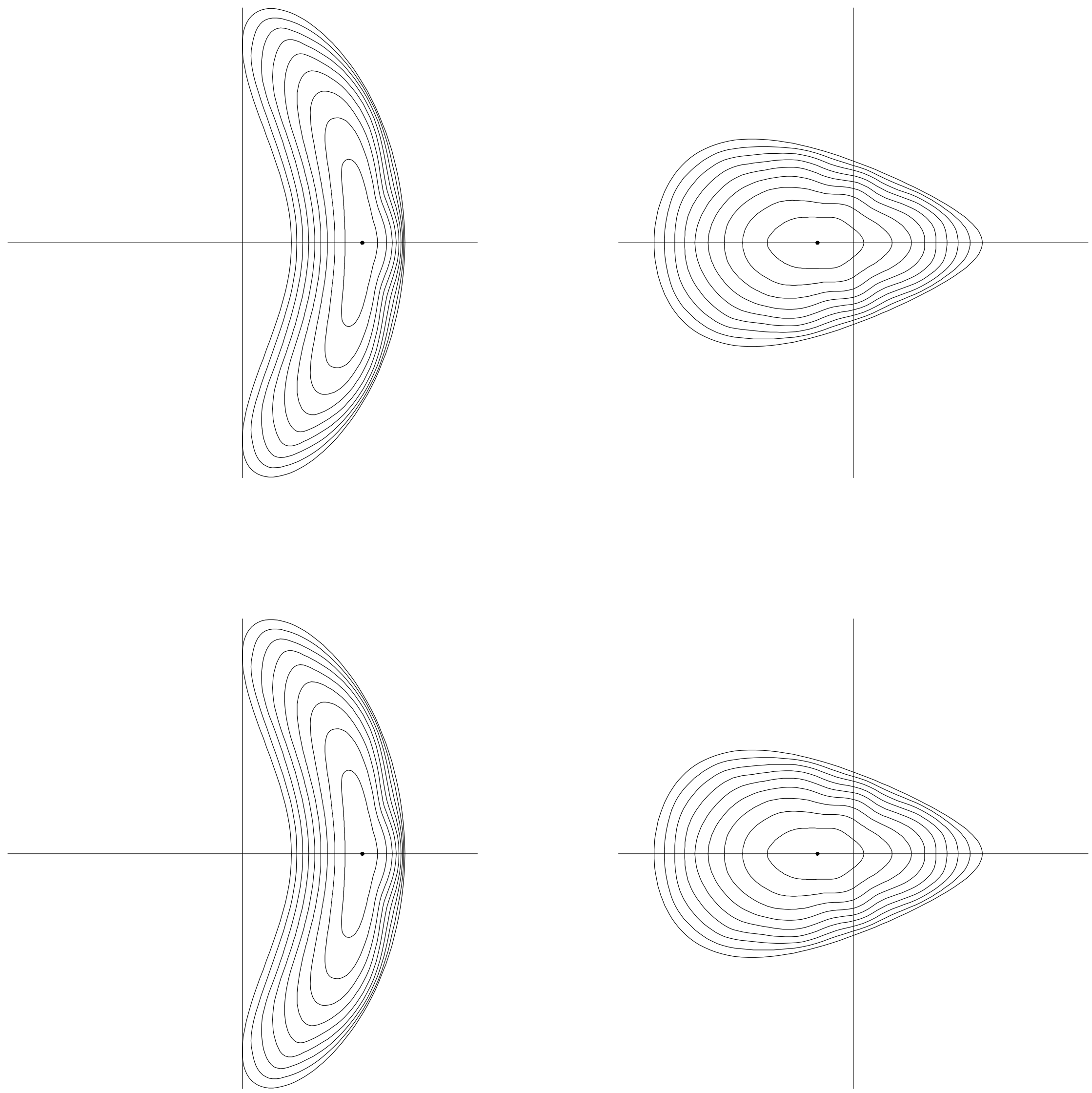
$$\eta\,\left(\Psi_{n+2} - 3\Psi_{n+1} + 3\Psi_n - \Psi_{n-1}\right)$$



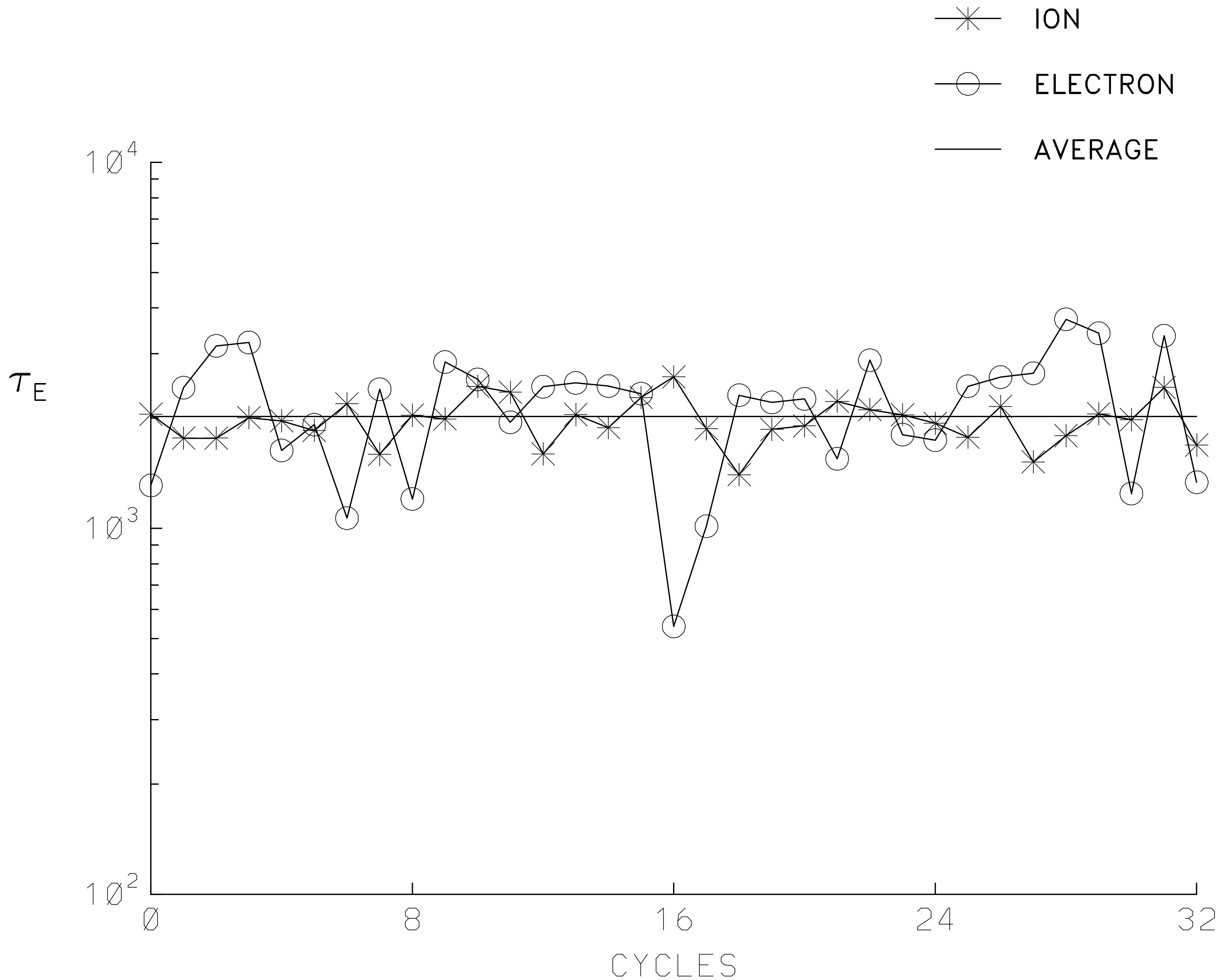
Bad solution for the flux $\Psi = \Psi(x)$ in the RFP problem using a finite difference scheme that is not in conservation form. If force balance were computed accurately then the two slopes at opposite ends of the curve would have the same size and the apex would be in the middle. The slopes characterize the magnetic field on opposite sides of a current sheet, which is like a chain of magnetic islands.



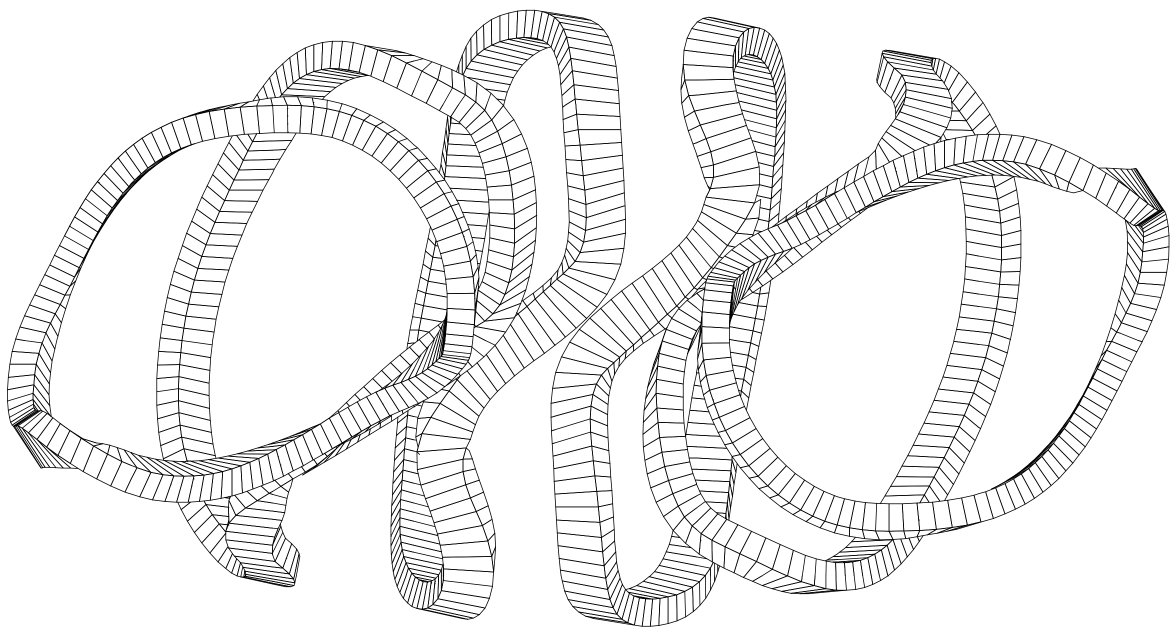
Poincaré map of the flux surfaces at four cross sections over the full torus of a bifurcated LHD equilibrium at $\beta = 0.032$ with the magnetic axis at a position with plasma radius $R = 3.6$ m. For a standard pressure profile $p = p_0(1 - s)$ the global $m = 1,\ n = 1$ mode of this solution is linearly unstable, but nonlinearly stable. This NSTAB calculation was performed using harmonics of degree up to 24 in the poloidal angle and up to 120 in the toroidal angle.



Four cross sections of the flux surfaces over two field periods of a bifurcated MHH2 equilibrium at average $\beta = 0.06$ with pressure $p = p_0(1 - s^{1.1})^{1.1}$ and with net current bringing the rotational transform into the interval $0.64 > \iota > 0.44$. A low order ballooning mode appears in the solution, and its structure does not change much when the mesh is refined.



Iterations to quasineutrality in a Monte Carlo computation of the energy confinement time τ_E, measured in milliseconds, for an MHH2 reactor with major radius 7 m and plasma radius 2 m at efficient conditions with average $T = 20\,\mathrm{keV}$, $n = 1.4 \times 10^{14}\,\mathrm{cm}^{-3}$, and $B = 6\,\mathrm{T}$. The magnetic spectrum has excellent quasiaxial symmetry, and the radial electric field rises to a potential level twice as big as the temperature.



Exterior view of 6 out of 12 modular coils of the MHH2 reactor in a magnetic field given by the Biot-Savart law. There is ample room between each pair of coils to allow for ports to take care of maintenance from the outside, where the geometry is similar to that in a tokamak. At the isolated point where they touch the coils can be separated a little by reshaping them. Smooth coils produce robust flux surfaces that do not deteriorate when changes are made in the vertical and toroidal fields.

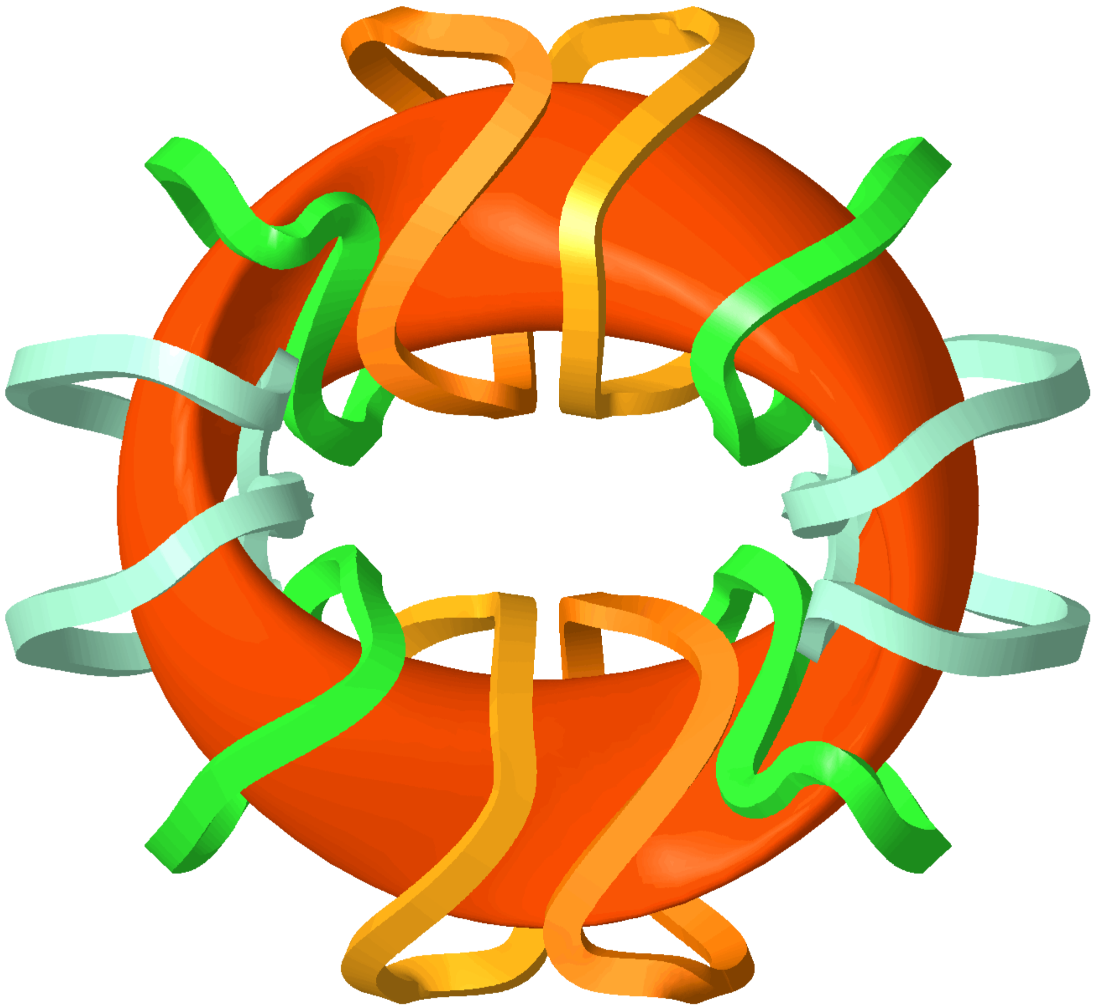
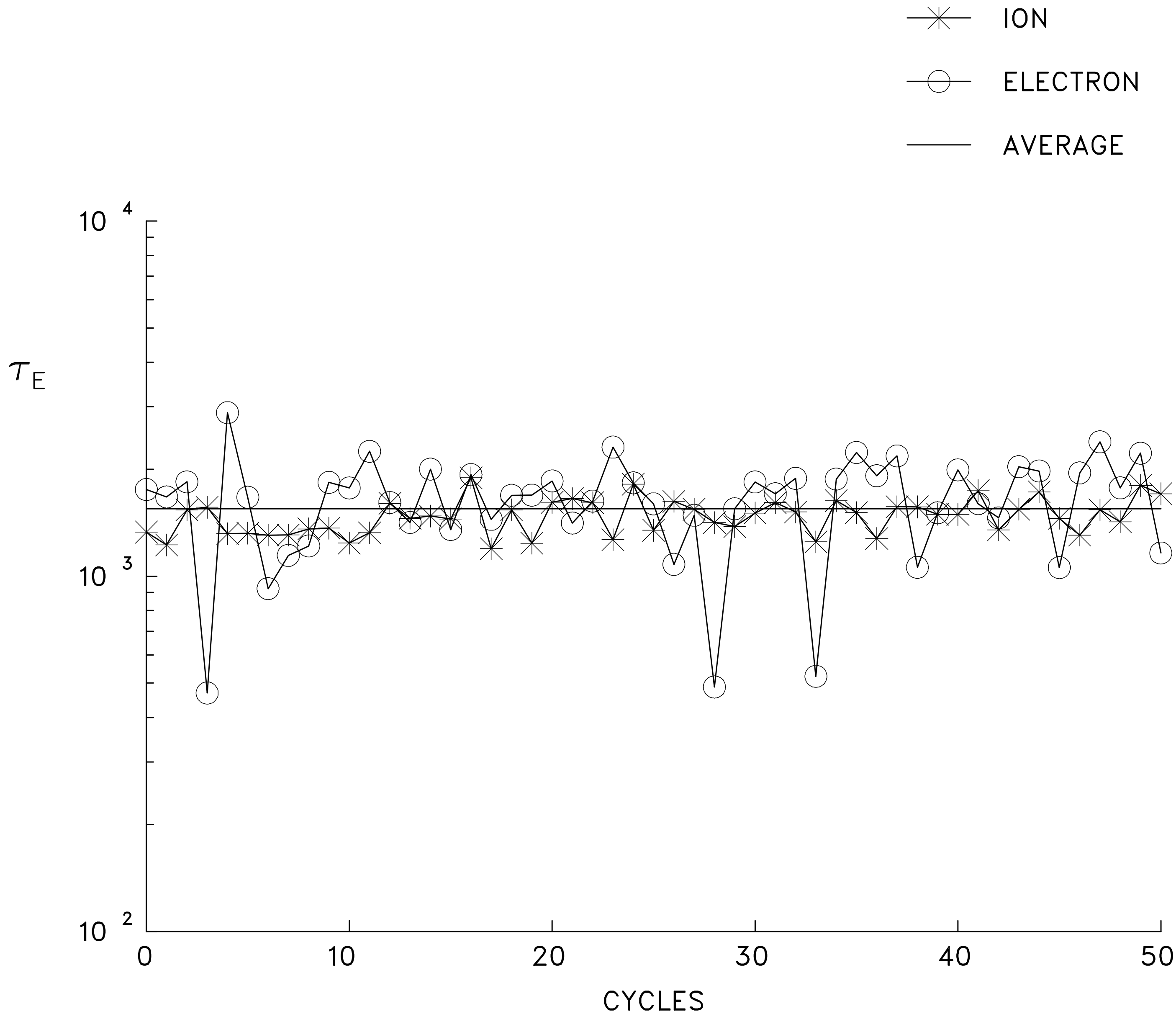
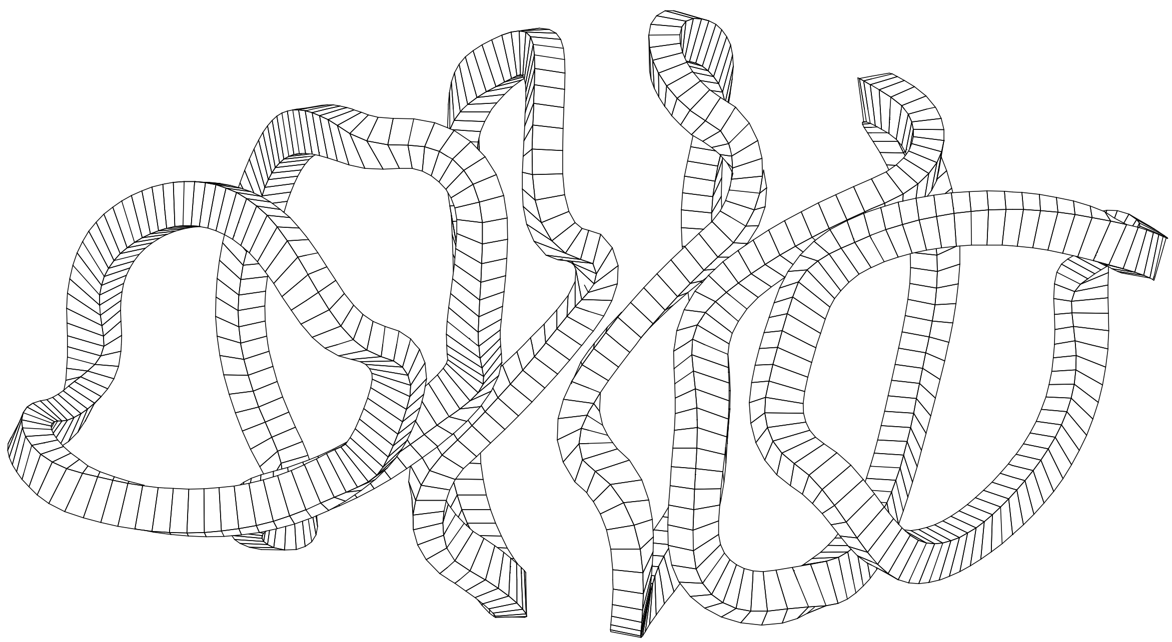


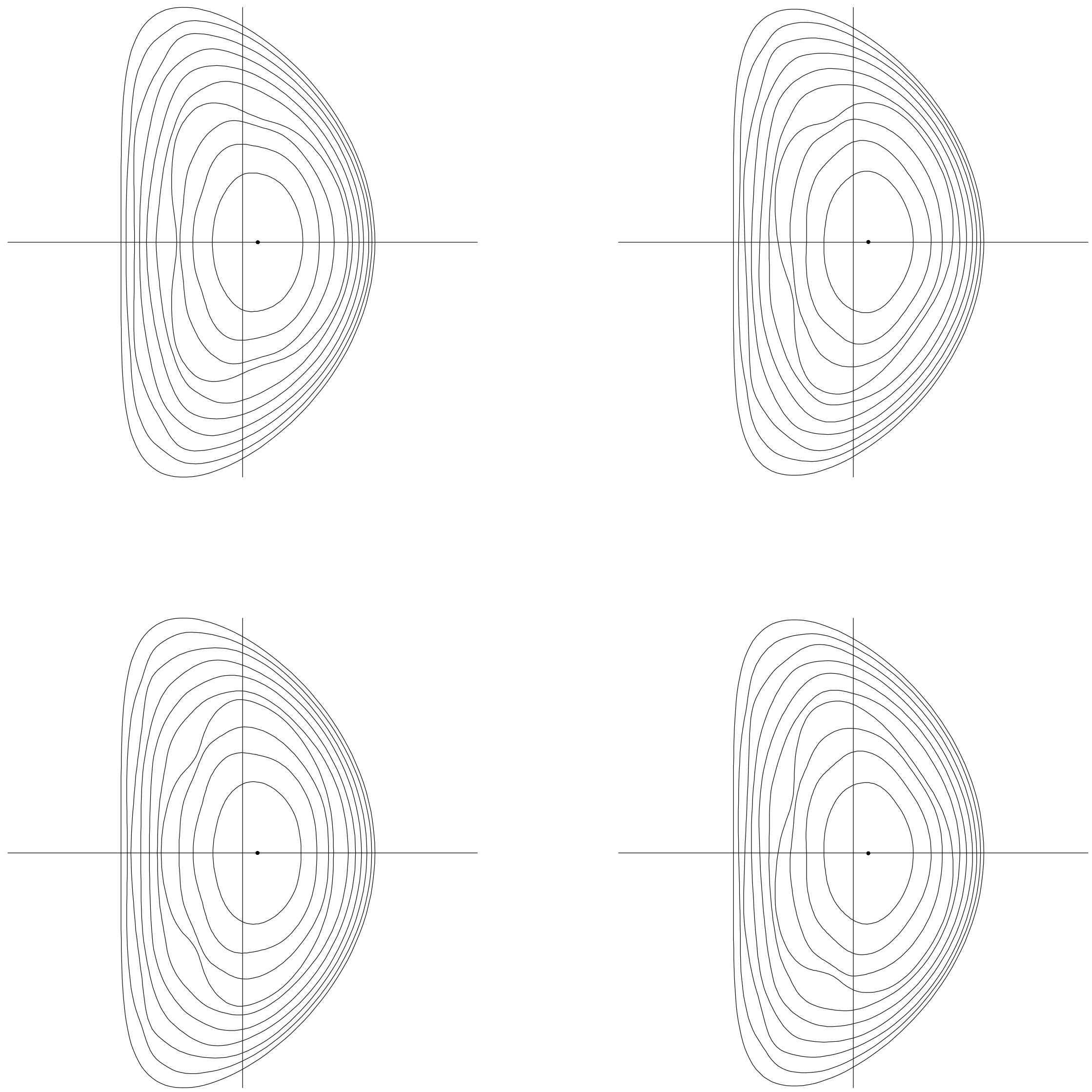
Diagram of an MHH2 stellarator with $A = 3.5$ designed by running the NSTAB equilibrium code. Twelve moderately twisted modular coils needed to produce the external field are shown. This configuration is a candidate for the stellarator reactor study being conducted at UCSD. Maintenance seems to be feasible through ports between each pair of coils. (Courtesy of Tak-Kuen Mau and Tsueren Wang.)



Iterations to quasineutrality in a Monte Carlo computation of the energy confinement time τ_E, measured in milliseconds, for a KG3 reactor with major radius 7.2 m and plasma radius 1.6 m at conditions with average $T = 15\,\mathrm{keV}$, $n = 2\times 10^{14}\,\mathrm{cm}^{-3}$, and $B = 6.5\,\mathrm{T}$. The magnetic spectrum has good quasiaxial symmetry, and the radial electric field rises to a potential level twice as big as the temperature.



Asymmetric view of 6 out of 18 modular coils for the KG3 stellarator in a vacuum magnetic field given by the Biot-Savart law. Parameters have been adjusted to provide ample space around each coil, and the aspect ratio of the plasma is 4.5. The low number of coils generates significant ripple in the magnetic field. The smallest gap between the separatrix and the filaments defining the coils is two thirds of the plasma radius.



Four cross sections of the flux surfaces over half the torus of a bifurcated ITER equilibrium at $\beta = 0.05$ with $p = p_0(1 - s^{1.1})^{1.1}$ and with net current bringing the rotational transform into the interval $0.9 > \iota > 0.3$. There is a large $m = 3,\ n = 2$ magnetic island at $\iota = 2/3$ in the solution. The calculation suggests that this advanced tokamak reactor is dangerously close to being nonlinearly unstable.