POWER PLANT STUDY OF COMPACT STELLARATORS

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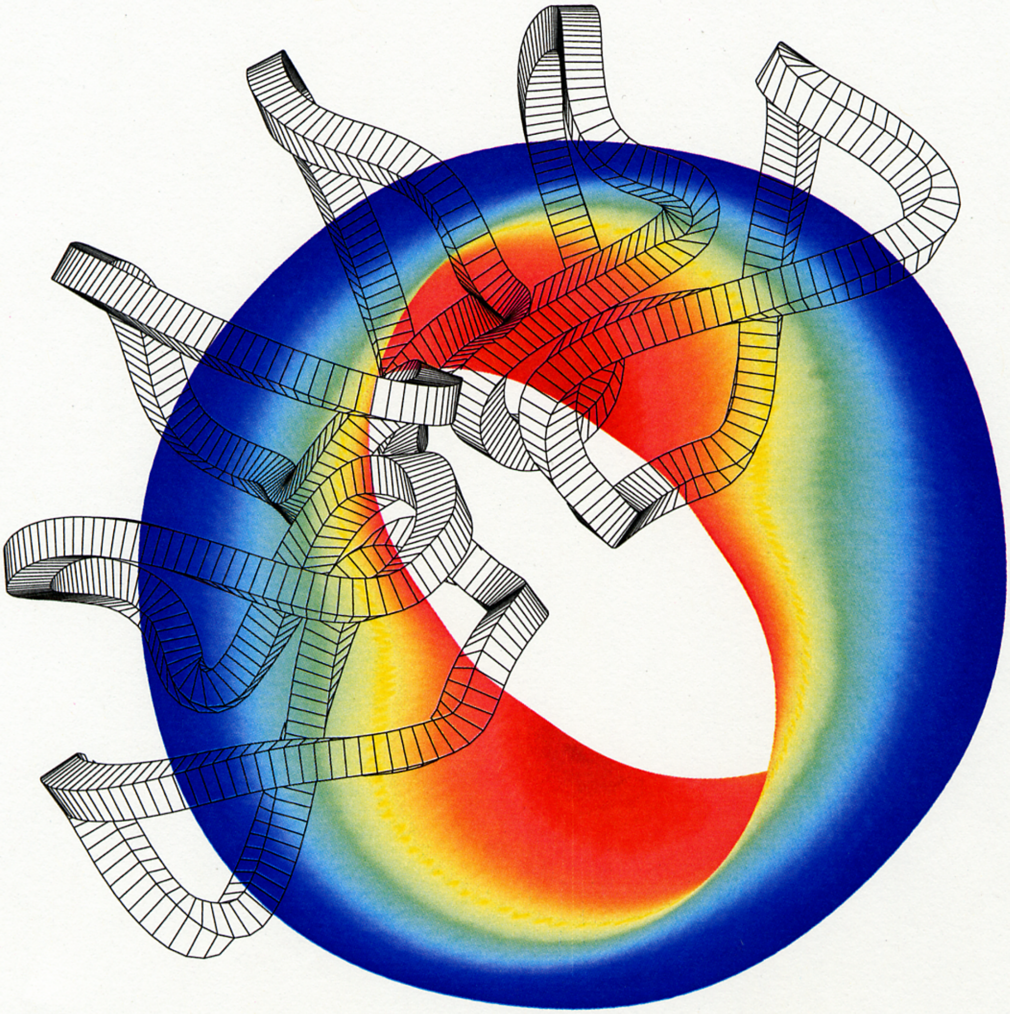
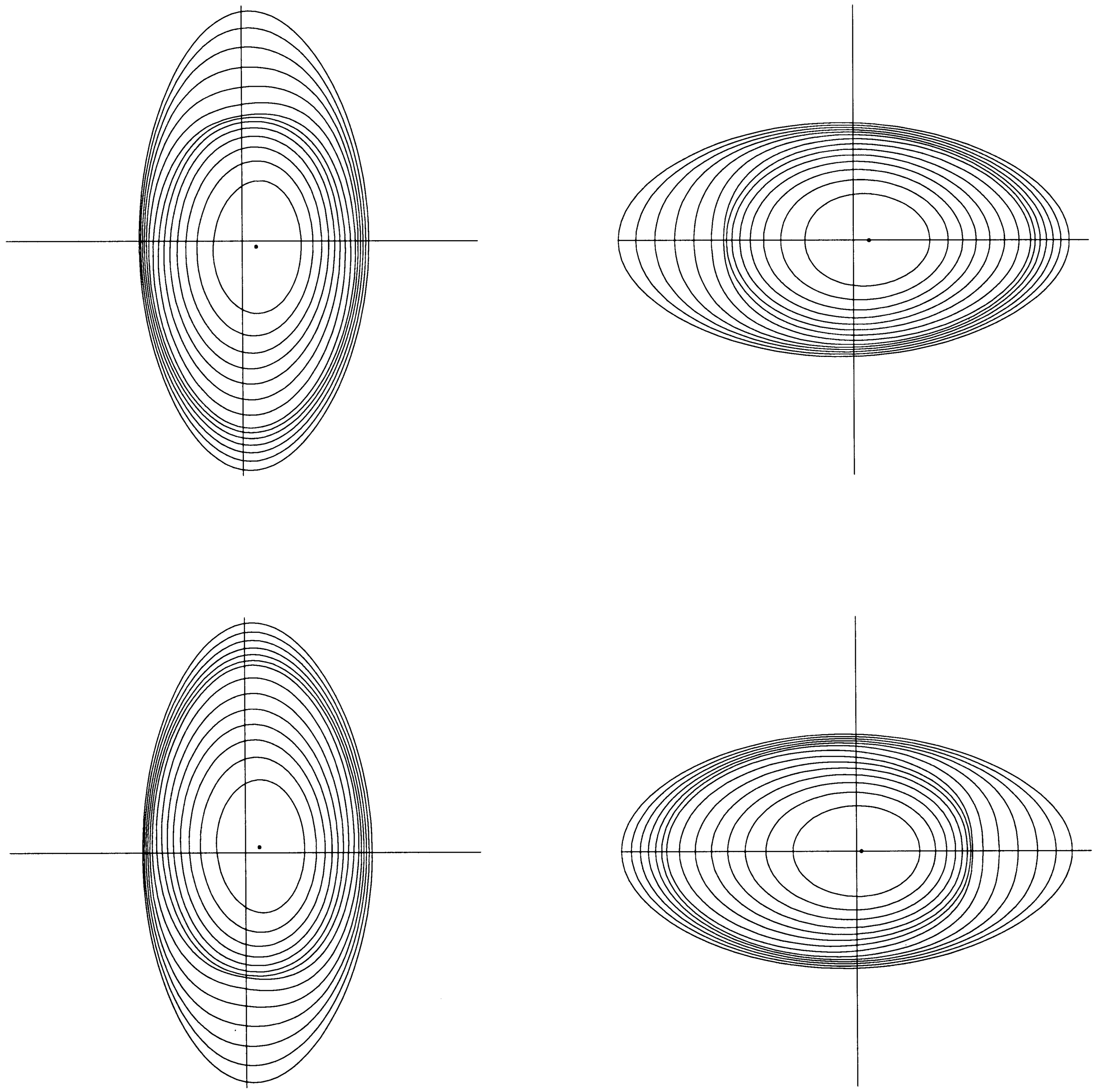
The NSTAB code has been run to show that the LHD stellarator is linearly unstable, but remains nonlinearly stable, at the β of 3.2% achieved experimentally. At observed temperatures of 3 keV the TRAN code predicts an energy confinement time of 160 ms that agrees with measured values. Predictions of ballooning stability for the LHD are more pessimistic than estimates from bifurcated solutions calculated over 1, 2, 5 or 10 periods.

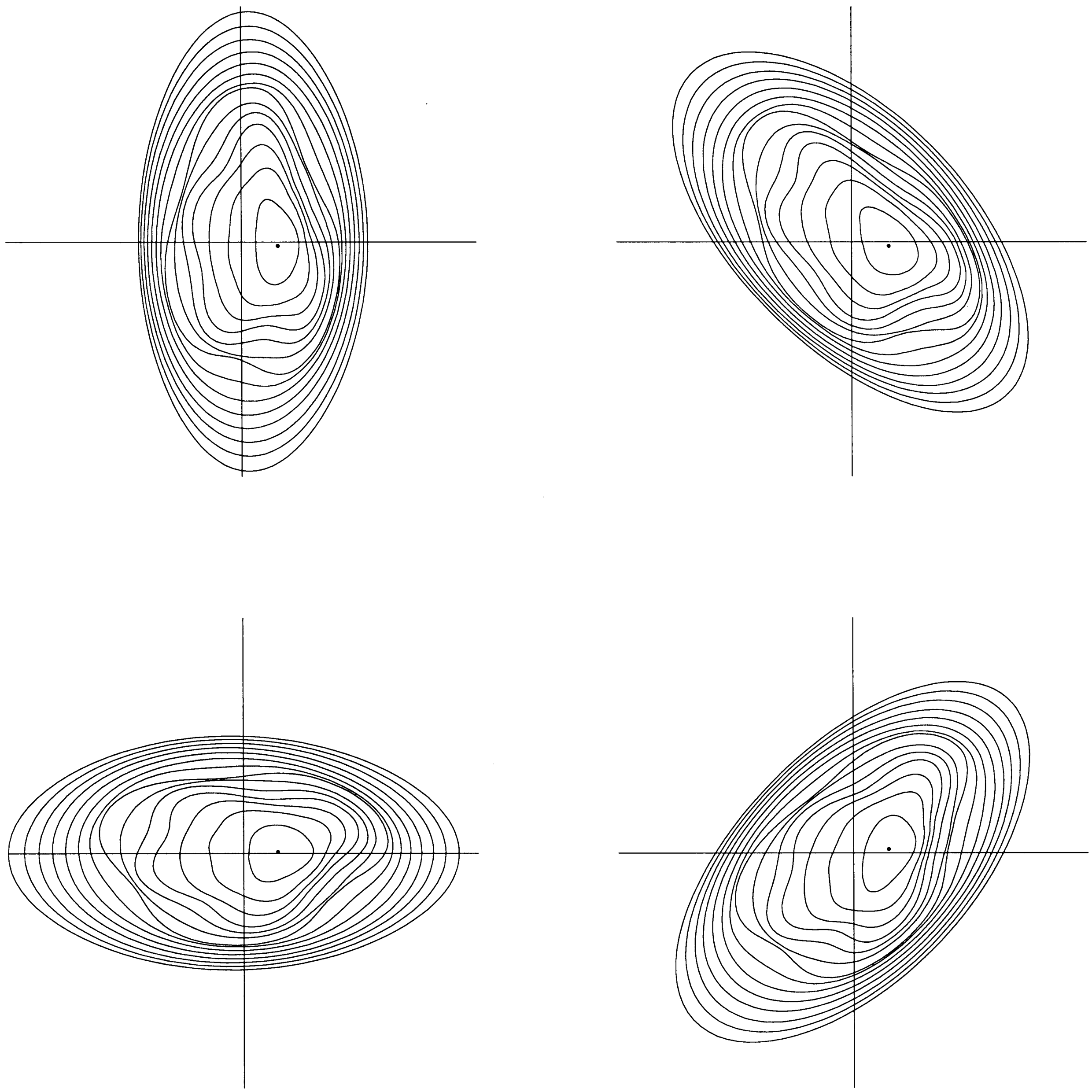
Good correlation of computations with observations in the LHD have been applied to assess equilibrium, stability, and transport for a quasiaxially symmetric MHH2 stellarator. A reactor has been designed that has major radius 9 m and plasma radius 3 m. The β limit is 4.5%, and 12 only moderately twisted coils provide robust magnetic surfaces.



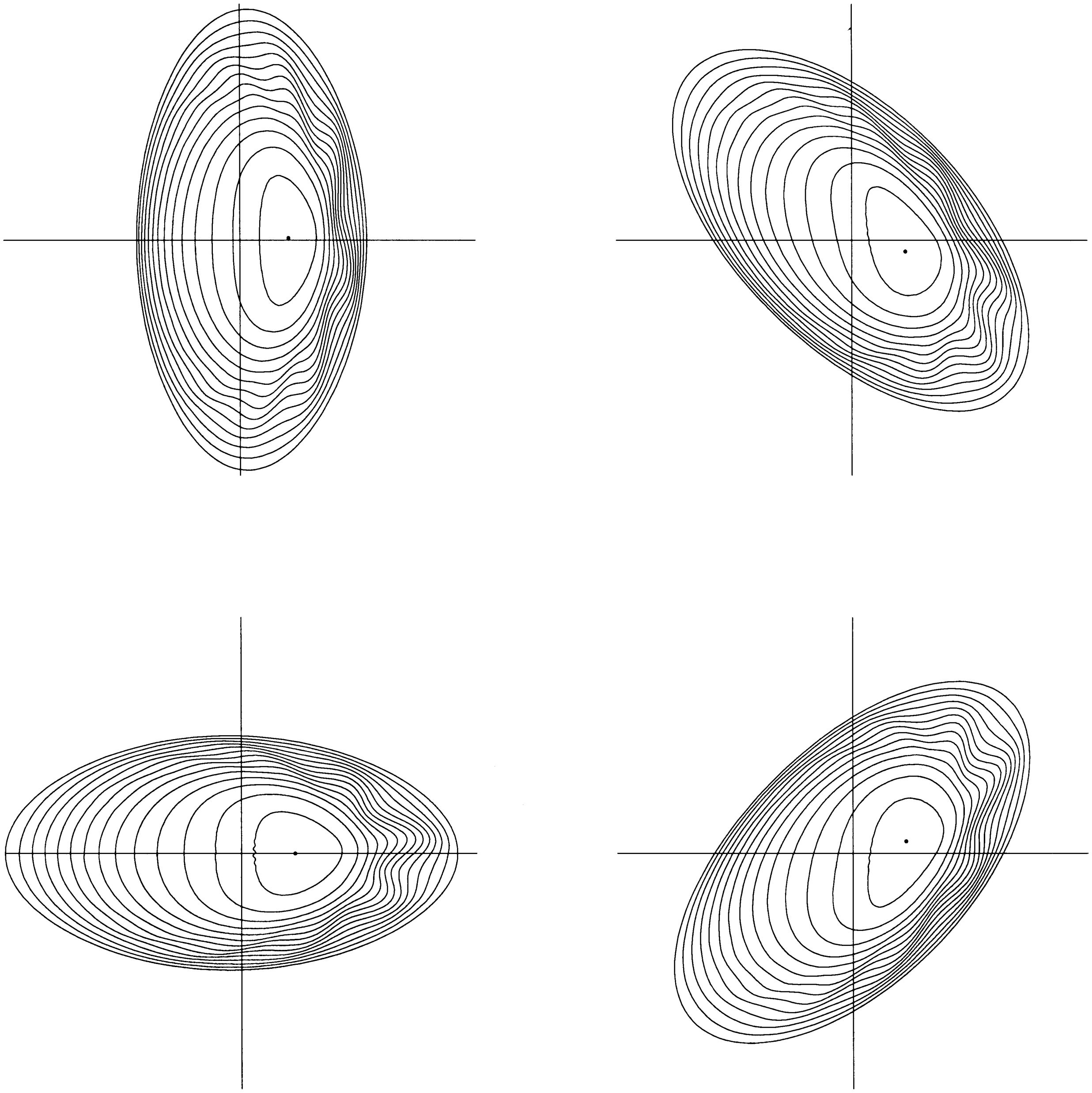
Computational model of fusion plasma in a thermonuclear reactor based on the stellarator concept for magnetic confinement of hot ions and electrons. Twelve moderately twisted modular coils, half of which are plotted, produce a magnetic field whose strength has a desirable symmetry displayed by the color map of the plasma surface.



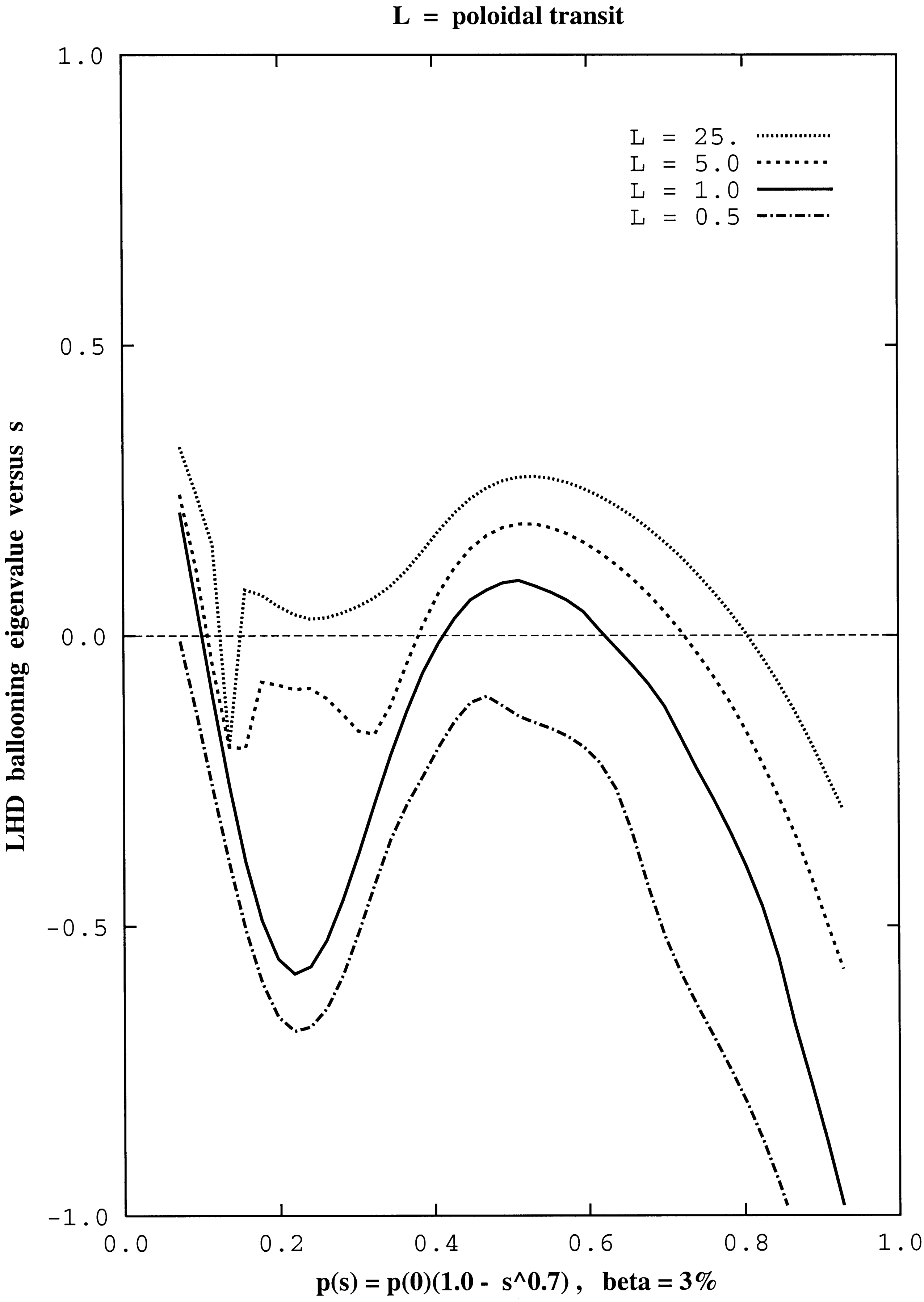
Poincaré map of the flux surfaces at four cross sections over the full torus of a bifurcated LHD equilibrium at $\beta = 0.025$ with the magnetic axis shifted inward to a position with plasma radius $R = 3.6$. For a standard pressure profile $p = p_0(1 - s)$, and with bootstrap current, the global $m = 1, n = 1$ mode of this solution is linearly unstable, but nonlinearly stable.

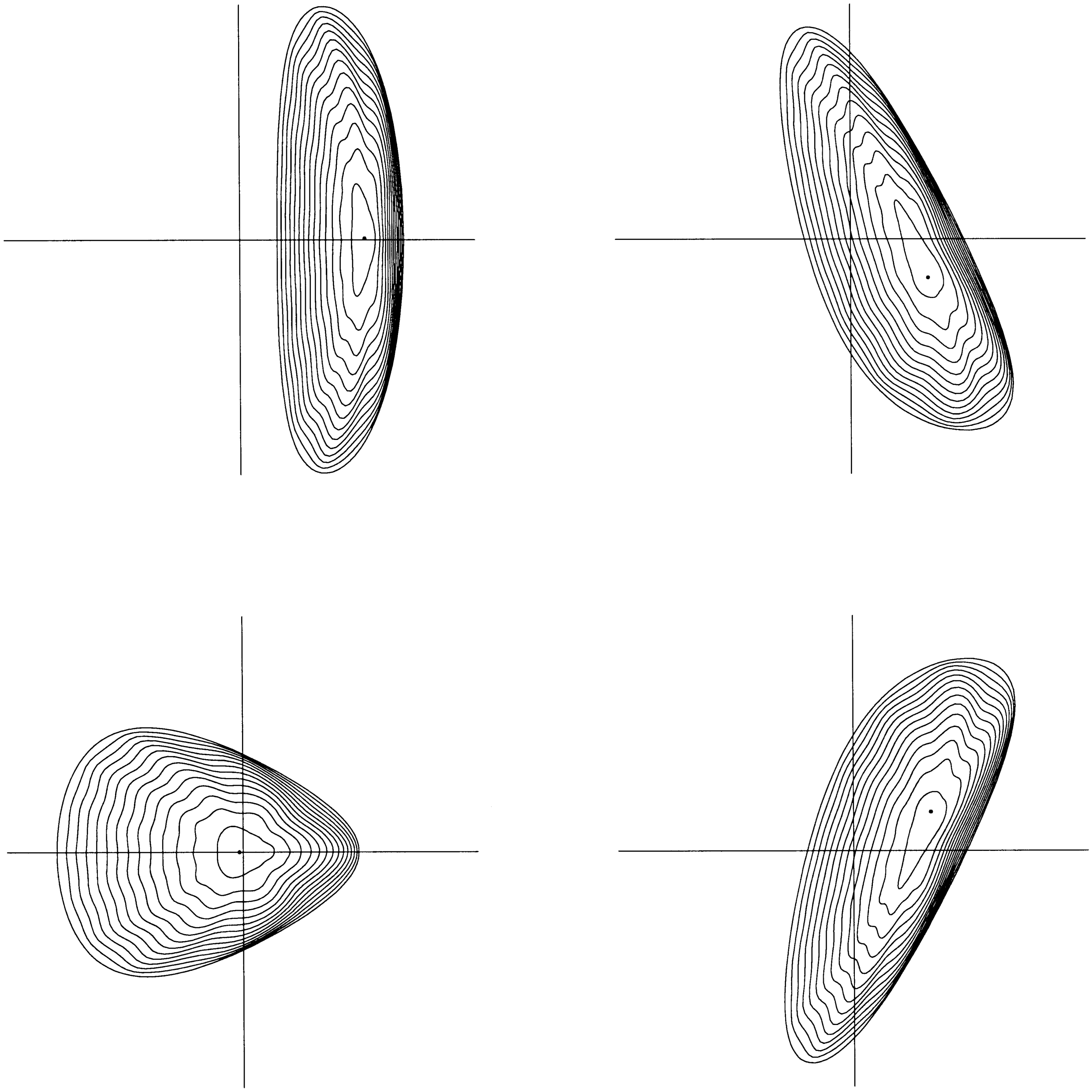


Poincaré map of the flux surfaces at four cross sections over five field periods of a bifurcated LHD equilibrium at $\beta = 0.02$ with the magnetic axis shifted inward to a position with plasma radius $R = 3.6$. For a triangular pressure profile $p = p_0(1 - s^{0.7})$ like observed values of the electron temperature, the solution is linearly unstable but nonlinearly stable.

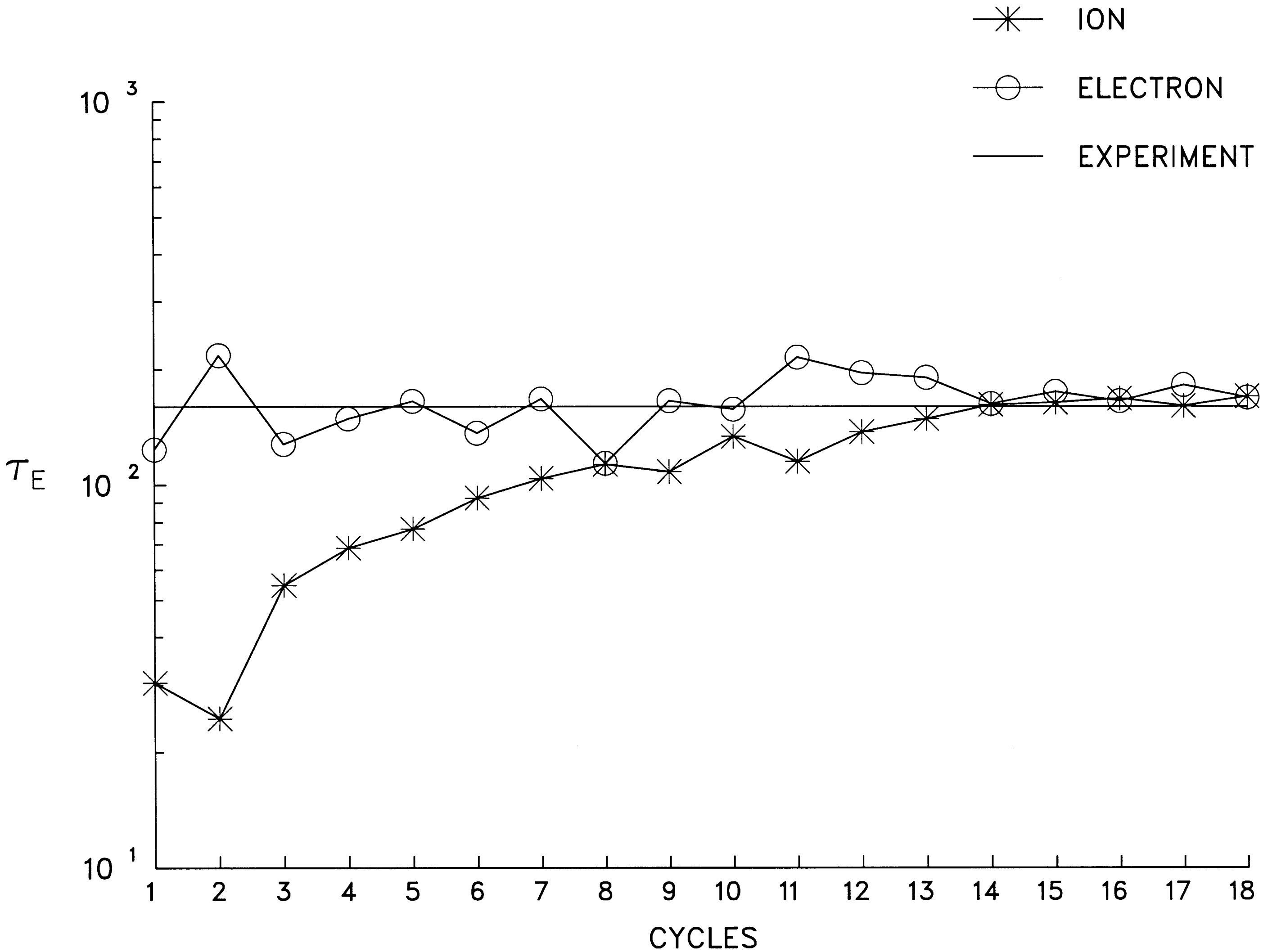


Poincaré map of the flux surfaces at four cross sections over one field period of a bifurcated LHD equilibrium at $\beta = 0.04$ with the magnetic axis shifted inward to a position with plasma radius $R = 3.6$. For a standard pressure profile $p = p_0(1 - s)$, this solution developed a ballooning mode and is becoming nonlinearly unstable. The mode was stable at $\beta = 0.03$.

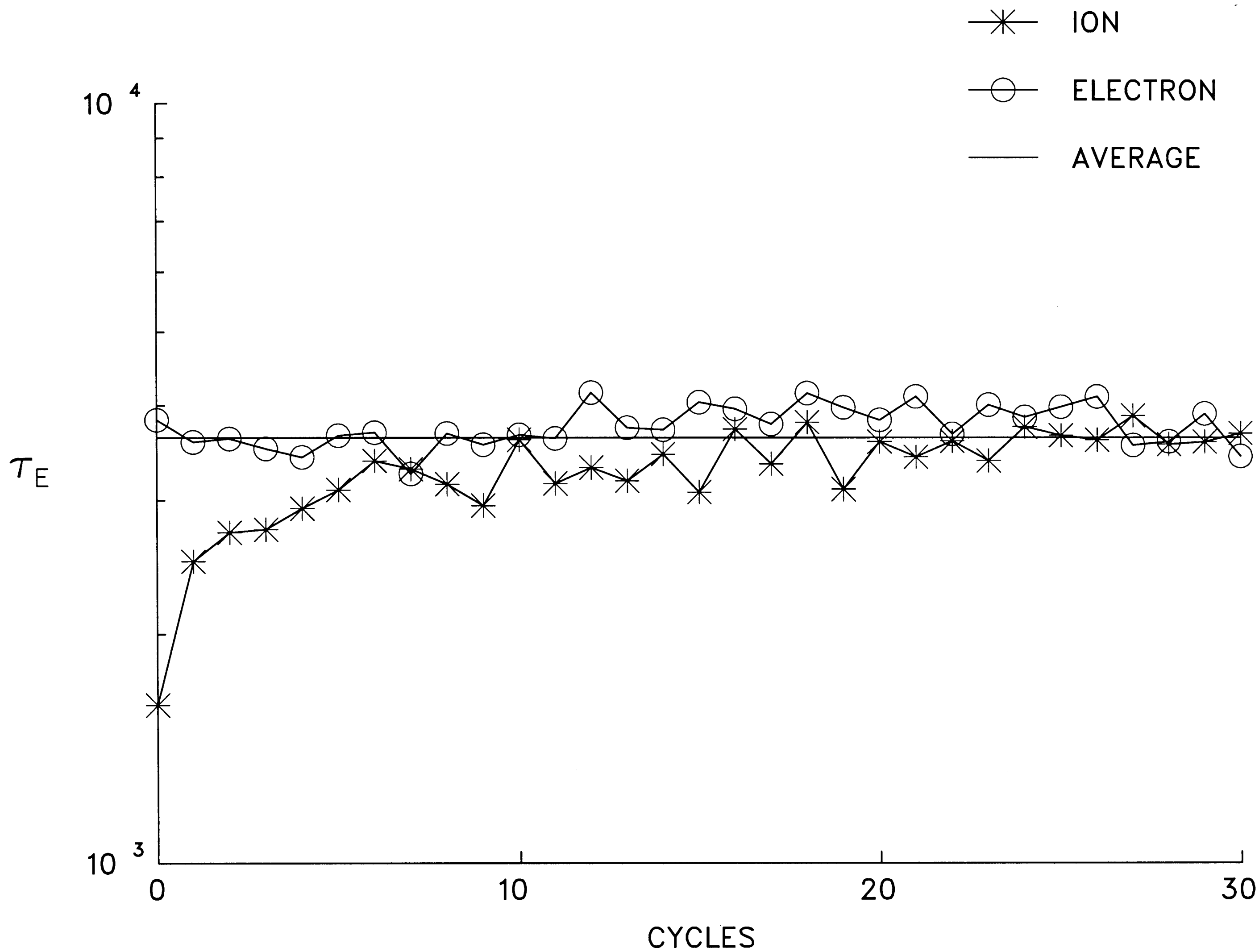

L = poloidal transit
L = 25.
L = 5.0
L = 1.0
L = 0.5
1.0
0.5
0.0
-0.5
-1.0
0.0
0.2
0.4
0.6
0.8
1.0
LHD ballooning eigenvalue versus s
p(s) = p(0)(1.0 - s^0.7) , beta = 3%



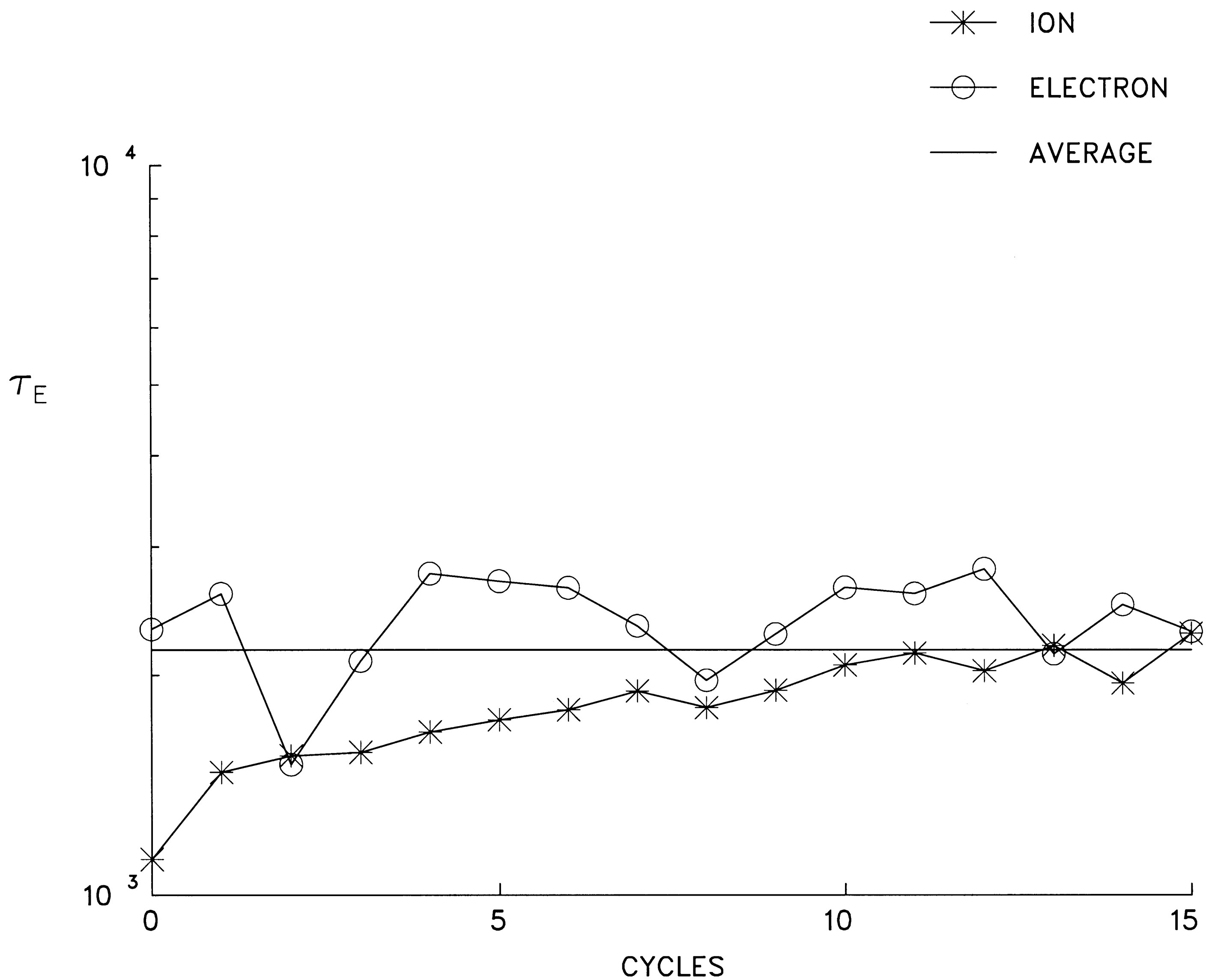
Four cross sections of the flux surfaces over one field period of a bifurcated W7-AS equilibrium at $\beta = 0.03$ with a pressure profile $p = p_0(1 - s)$ and with net current bringing the rotational transform into the interval $0.6 > \iota > 0.5$. At conditions related to those in the experiment an ideal MHD mode with ballooning structure appears in the calculation. After some of the net current was removed the solution became stable, which is consistent with recent obsrvations at $\beta = 0.033$.



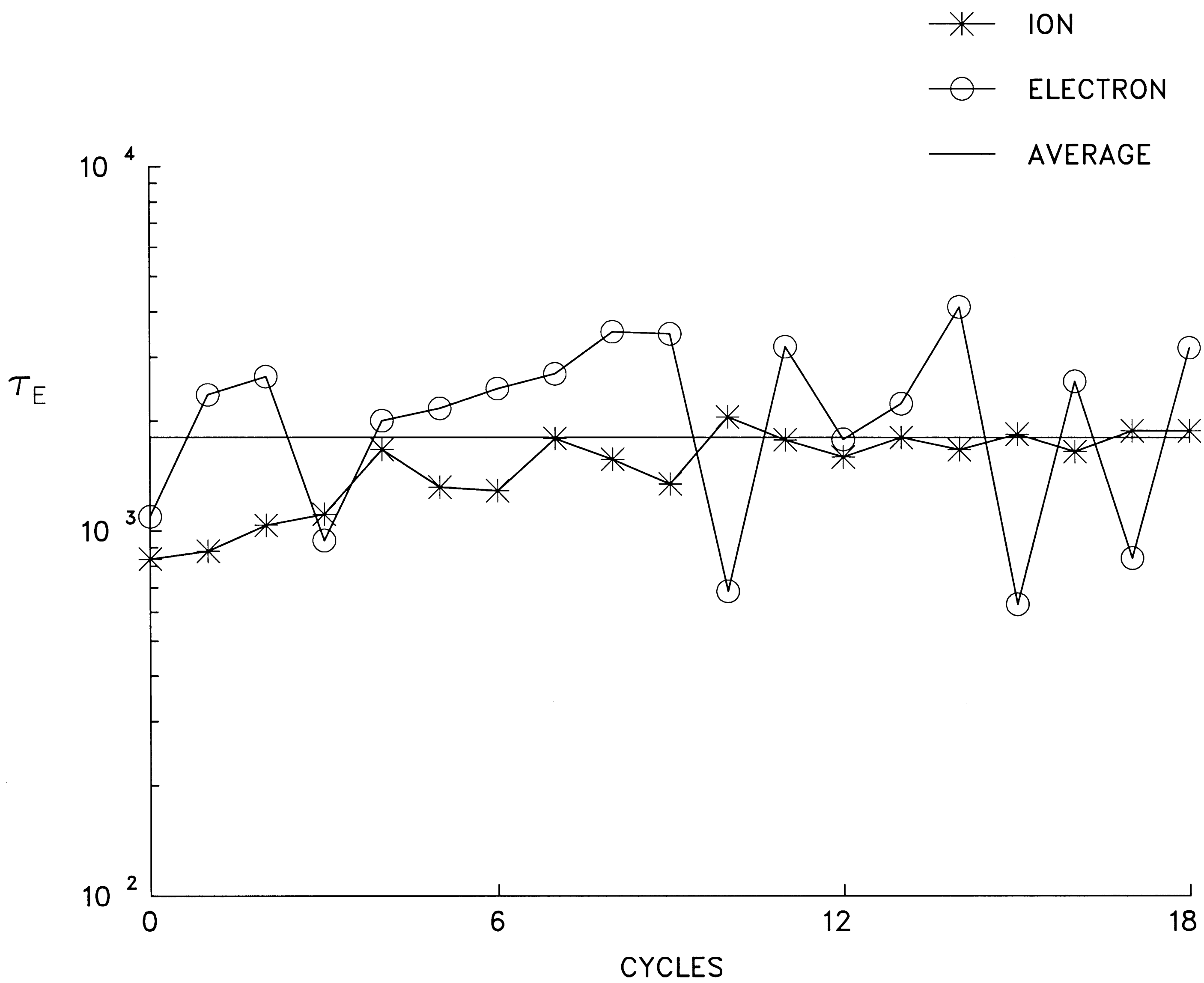
Cycles of a calculation of the energy confinement time τ_E in milliseconds for an NBI shot of the LHD experiment using a quasineutrality algorithm to adjust the electric potential Φ. Oscillations of Φ along the magnetic lines model turbulence and anomalous transport, so there is good agreement with the measured value.



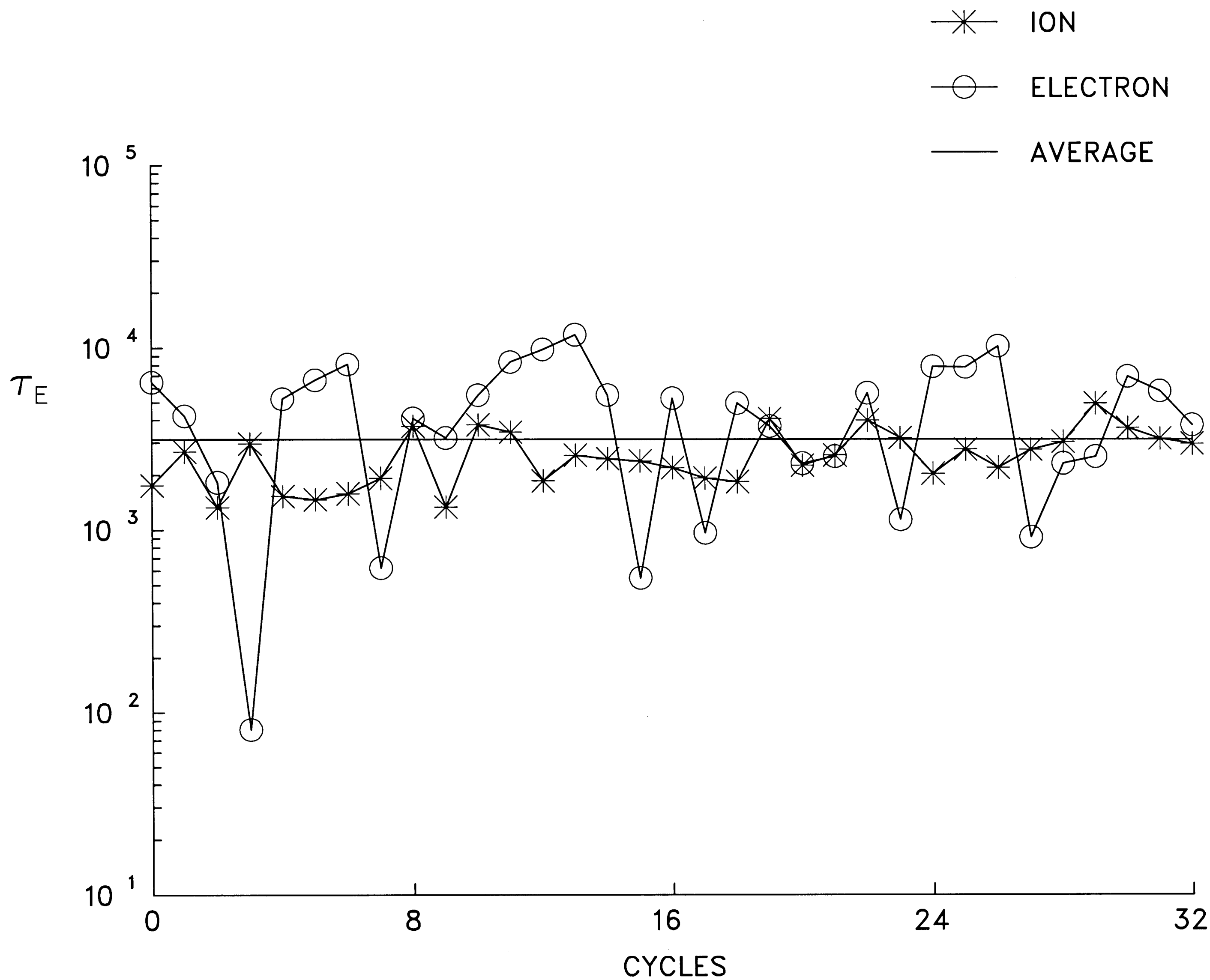
Iterations to quasineutrality in a Monte Carlo study of the energy confinement time τ_E, measured in milliseconds, for an LHD stellarator with major radius 25 m and plasma radius 4.5 m at reactor conditions with average $T = 12\,\text{keV}$, $n = 1.2 \times 10^{14}\,\text{cm}^{-3}$, and $B = 5\,\text{tesla}$. Transport is good because the radial electric field has risen to a potential level four times as big as the temperature.



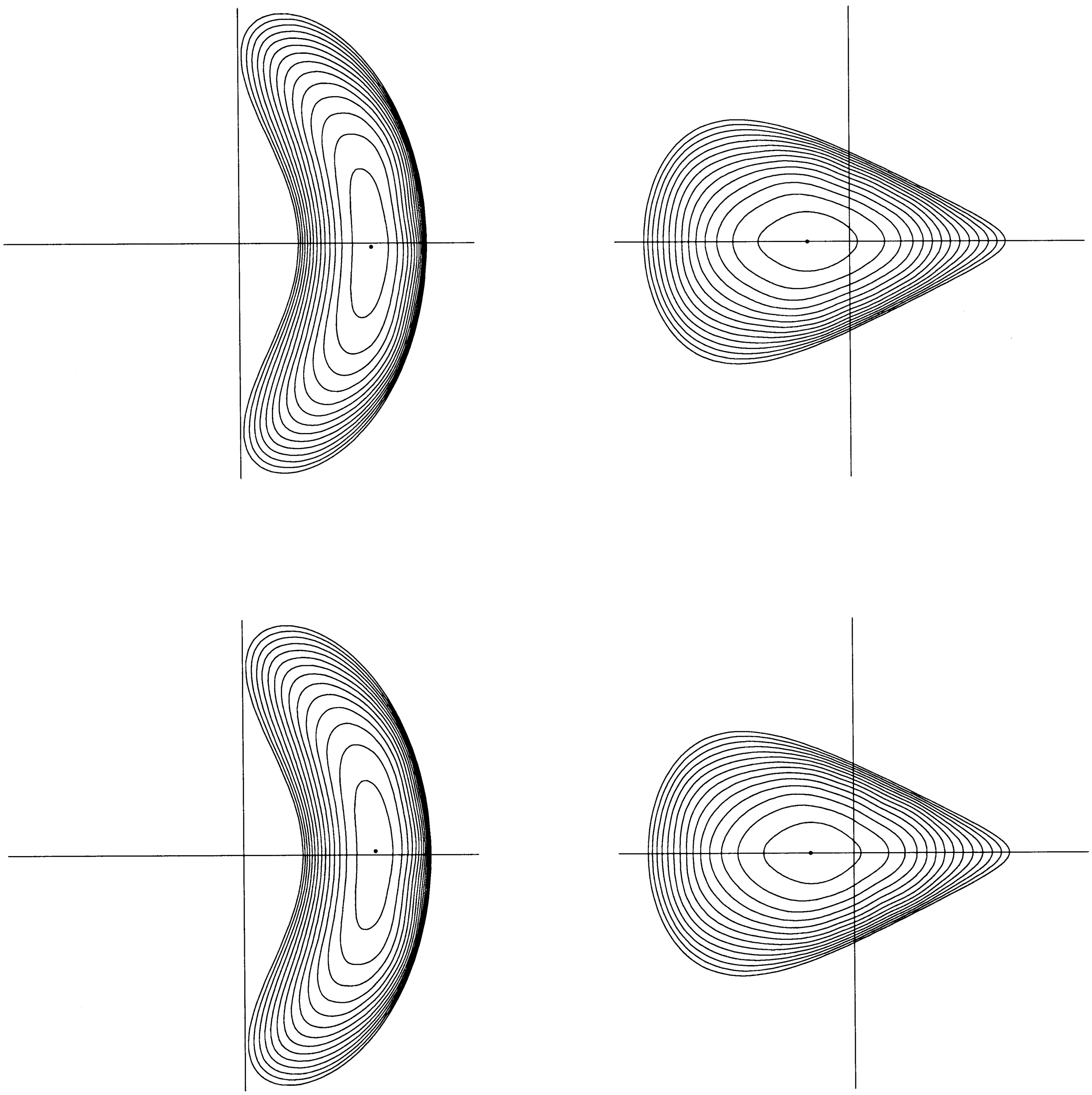
Iterations to quasineutrality in a Monte Carlo computation of the energy confinement time τ_E, measured in milliseconds, for a QPS stellarator with major radius 12 m and plasma radius 4.5 m at reactor conditions with average $T = 12\,\mathrm{keV}$, $n = 1.4 \times 10^{14}\,\mathrm{cm}^{-3}$, and $B = 5\,\mathrm{tesla}$. The magnetic spectrum has mediocre two-dimensional symmetry, but the Pfirsch-Schlueter term B_{10} is small compared to the mirror term B_{01}.



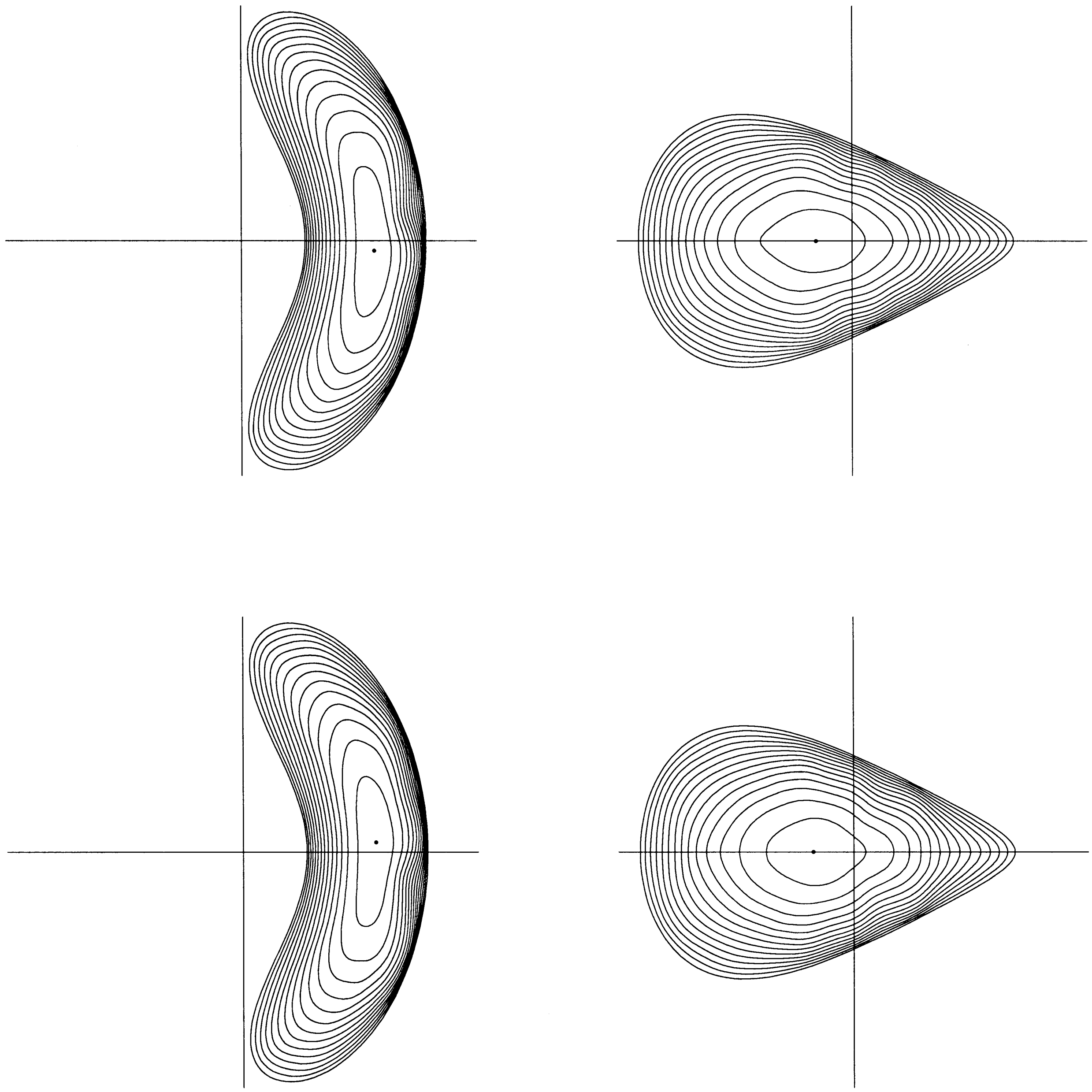
Iterations to quasineutrality in a Monte Carlo computation of the energy confinement time τ_E, measured in milliseconds, for an MHH2 stellarator with major radius 9 m and plasma radius 3 m at reactor conditions with average $T = 18\,\mathrm{keV}$, $n = 10^{14}\,\mathrm{cm}^{-3}$, and $B = 5\,\mathrm{tesla}$. The magnetic spectrum has good axial symmetry, and the radial electric field rises to a potential level twice as big as the temperature.



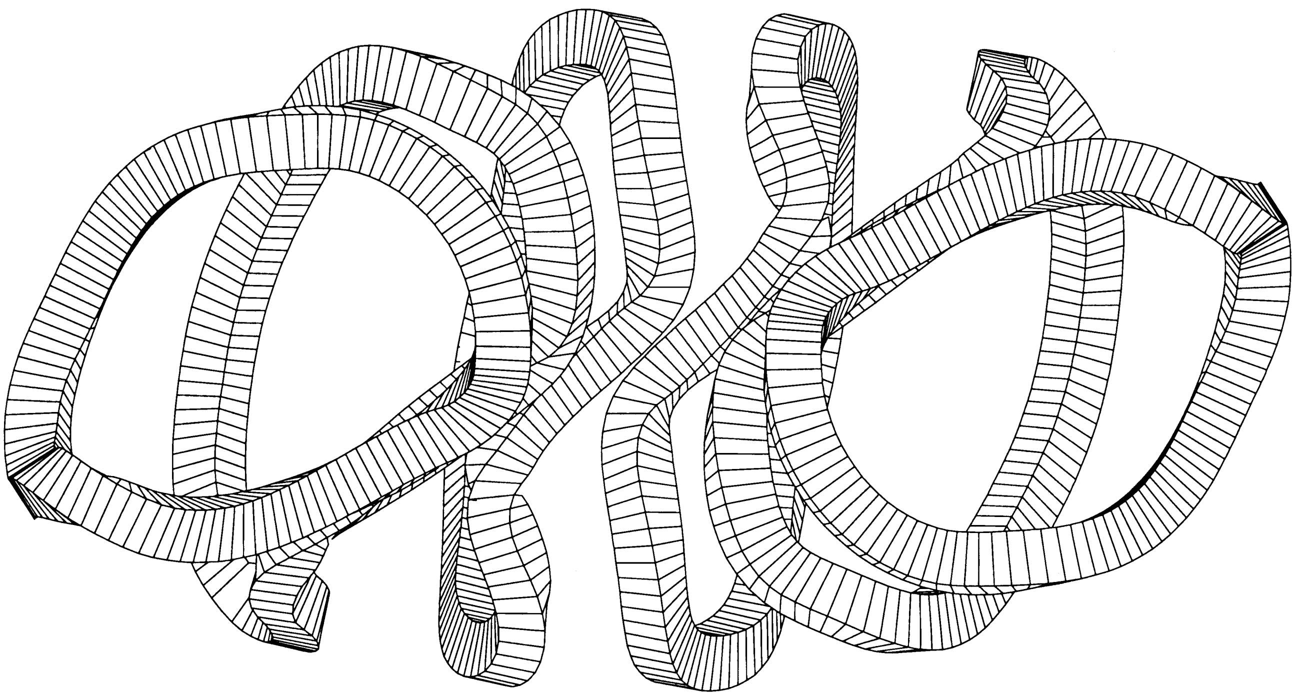
Iterations to quasineutrality in a Monte Carlo computation of the energy confinement time τ_E, measured in milliseconds, for an MHH2 stellarator with major radius 9 m and plasma radius 3 m at reactor conditions with average $T = 15\,\text{keV}$, $n = 1.2 \times 10^{14}\,\text{cm}^{-3}$, and $B = 5\,\text{tesla}$. The magnetic spectrum has good axial symmetry, but we have superimposed a mirror term anyway that improves transport by driving the radial electric field to a potential level four times as big as the temperature.



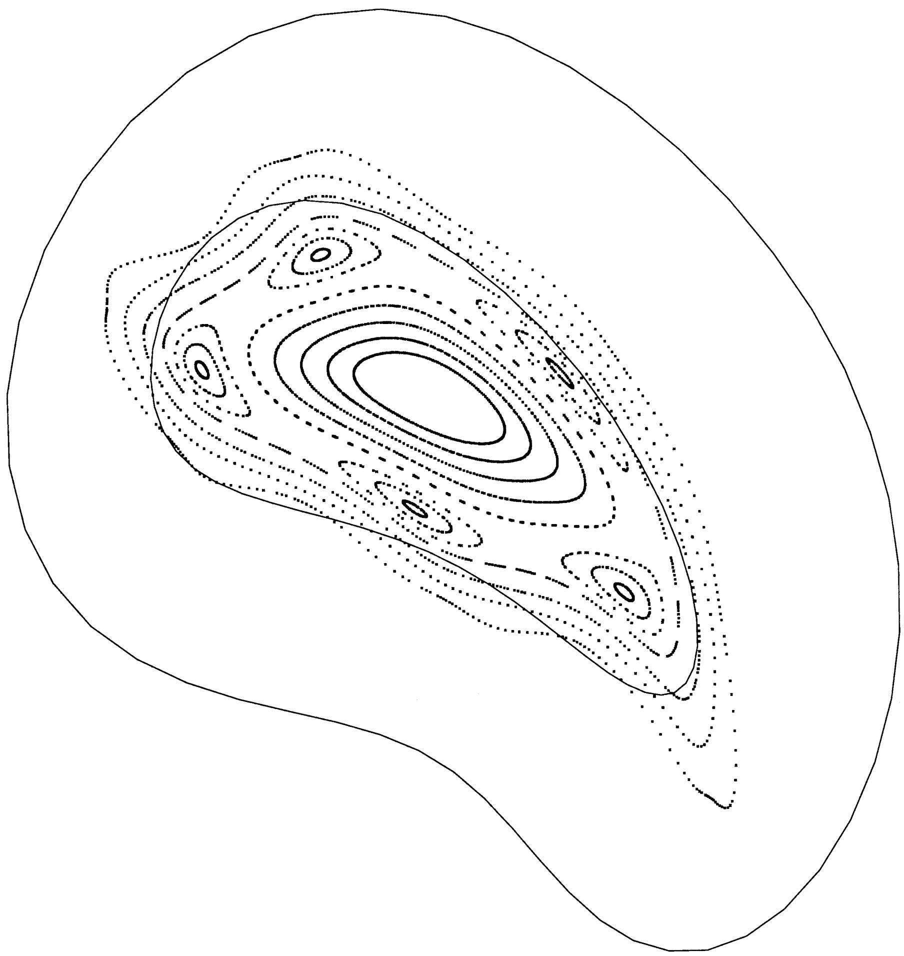
Four cross sections of the flux surfaces over the full torus of a stable MHH2 equilibrium at $\beta = 0.045$ with pressure $p = p_0(1 - s^{1.5})^{1.5}$ and with net current bringing the rotational transform into the interval $0.52 > \iota > 0.46$. In this example the NSTAB code was run 25,000 cycles using spectral terms of degree 24 in each of the poloidal and toroidal angles and using 27 radial mesh points.



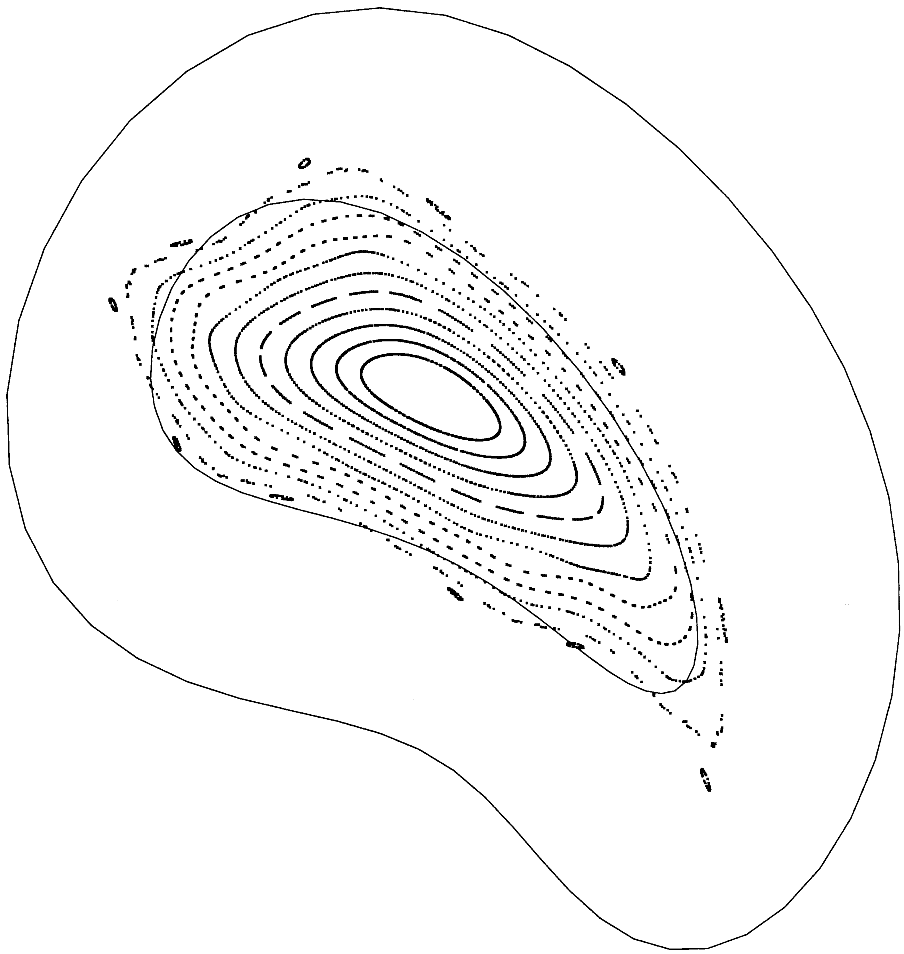
Four Poincaré sections of the flux surfaces over two field periods of a bifurcated MHH2 equilibrium with a pressure profile $p = p_0(1 - s^{1.5})^{1.5}$, a β of 6%, and with net current putting the rotational transform in the interval $0.53 \geq \iota \geq 0.51$. During a run of 25,000 cycles of the NSTAB code using trigonometric polynomials of degree 24, an asymmetric ballooning mode appeared in the solution. After the net current was reduced, the equilibrium bacame linearly stable.



Six out of twelve modular coils of the MHH2 stellarator in a vacuum magnetic field given by the Biot-Savart law. Judicious filtering of the Fourier series used to calculate filaments specifying the geometry of the configuration defines shapes that are not excessively twisted. Parameters have been adjusted to provide ample space around each coil, and the aspect ratio of the plasma is 3.5.



Poincaré section of magnetic surfaces for the MHH2 stellarator displaying the control surface for the coils, the known shape of the plasma at $\beta = 0$, and magnetic lines computed in a plasma with five big islands where the rotational transform crosses the resonant value $\iota = 2/5$.



Poincaré section of magnetic surfaces for the MHH2 stellarator displaying the control surface for the coils, the known shape of the plasma at $\beta = 0$, and magnetic lines computed in a plasma with islands that have been suppressed where the rotational transform crosses the resonant value $\iota = 2/5$.

$$\int\int\int(\frac{1}{2}B^2 - p)\,dV \;=\; \text{minimum}$$

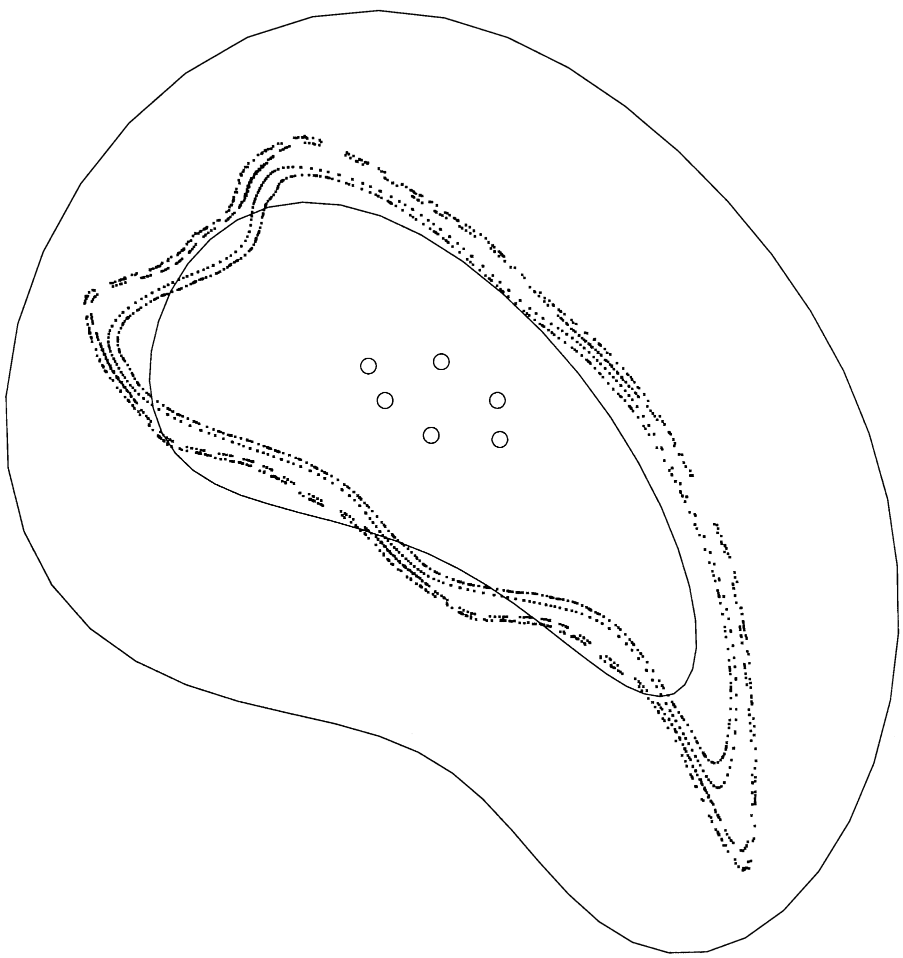
$$\mathbf{B} = \nabla s \times \nabla\theta = \nabla\phi - \zeta\nabla s\;, \quad \mathbf{J} = \nabla s \times \nabla\zeta$$

$$r + iz = e^{iu}\,\Sigma\,\Delta_{mn}\,e^{-imu+inv}$$

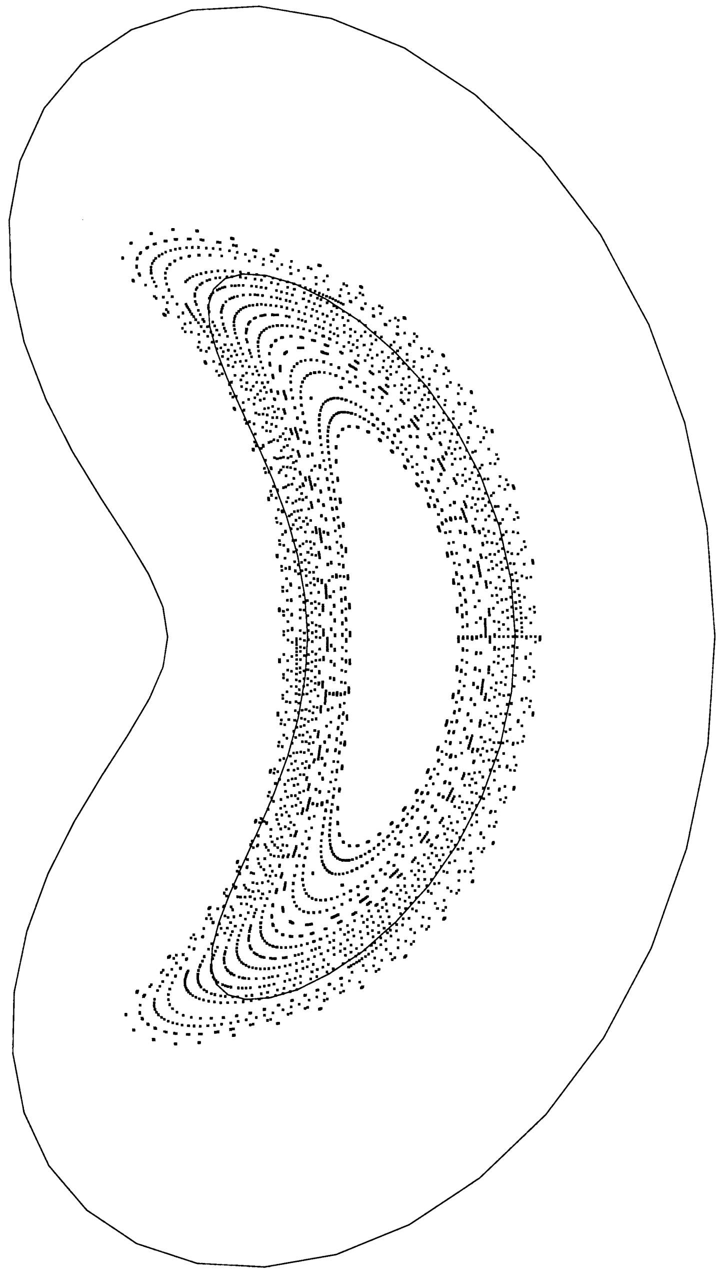
$$\frac{1}{B^2} = \Sigma\,B_{mn}\cos(m\theta - [n - \iota m]\phi)$$

$$\zeta = p'\,\Sigma\,\frac{B_{mn}}{n - \iota m}\sin(m\theta - [n - \iota m]\phi)$$

$$\mathbf{B} = \nabla \times \sum_{j=0}^{k}\;\delta s_j \int\int \frac{\nabla\zeta_j \times \mathbf{N}}{4\pi r}d\sigma$$



Poincaré section of a free boundary calculation for the MHH2 stellarator displaying the control surface for the coils, the known shape of the plasma at $\beta = 0$, filaments that simulate currents in the plasma driven by the pressure, and magnetic lines computed at finite β in the scrape-off layer of the solution, where the rotational transform is crossing the resonant value $\iota = 2/5$.



Poincaré section of magnetic surfaces for the PG3 (LI383) stellarator displaying the control surface for the coils, the known shape of the plasma at $\beta = 0$, and magnetic lines computed in a plasma with islands that have been suppressed where the rotational transform has low order resonances. It is difficult to control islands that may overlap when ι crosses 3/7, 3/6, and 3/5 near the separatrix.