QAS Design of the DEMO Reactor

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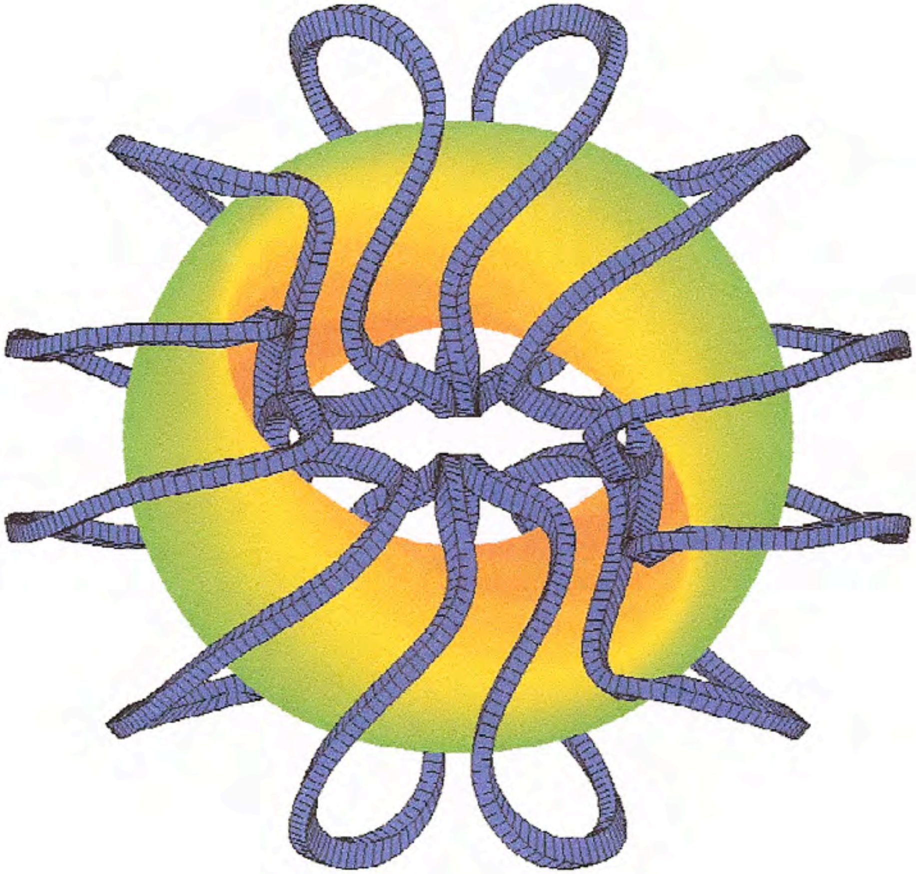
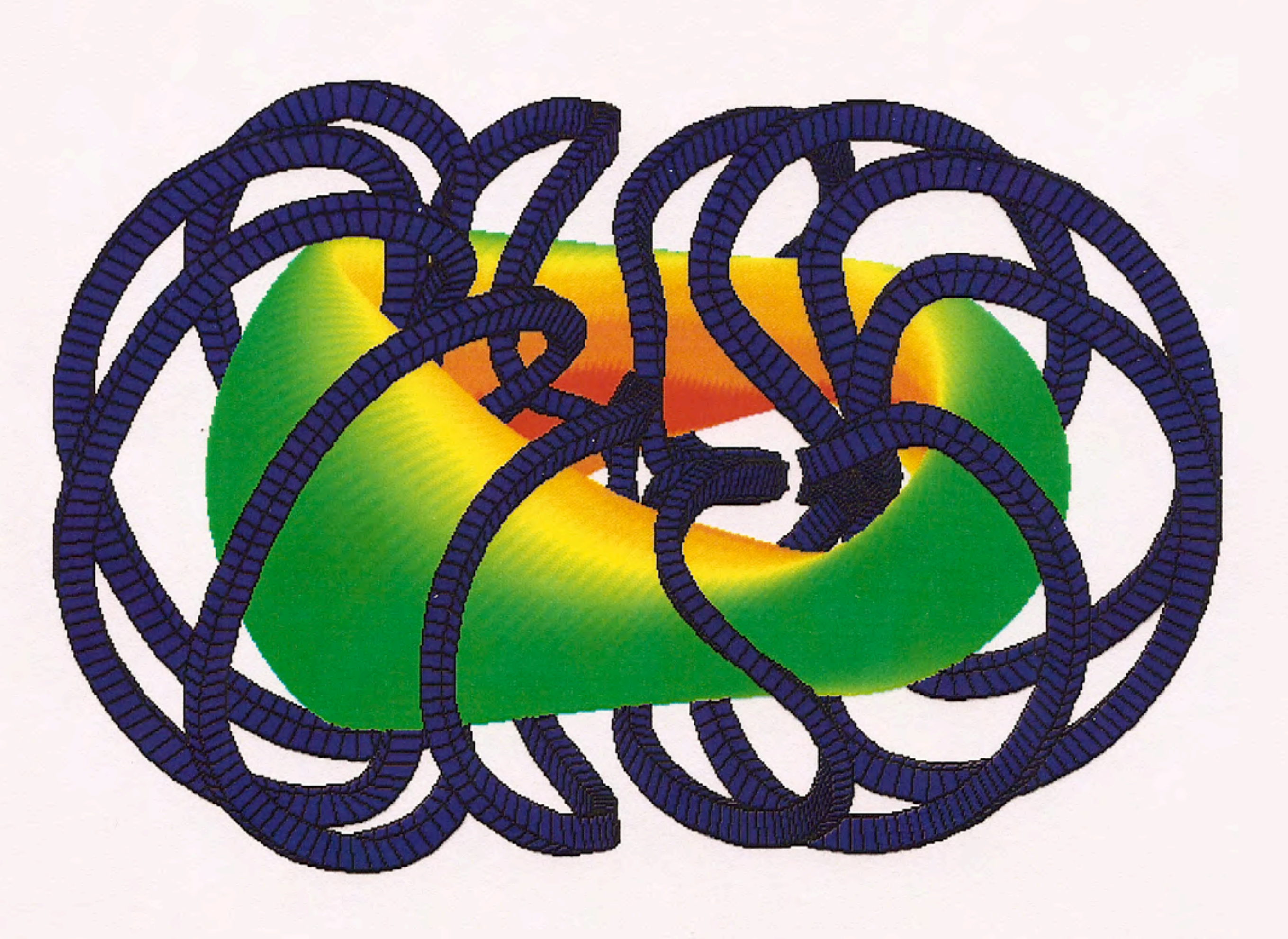
[1] Garabedian, P.R. and McFadden, G.B., J. Research NIST 114 (2009) 229-236; online at http://www.nist.gov/jres.

Quasi-Axisymmetric Stellarator Design



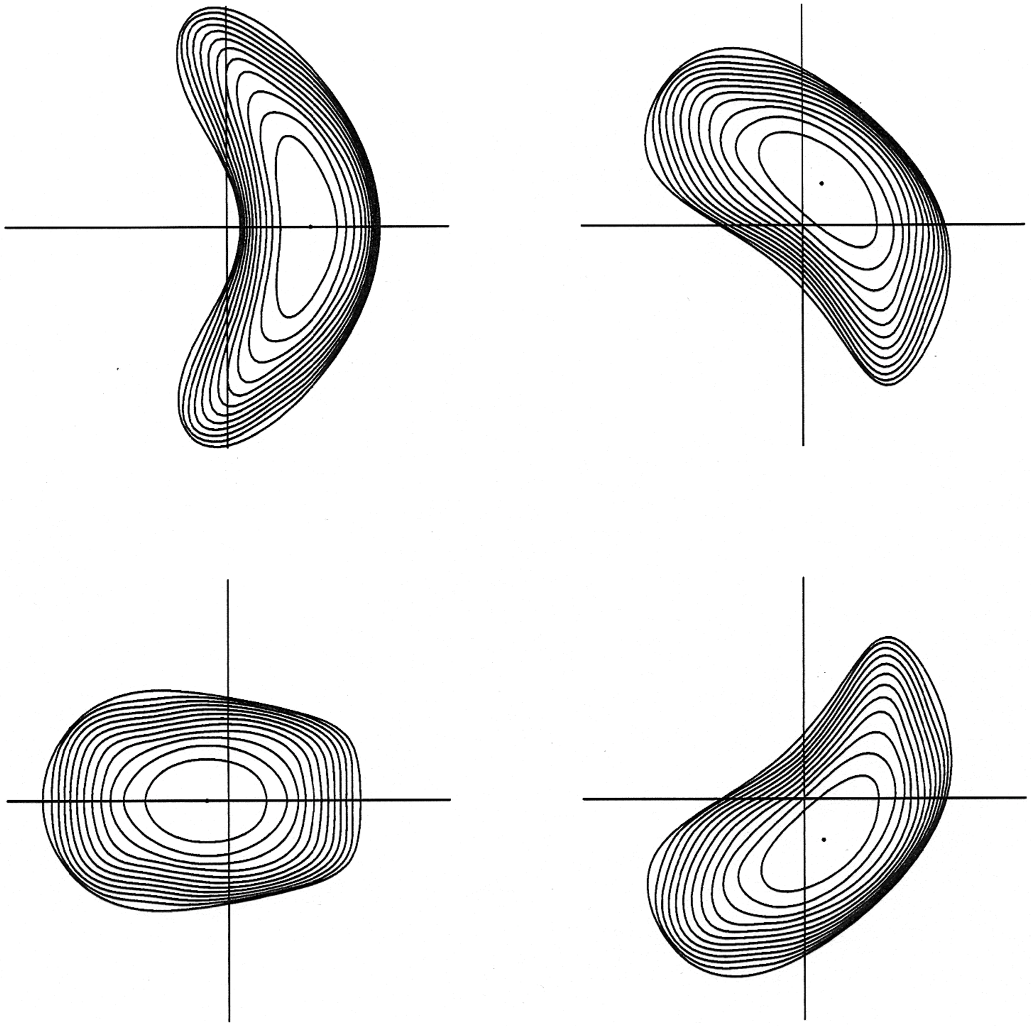
Magnetic fusion of hydrogen forms helium and emits energetic neutrons from a torus of plasma shaped to optimize confinement. Modular coils generate a field keeping the ions from hitting walls.

QAS Design



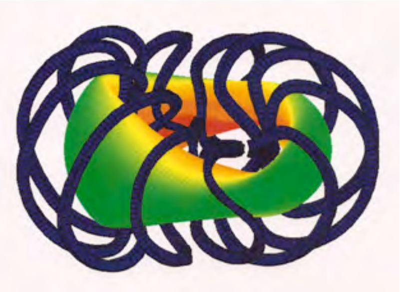
This configuration is a good candidate for DEMO because its geometry is similar to that of the ITER tokamak. There is enough flexibility in the shaping of the plasma to control the stellarator contribution to $\iota(s)$ so as to compensate for unforeseen complications with the bootstrap current.

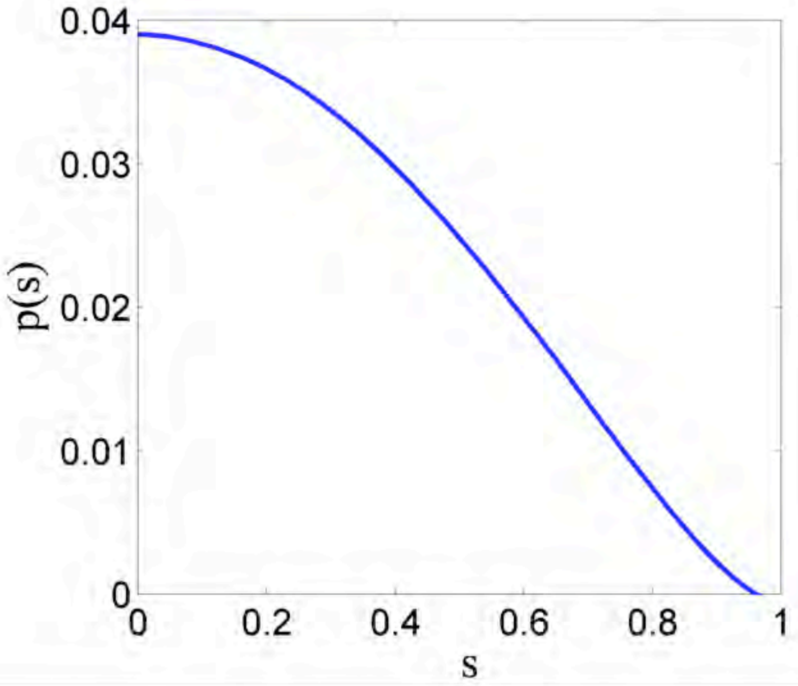
QAS Flux Surfaces

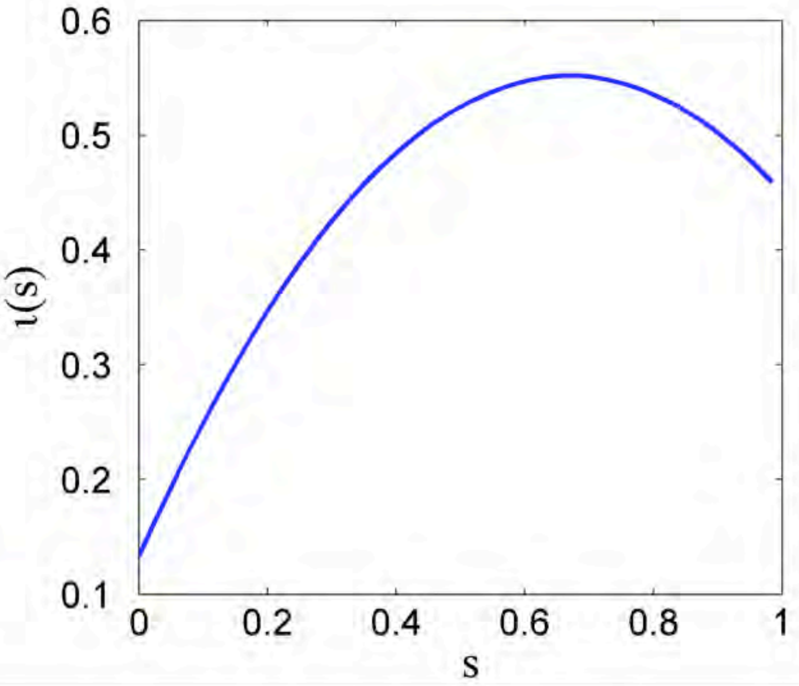


Flux surfaces at four cross sections over the two field periods of a stellarator equilibrium at $\beta = 0.04$.

QAS Pressure and Rotational Transform Profiles







For toroidal flux in the interval $0 < s < 1$ we have pressure $p(s) = 0.039(1 - s^2)^{1.5}$ and rotational transform $\iota(s) = 0.55-0.40(0.68-s)^2$.

QAS Outer Boundary

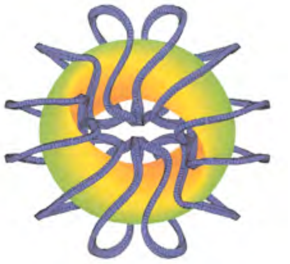
In cylindrical coordinates (r, v, z) :

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

Table 1. Fourier coefficients Δ_{mn} defining the QAS stellarator in Fig. 2 for values $m = -1, 0, 1, 2, 3, 4$ of the poloidal index and values $n = -1, 0, 1, 2, 3, 4$ of the toroidal index. This is a configuration that depends on bootstrap current for good performance

$m \backslash n$	−1	0	1	2	3	4
−1	0.200	0.140	0.000	0.000	0.000	0.000
0	0.000	1.000	0.006	0.007	0.000	0.000
1	0.042	2.500	0.084	0.006	−0.002	0.000
2	0.010	−0.100	−0.350	−0.058	−0.010	0.000
3	0.000	0.000	0.030	0.050	0.017	0.004
4	0.000	0.000	0.025	−0.020	0.000	0.000

QAS Spectrum $B_{mn}(s)$



$$B = \nabla s \times \nabla \theta = \nabla \phi + \varsigma \nabla s$$

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

$$\frac{J \cdot B}{|B|^2} = p'(s) \sum \frac{m B_{mn}(s)}{[n - \iota(s) m]} \cos[m\theta - (n - \iota(s) m)\phi]$$

$\delta B_{mn}(s) \sim \delta\Delta_{mn}$

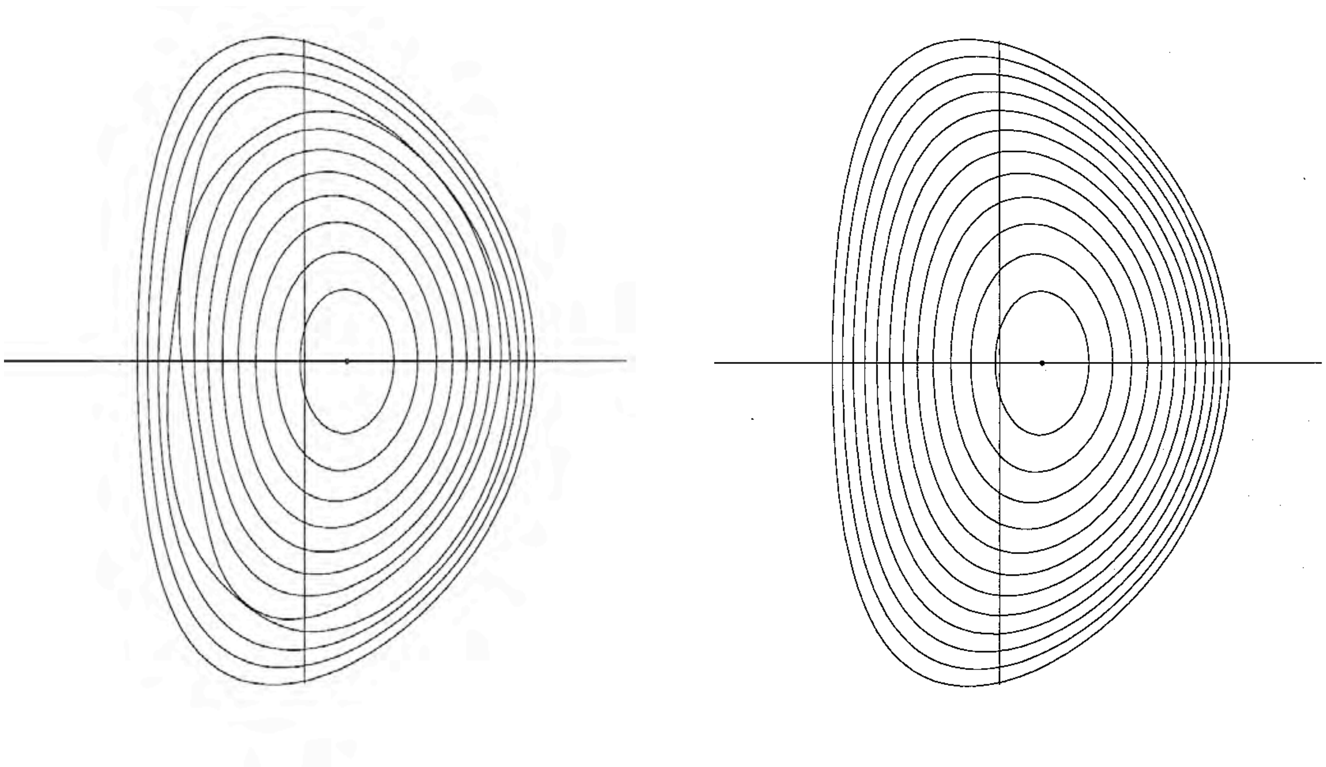
$B_{mn}(s) > 0.005$

		s		
m	n	0.188	0.535	0.966
0	0	0.913	0.863	0.789
0	1	0.012	-0.007	-0.016
1	-1	0.003	-0.003	-0.009
1	0	0.222	0.348	0.405
1	1	0.000	-0.002	0.017
1	3	0.002	0.003	0.005
2	0	0.027	0.082	0.128
2	1	-0.000	0.000	-0.001
2	2	0.004	0.005	-0.001
3	0	0.003	0.019	0.047
3	1	0.001	0.006	-0.008
3	2	0.001	0.004	0.006
3	3	-0.001	0.000	0.005
4	0	-0.001	0.004	0.018
5	0	-0.001	0.001	0.007

QAS Coils

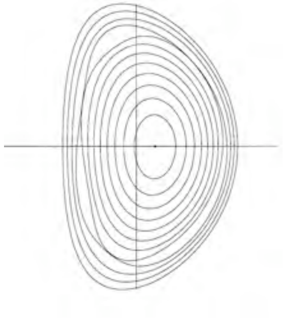
Three distinct coils of the QAS stellarator with just two field periods. When the torus of plasma is removed the coils are seen to be well enough separated so they can be constructed on the length scale of a reactor.

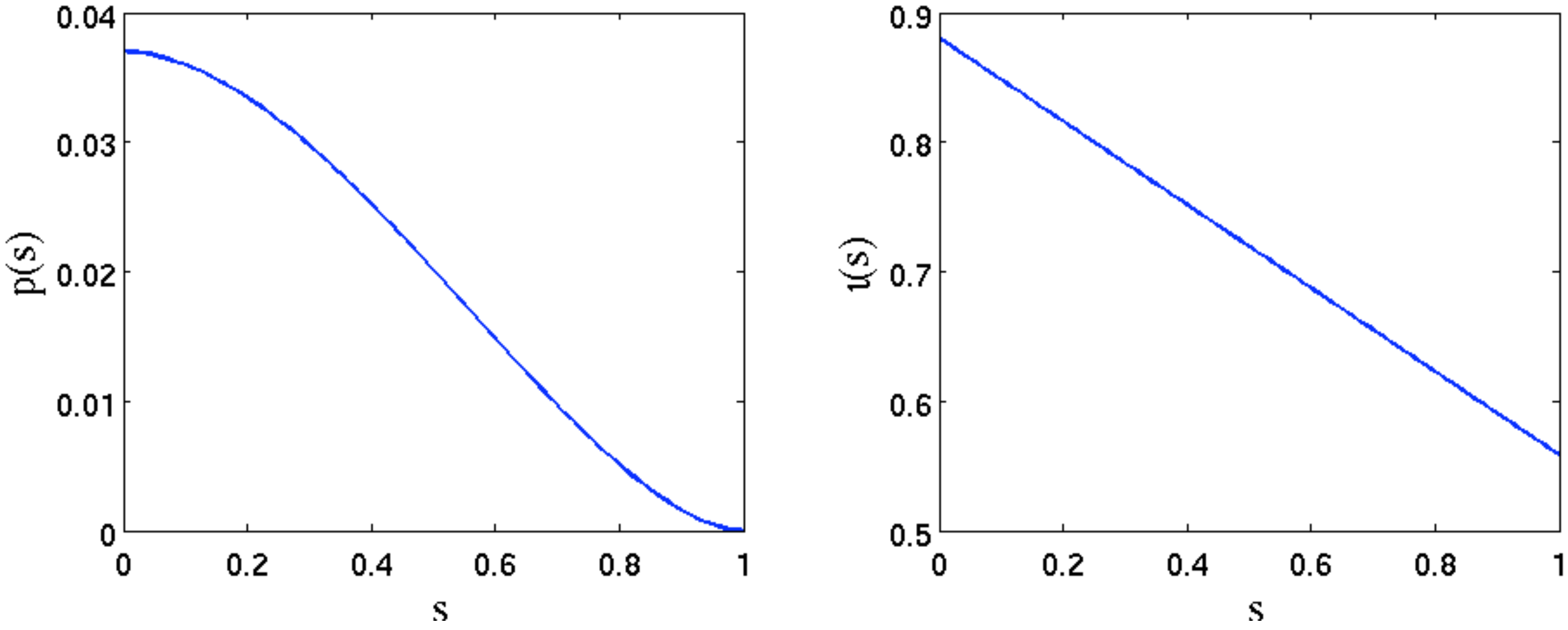
Bifurcated Tokamak Equilibrium



Left: cross section of a bifurcated tokamak equilibrium with $\beta = 0.035$ displaying a magnetic island at $\iota = 2/3$. The 2D solution (right) is stable for small perturbations of the plasma, but becomes unstable for larger 3D displacements. This behavior is symptomatic of neoclassical tearing modes (NTMs) and edge localized modes (ELMs).

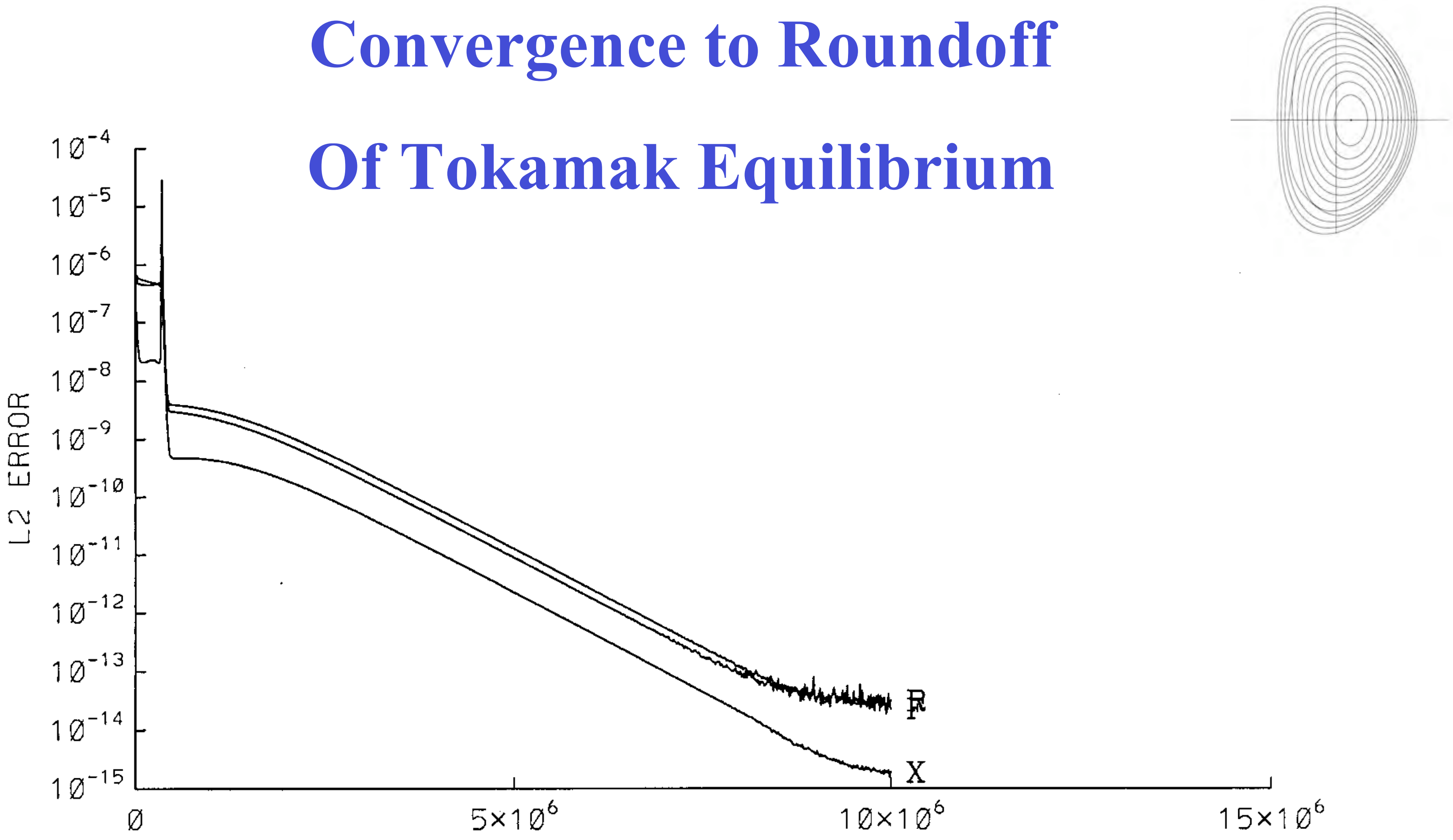
Tokamak Pressure and Rotational Transform Profiles





For toroidal flux in the interval $0 < s < 1$ we have pressure $p(s) = 0.037(1 - s^{1.8})^{1.8}$ and rotational transform $\iota(s) = 0.880 - 0.322\, s$.

Convergence to Roundoff
Of Tokamak Equilibrium



Convergence of the discrete 3D solution of a 2D tokamak problem to the level of roundoff error after 10^7 iteration cycles. This NSTAB simulation establishes the risk of disruptions and ELMs crashes in the ITER project.

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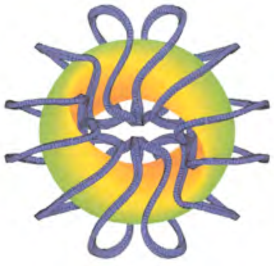

Thank You