Physics Evaluation of Coil Designs

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- Sixteen modular coil designs by Dennis Strickler have been evaluated. We’ll focus on three in this presentation.

  - Symmetry coil @ v=0, 7 coils/period:

    0907a2(M2), 1017a2(M3), 0105c2(M8), 0305a1(M11), 0123a1(M9), 0125a1(M10), 0227a1(M12).

  - Symmetry coil @ v=1/2, 7 coils/period:

    1115b8(M4), 1219a6(M7), 0321a1(M15), 0321a4(M16), 0321a5(M17).

  - Symmetry coils @ v=0 & v=1/2, 6 coils/period:

    1207a6(M5),

    1215b4(M6),

    0312a3(M13), 0312a4(M14).

- General features of the reconstructed plasmas from designs directly from Dennis' coil optimization (assuming good, nested flux surfaces):

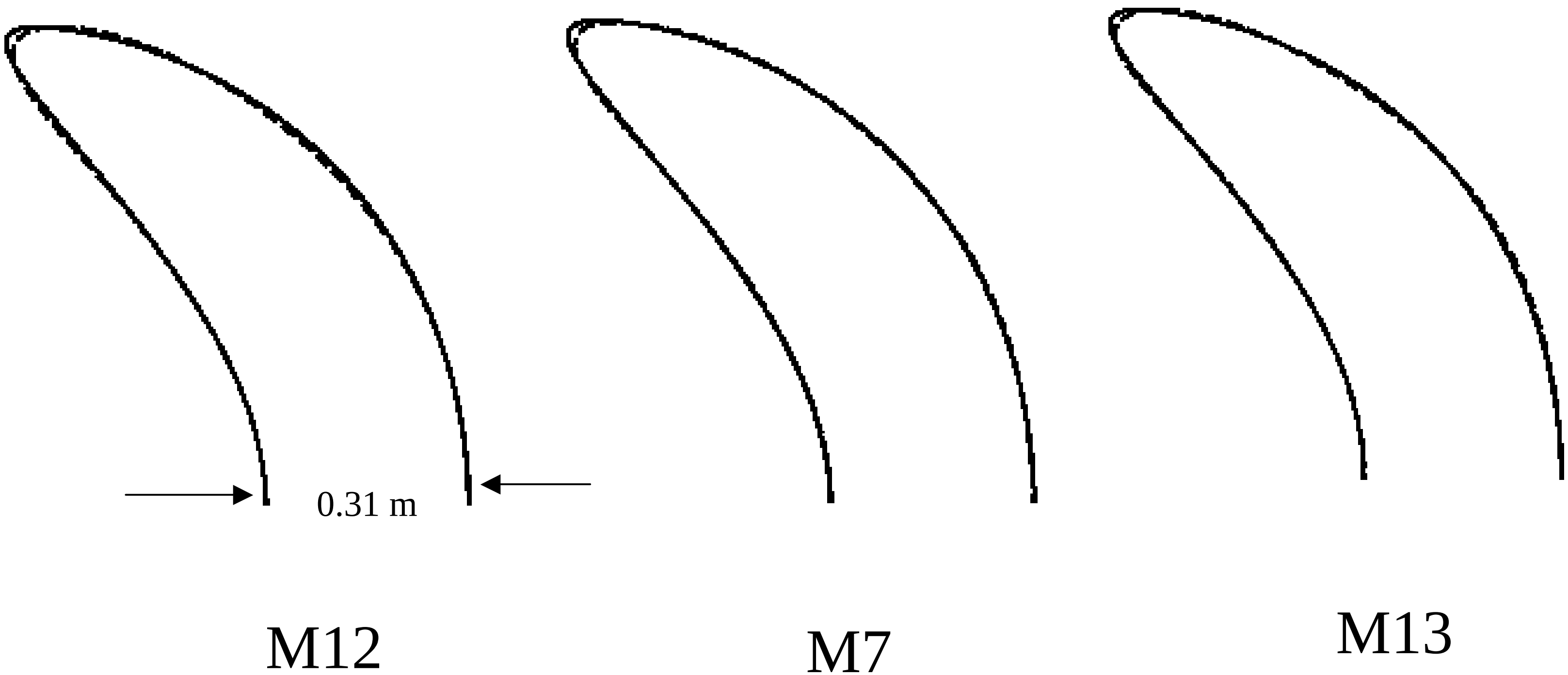
  – Excellent match of A, β, ι profile, and ballooning characteristics.

  – Geometrically, all LCMS match the baseline LI383 reasonable well, but most miss out the tips in the crescent shaped section.

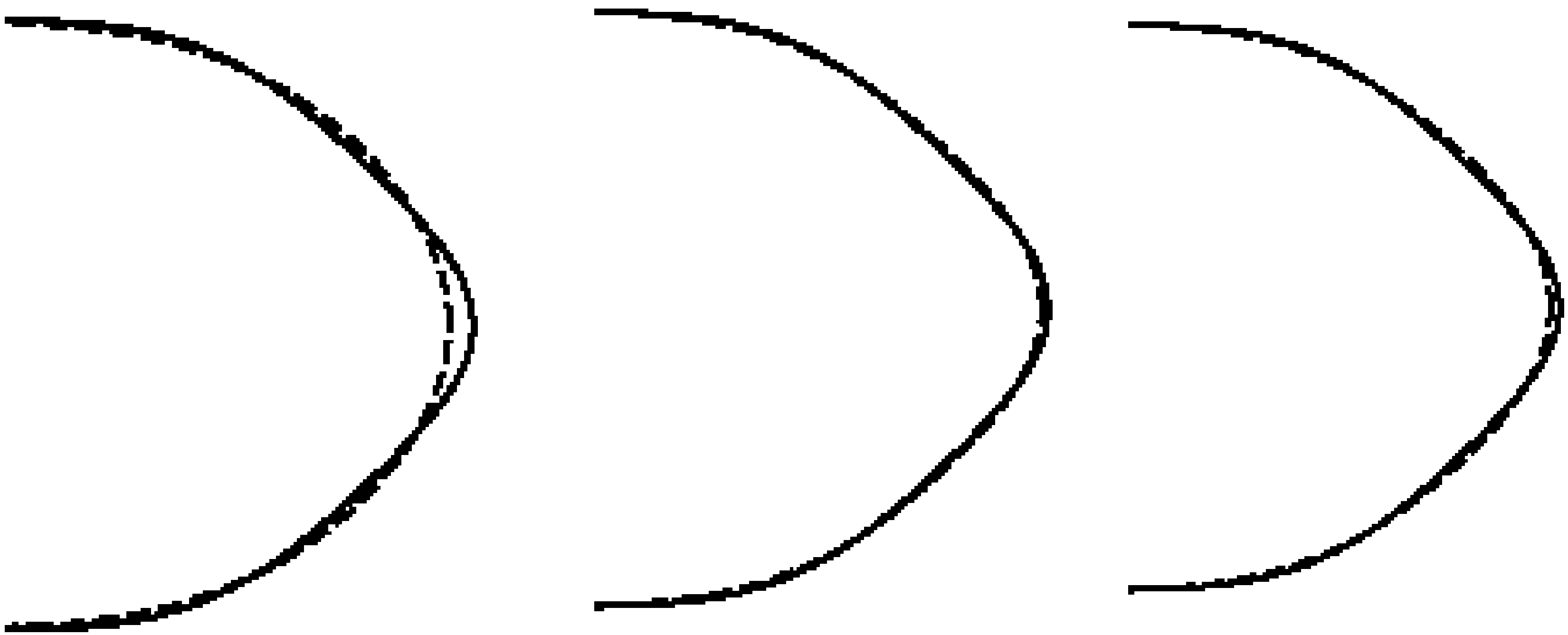
  – All have worse QA than the baseline LI383 plasma in the core region ($r/a<0.5$).

  – All are kink unstable (Terpsichore eigenvalue $>10^{-4}$), either to 5/8 or 3/6 mode.

Cross Section at v=0 for M12, M7, and M13, in comparison with the baseline LI383 plasma

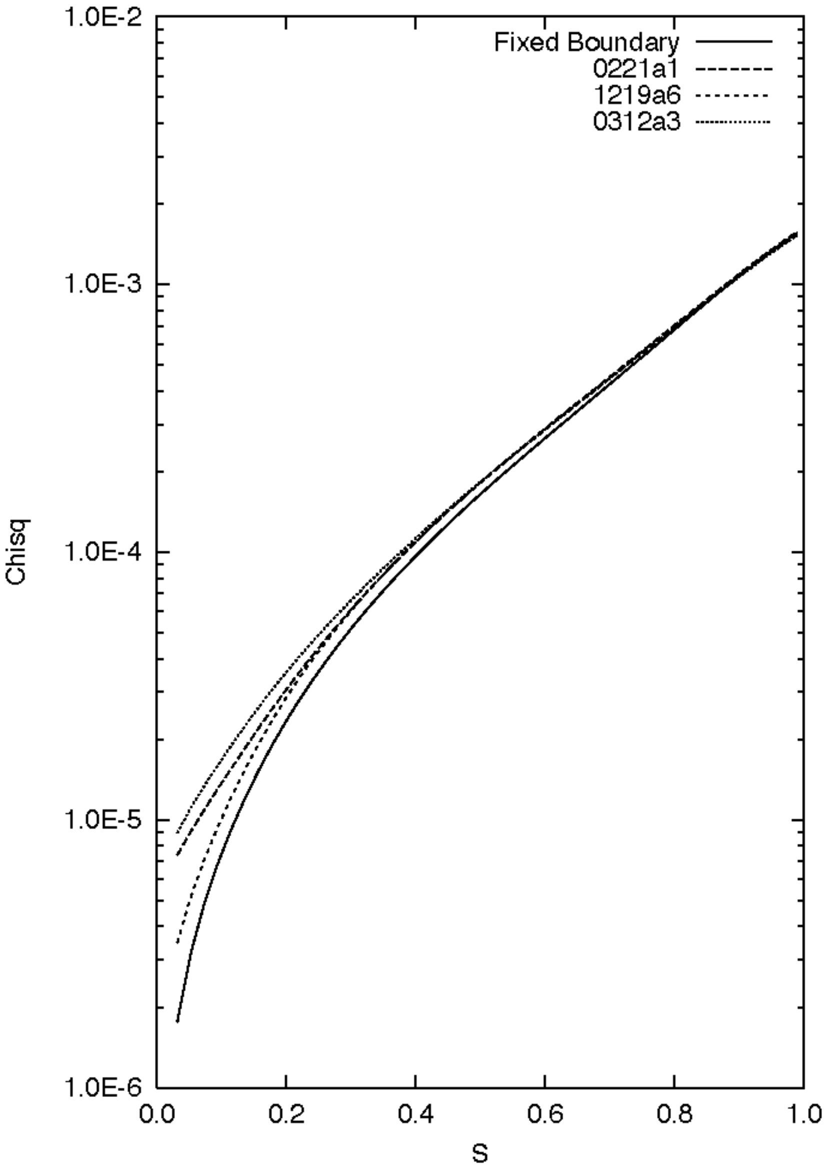


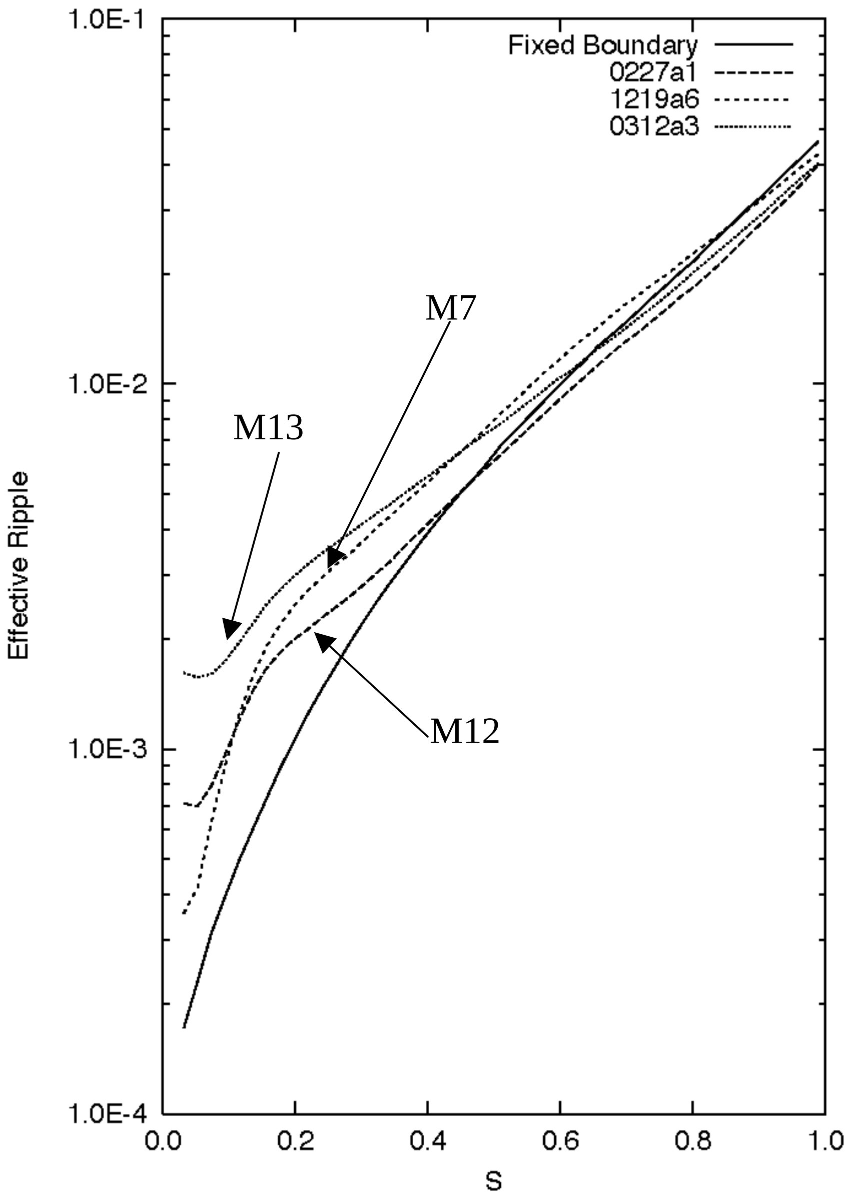
Cross Section at v=1/2 for M12, M7, and M13, in comparison with the baseline LI383 plasma



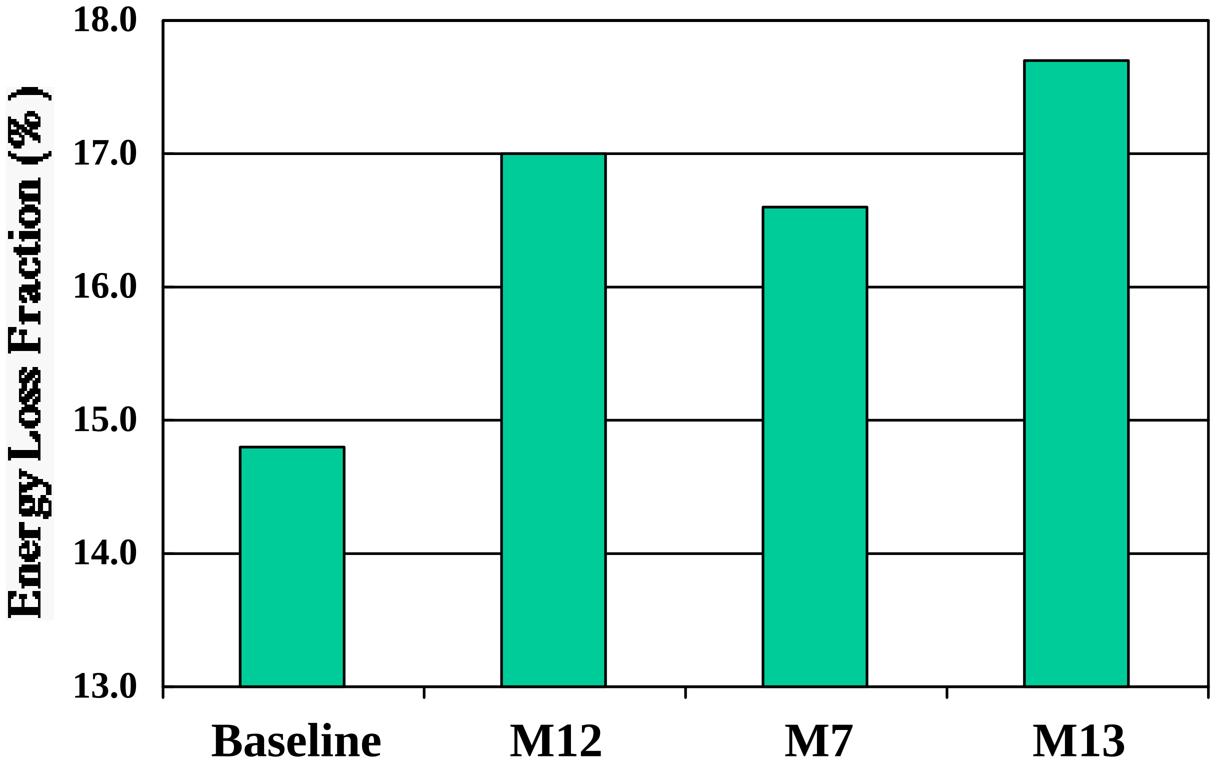
M12 M7 M13

Reconstructed plasmas from reference coil designs have larger residual non-axisymmetric components of |B| as well as the effective ripple.



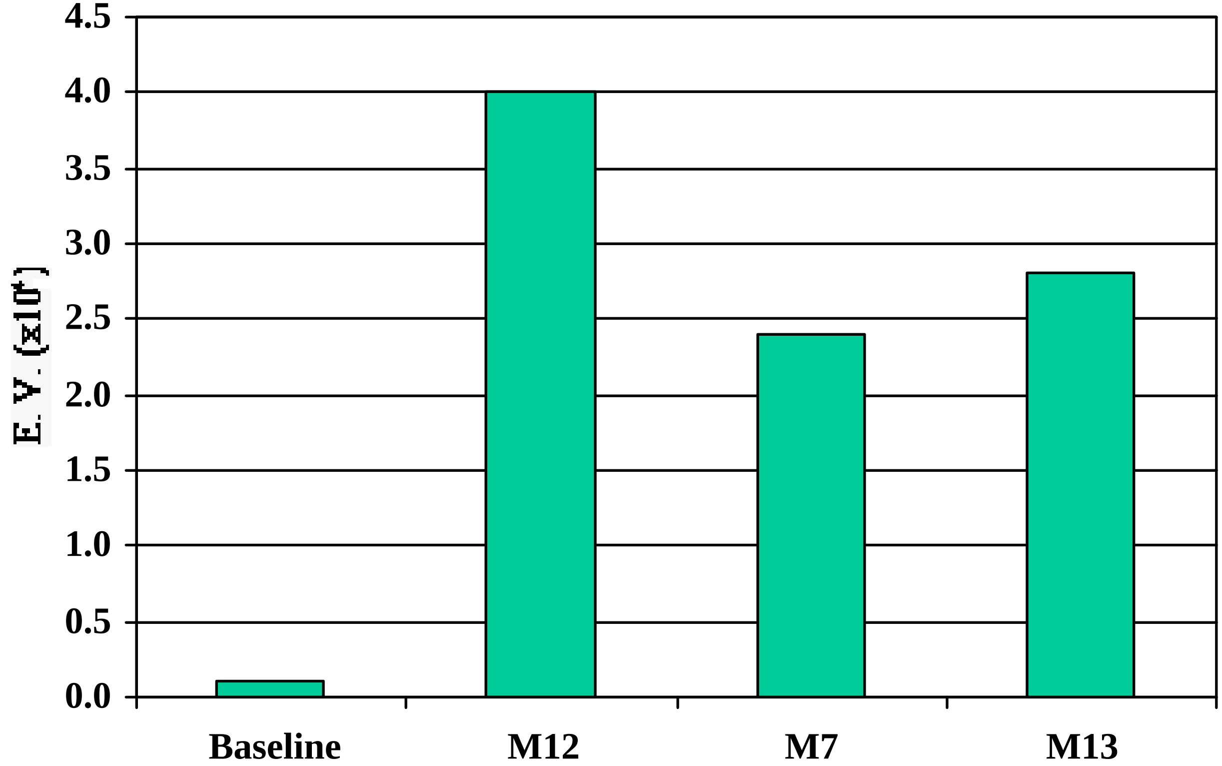


Reconstructed plasmas from reference coil designs all have larger NB particle losses.



Energy loss fraction of 40 keV H beam @ 2T.
R_{tan}=R_{maj}, Injection toroidal angle=0°.

Reconstructed plasmas from reference coil designs are all more unstable to kinks (5/8, 3/6).



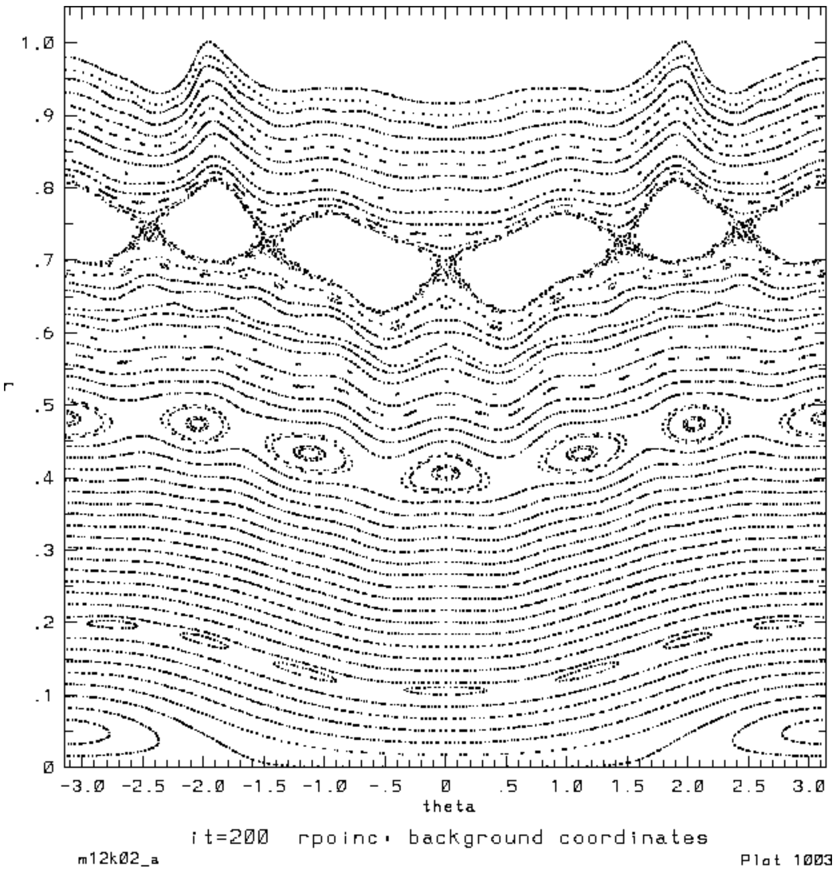
Eigenvalues from Terpsichore calculations for the N=1 family

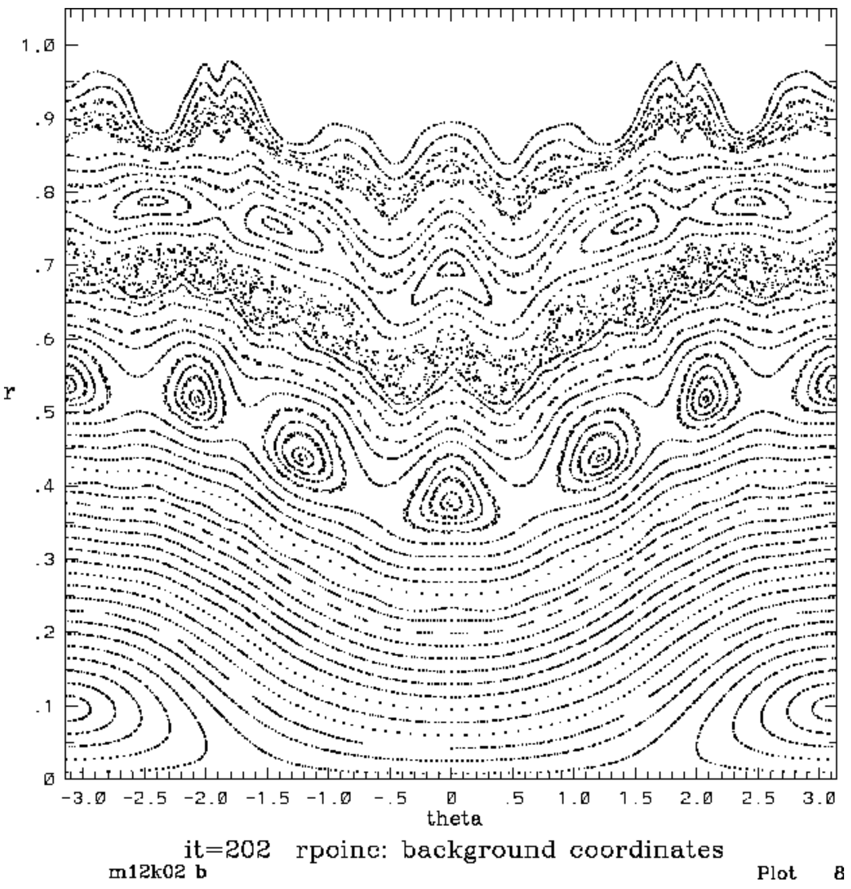
(49 low-n perturbation modes)

- PIES studies of flux surface quality showed different rate of convergence of the free boundary equilibrium from different coils, but the appearance of the 2/9 resonance eventually destroys most of the outer surfaces.

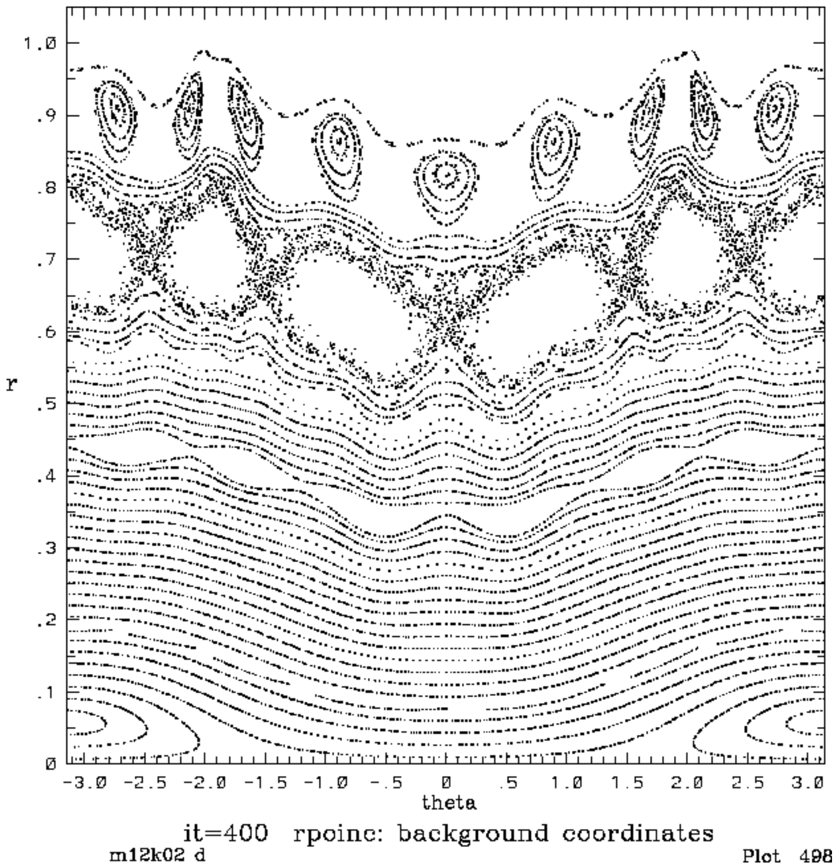
- Attempts have been made to improve surface qualities (non-hudson)
  - Decrease edge iota to be further away from 2/9
  - Reduce resonance Boozer Jacobian for 1/5 in VMEC solution by modifying coil currents

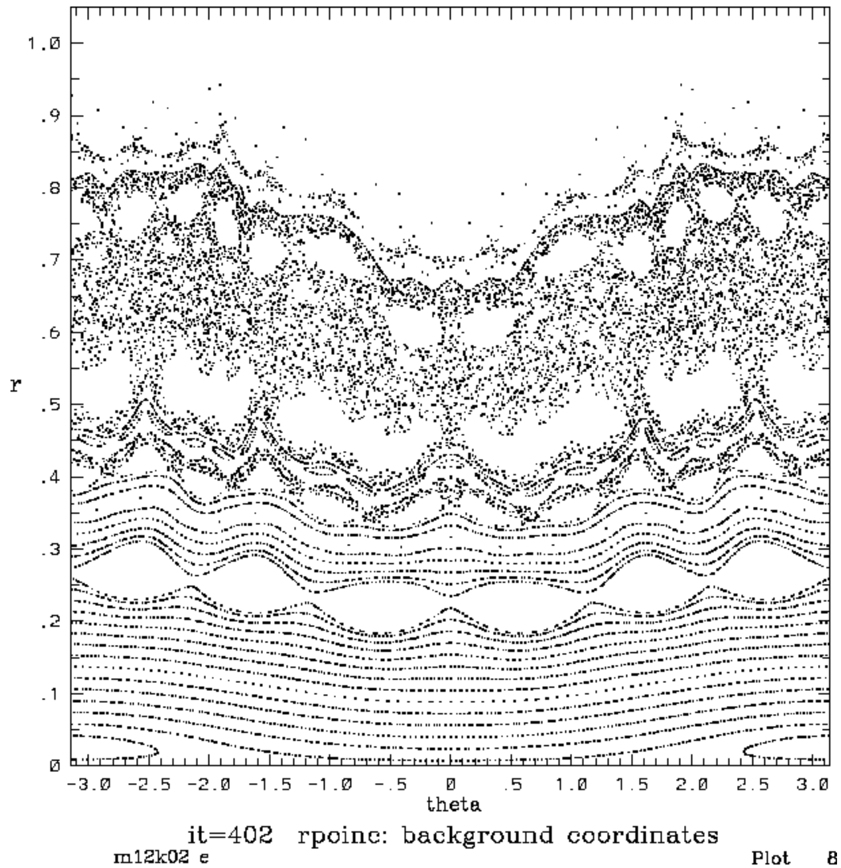
Flux surfaces in polar coordinates for M12 after 200 iterations (blend=0.99, pies20) (left) and with two additional iterations without blending (right).



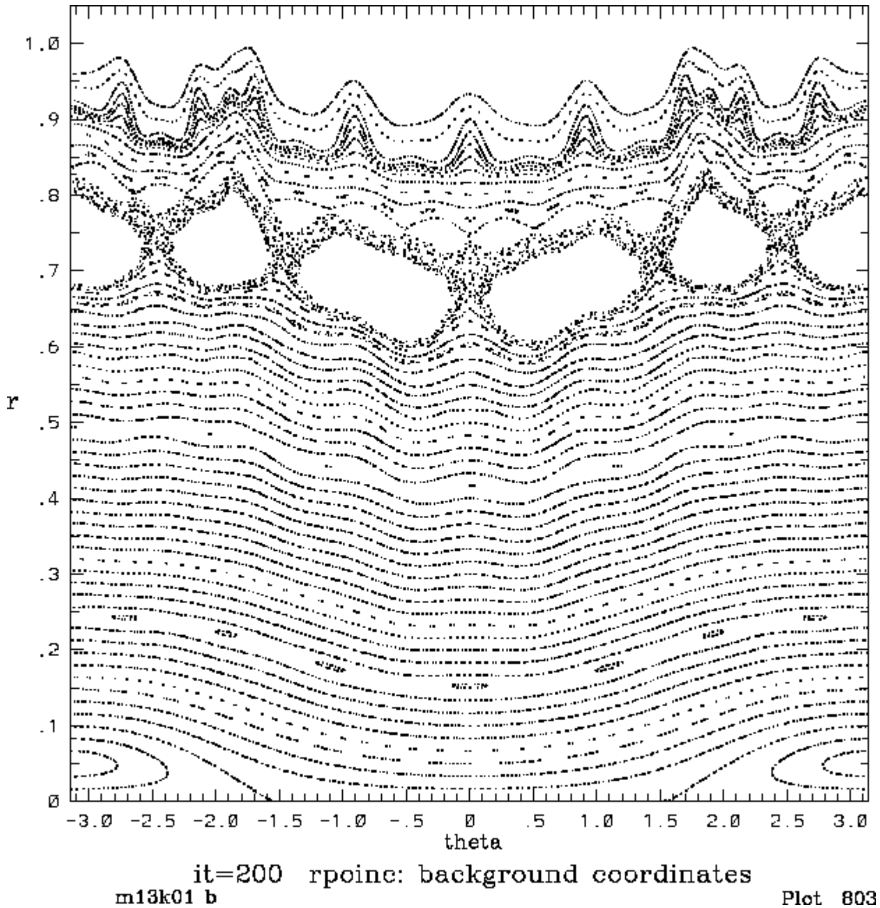


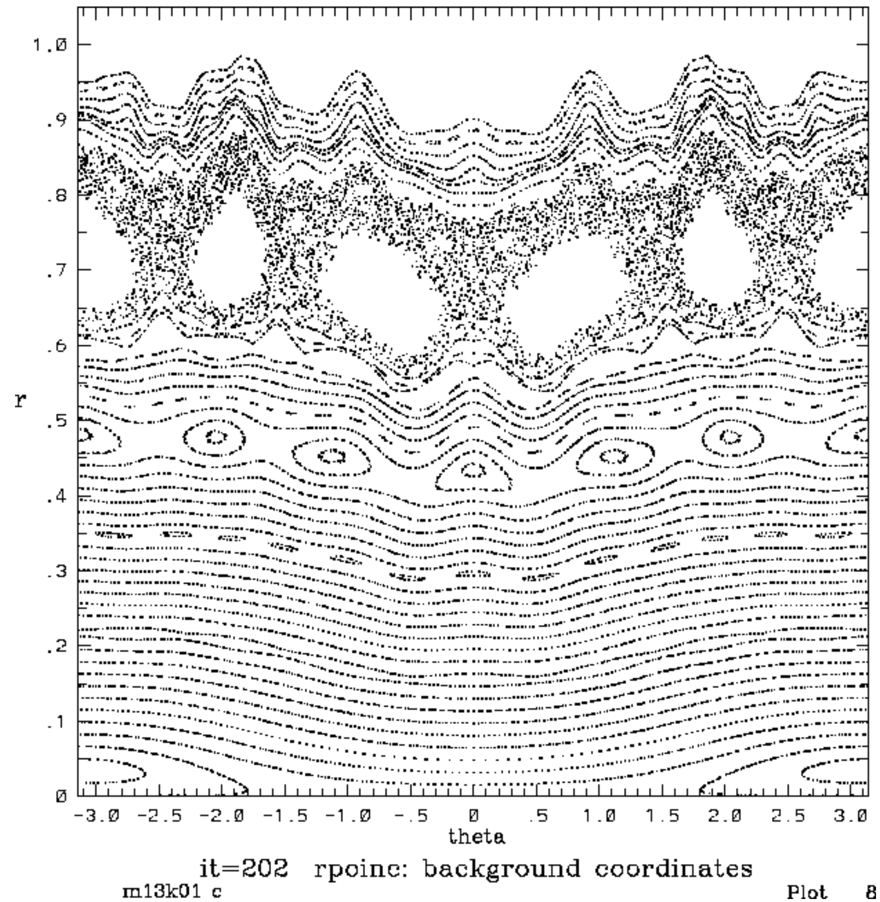
Flux surfaces in polar coordinates for M12 after 400 iterations (blend=0.99, pies20) (left) and with two additional iterations without blending (right).



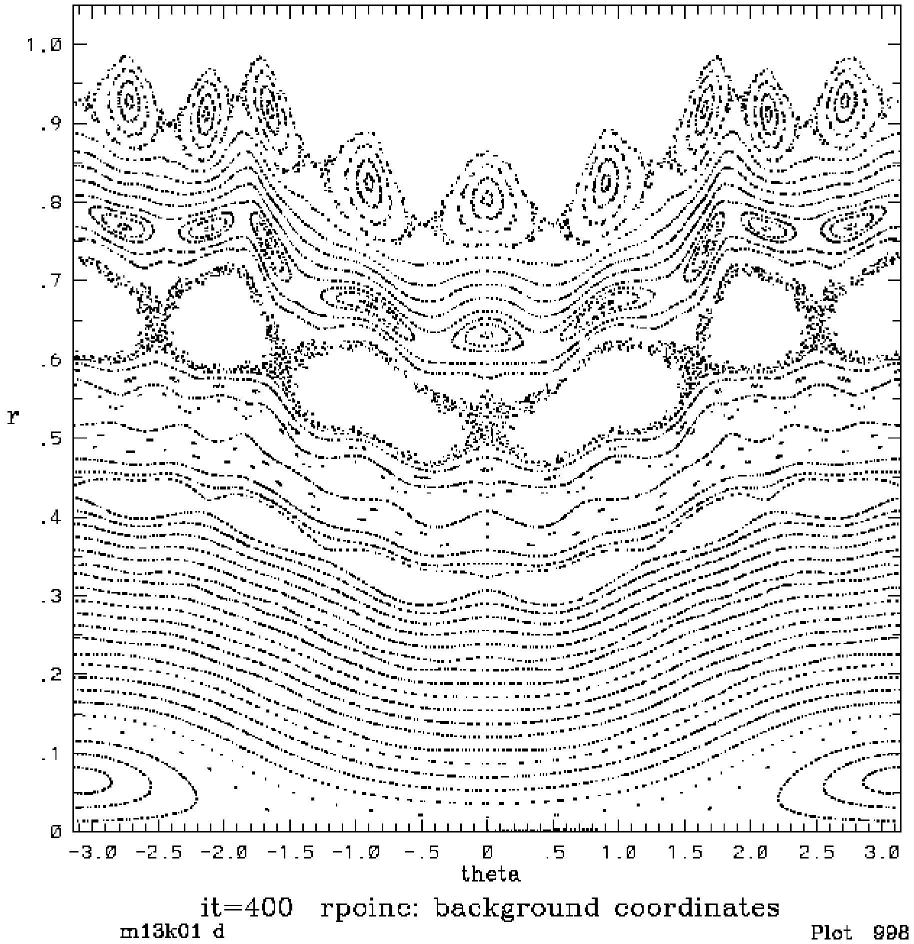


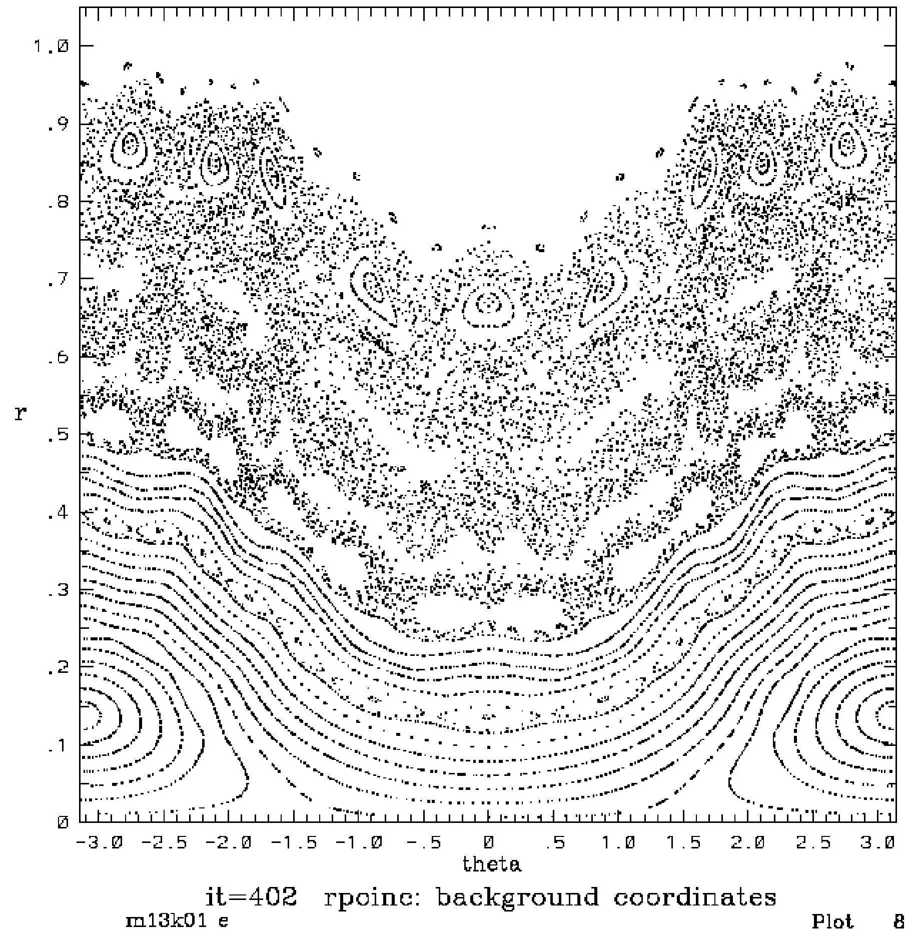
Flux surfaces in polar coordinates for M13 after 200 iterations (blend=0.99, pies20) (left) and with 2 additional iterations without blending (right).



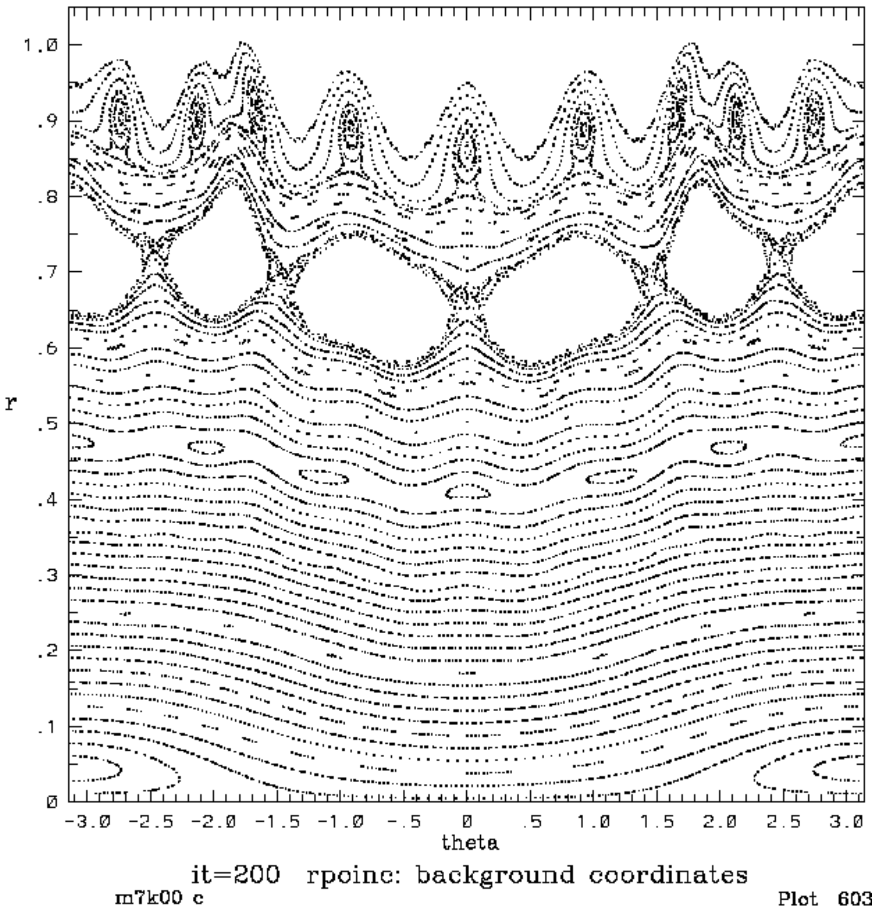


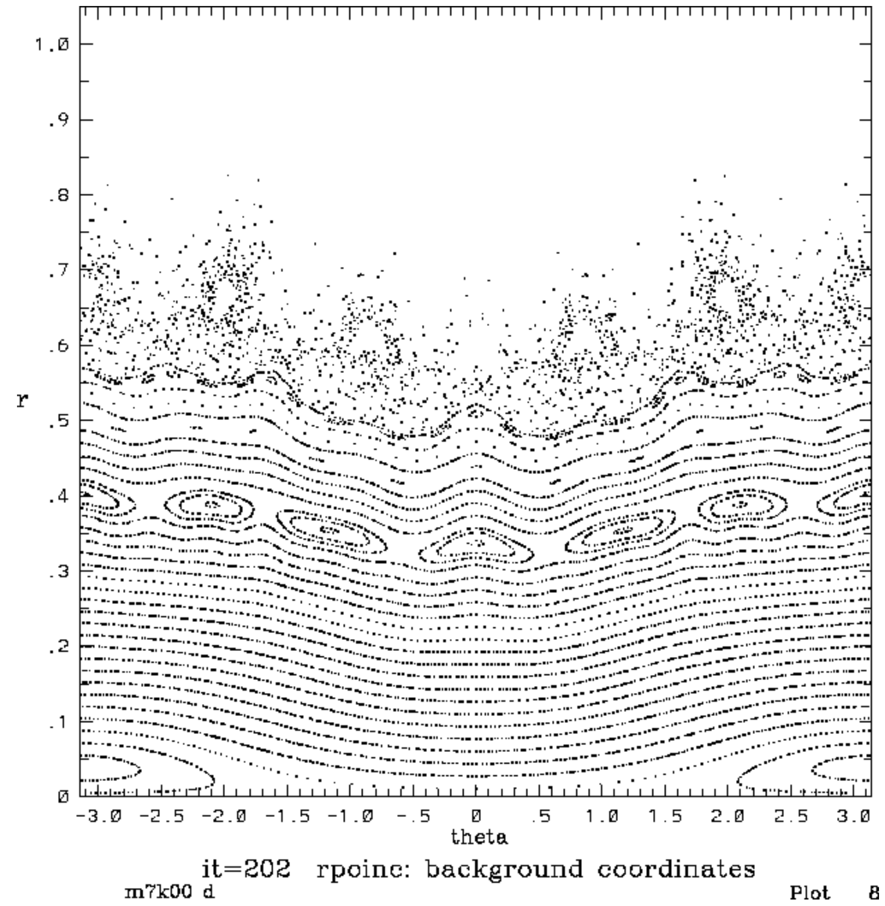
Flux surfaces in polar coordinates for M13 after 400 iterations (blend=0.99, pies20) (left) and with 2 additional iterations without blending (right).



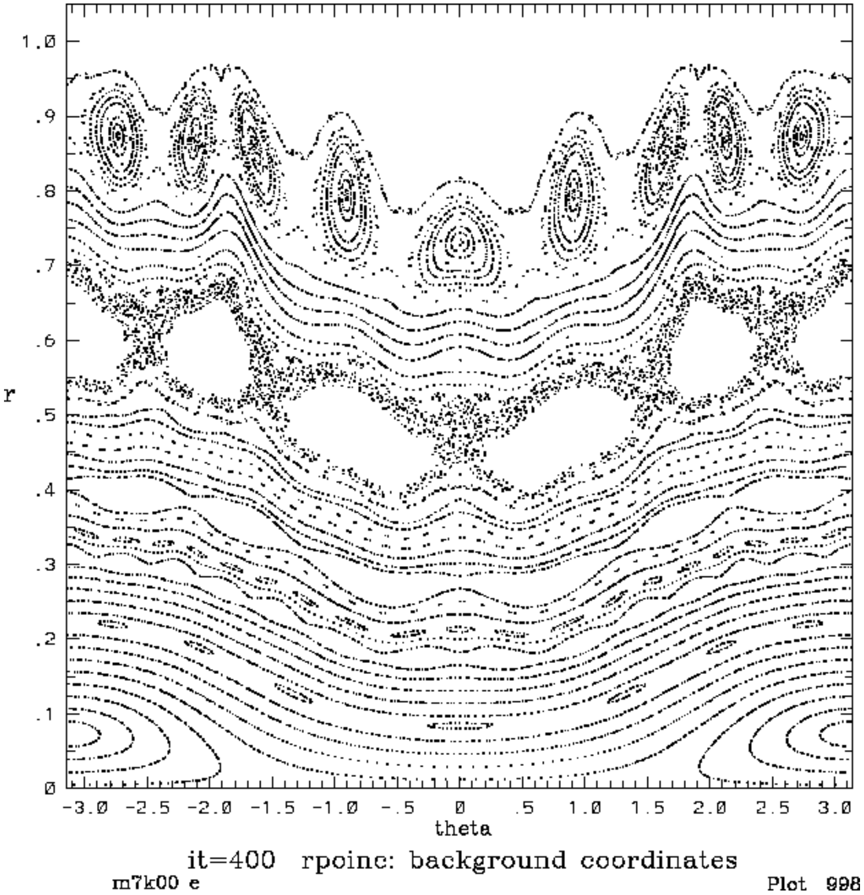


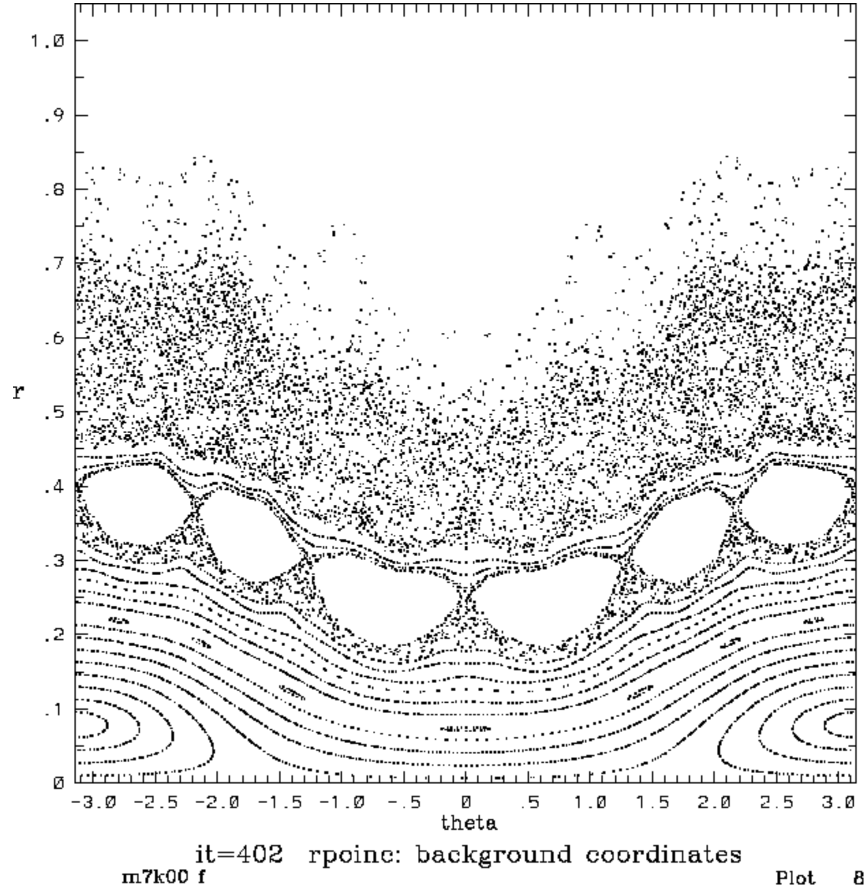
Flux surfaces in polar coordinates for M7 after 200 iterations (blend=0.99, pies20) (left) and with 2 additional iterations without blending (right).



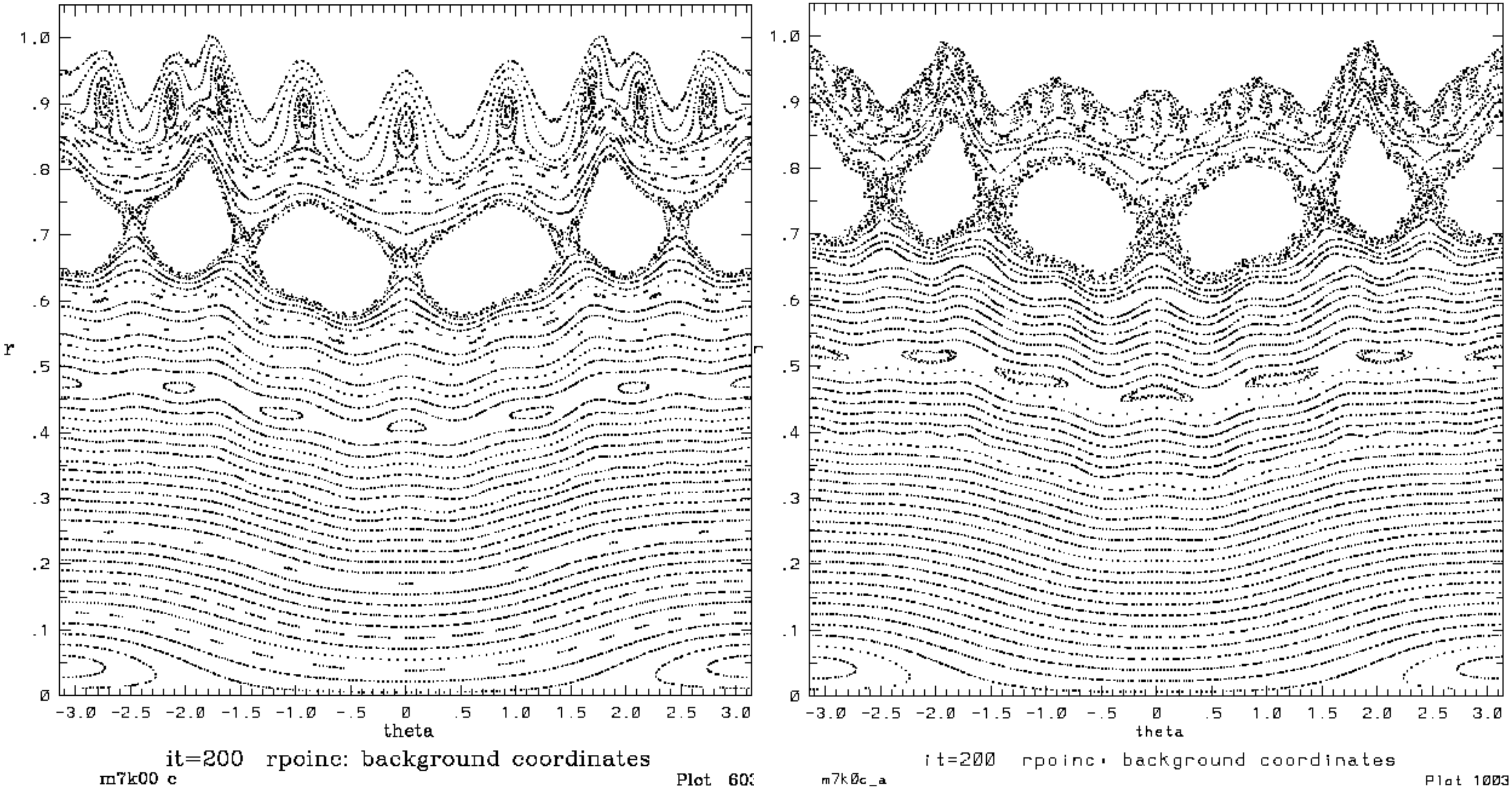


Flux surfaces in polar coordinates for M7 after 400 iterations (blend=0.99, pies20) (left) and with 2 more iterations without blending (right).

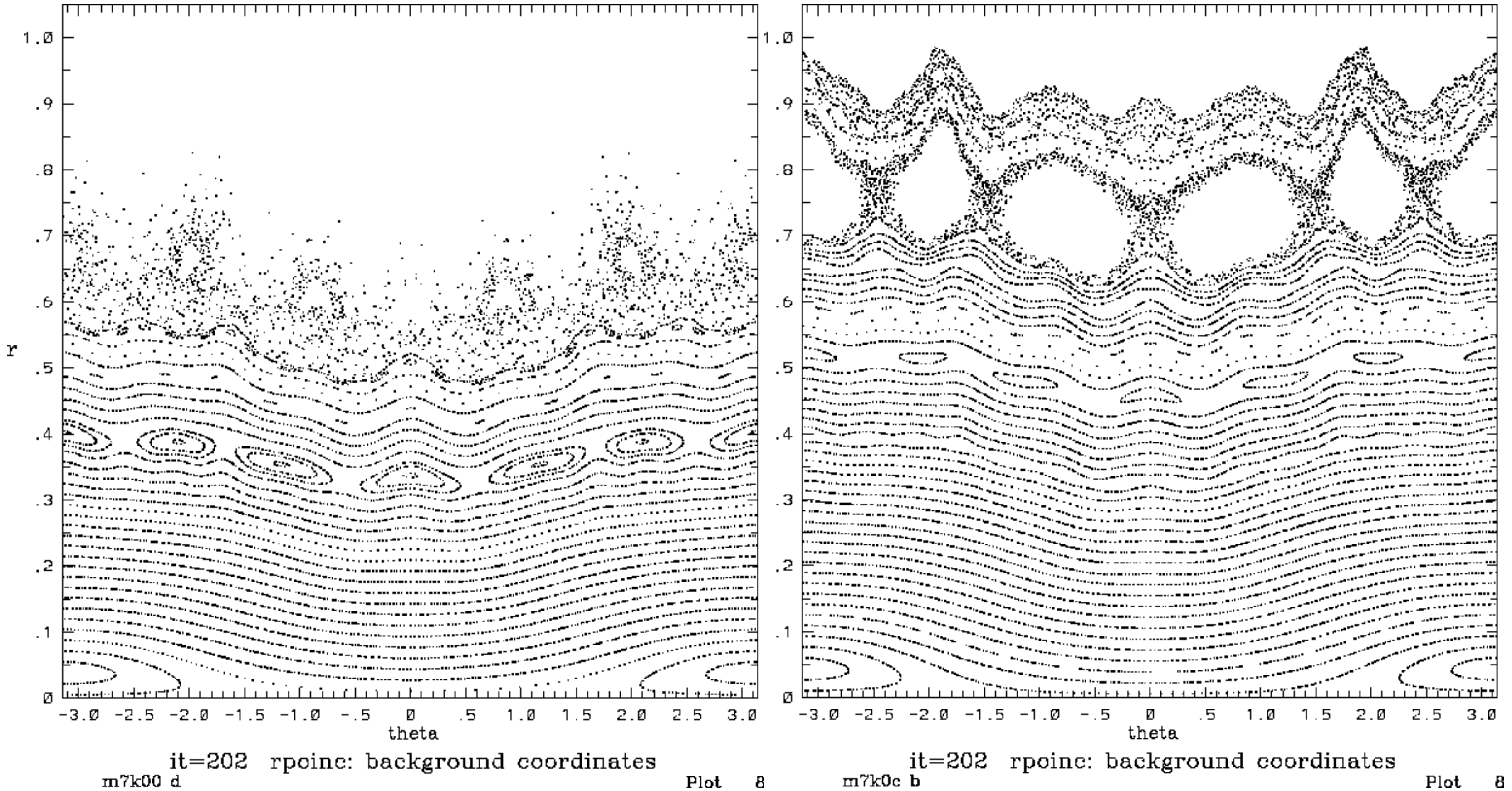




Flux surfaces from M7 coils with full plasma current (left) and 95% of the plasma current (right) after 200 iterations.



Flux surfaces from M7 coils with full plasma current (left) and 95% of the plasma current (right) after 200 iterations with blend=0.99 and two more iterations without blending.



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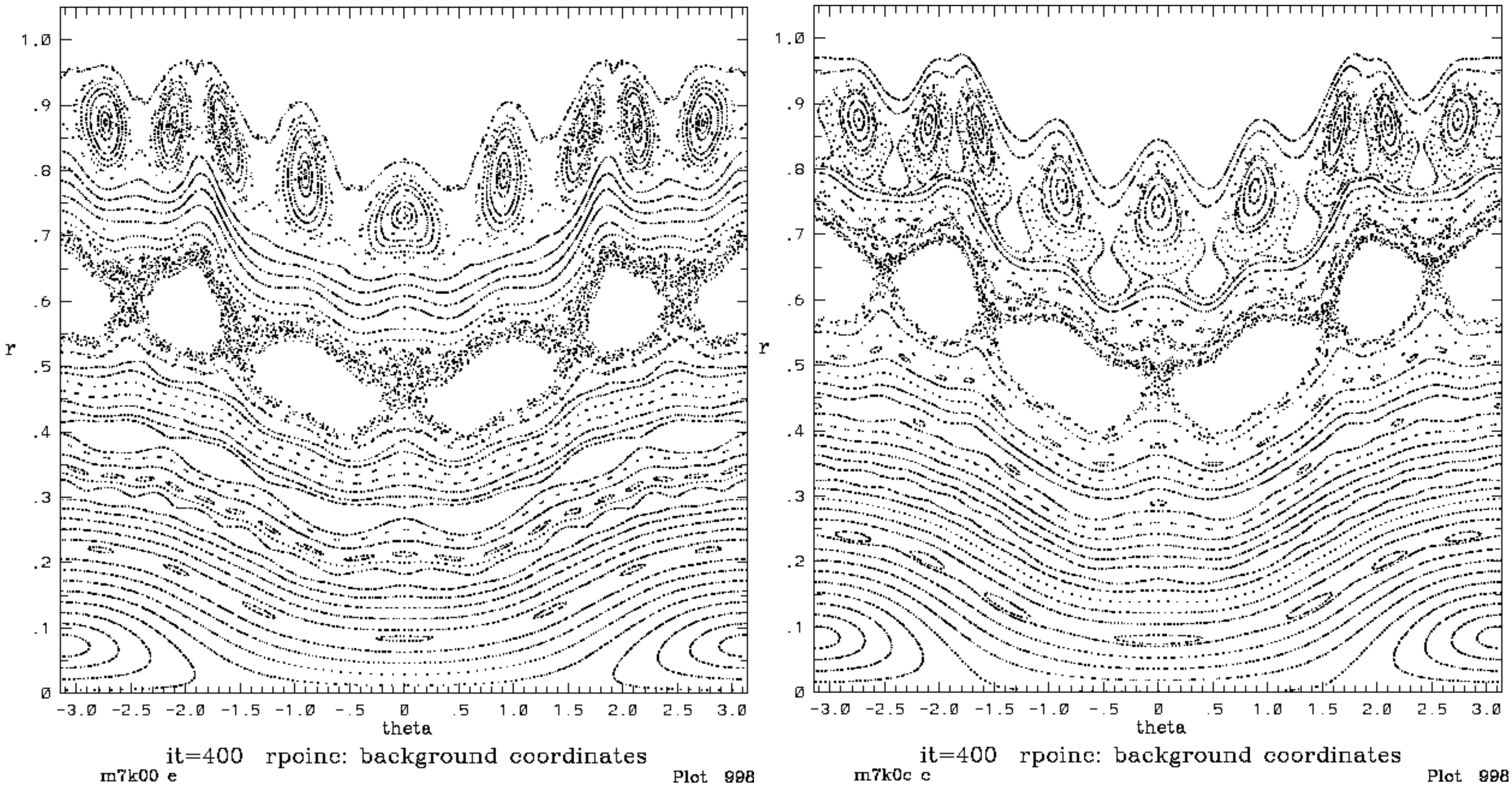
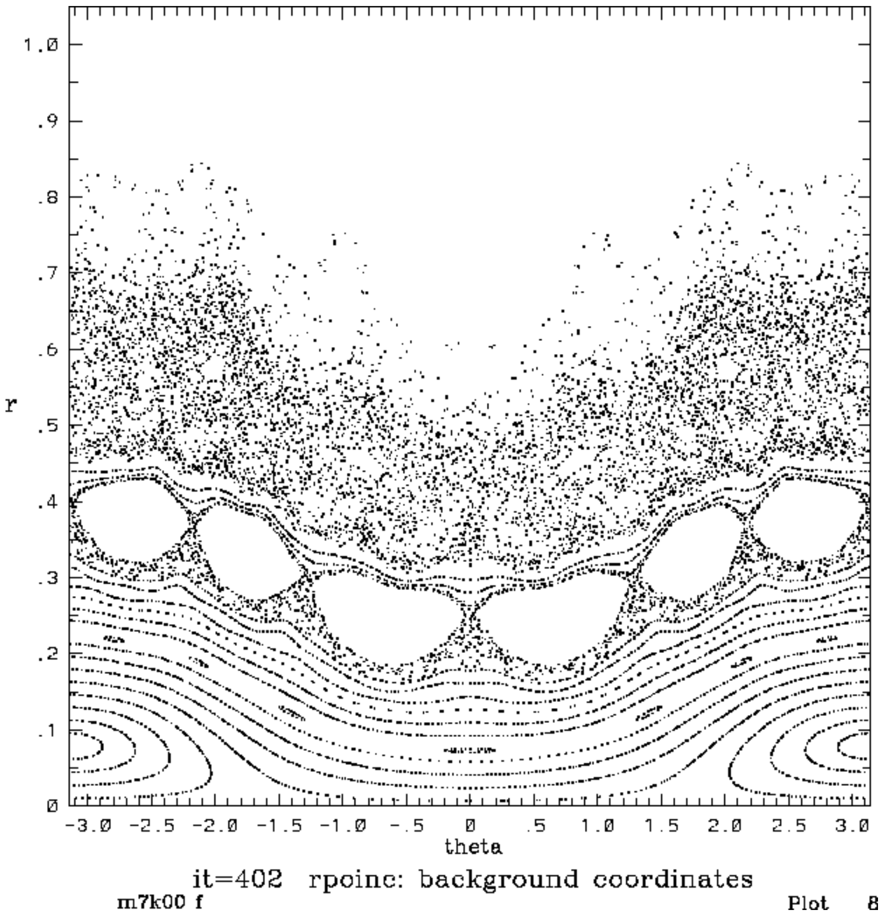
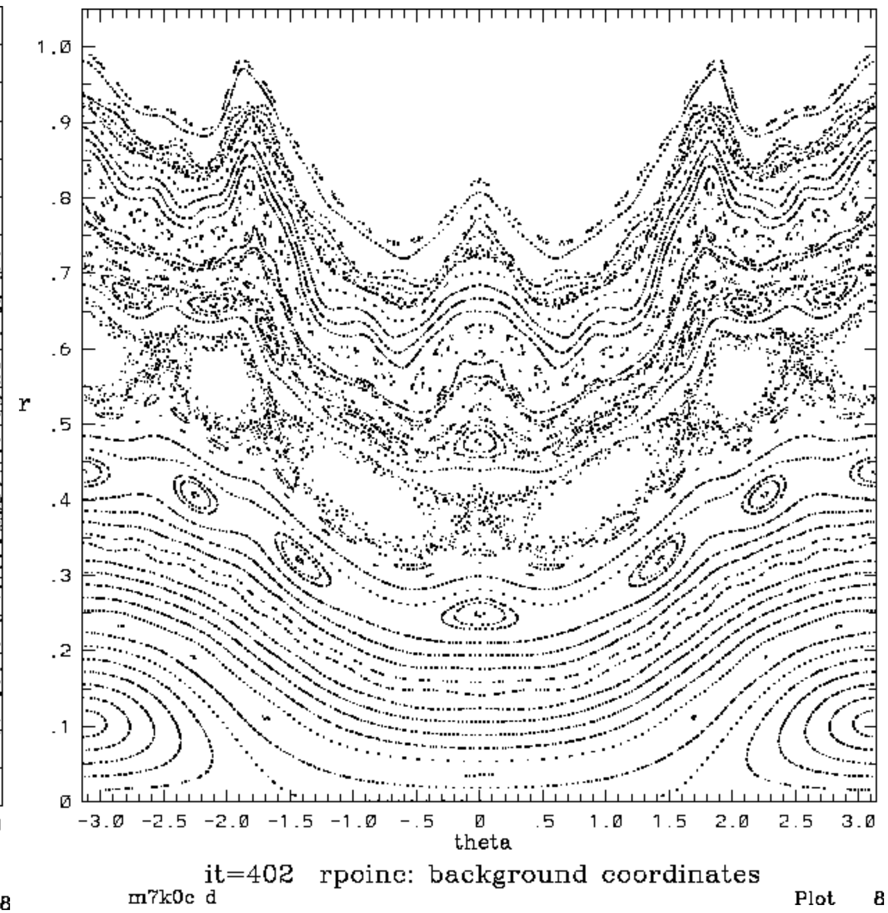
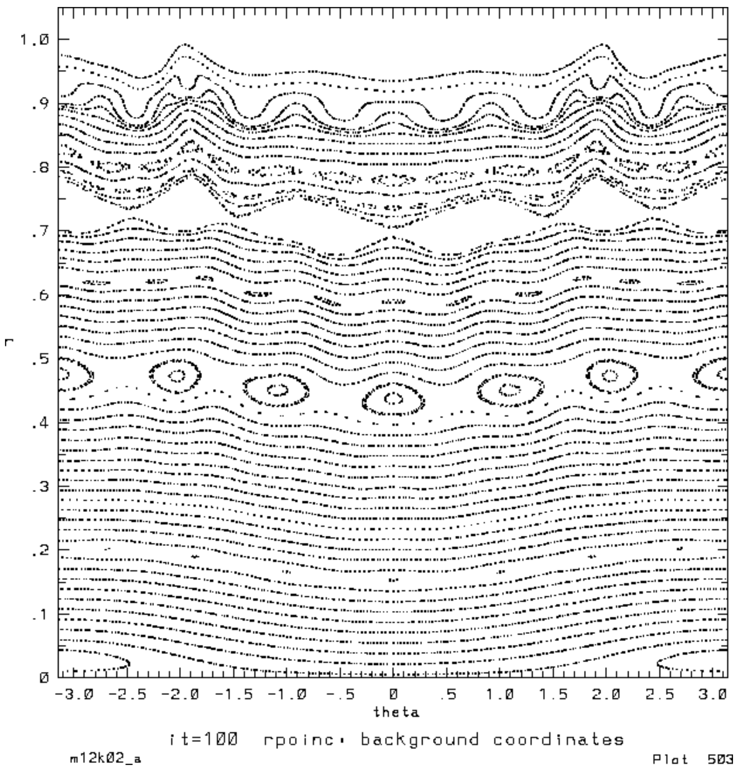


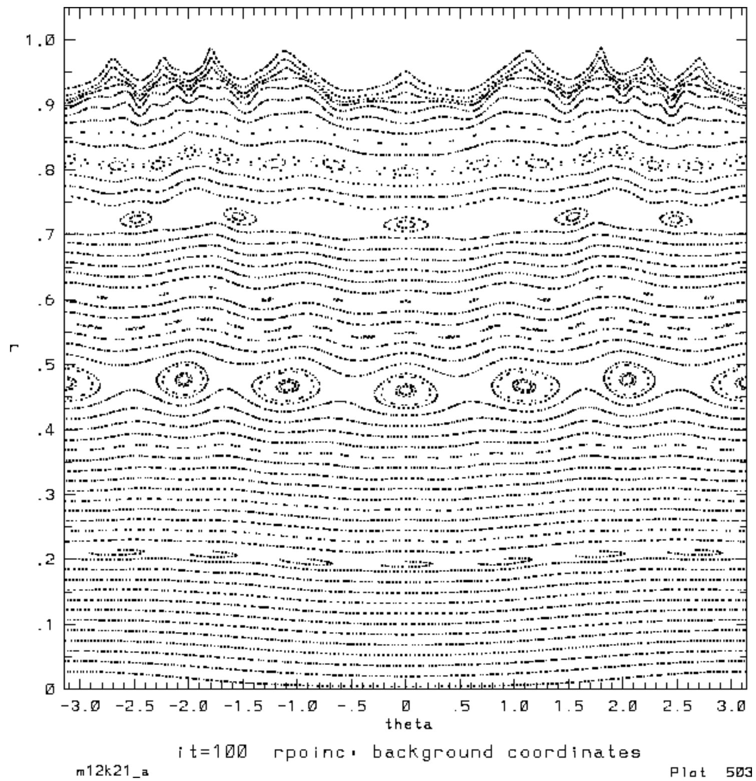
Flux surfaces from M7 coils with full plasma current (left) and 95% of the plasma current (right) after 400 iterations with blend=0.99 and two more iterations without blending.



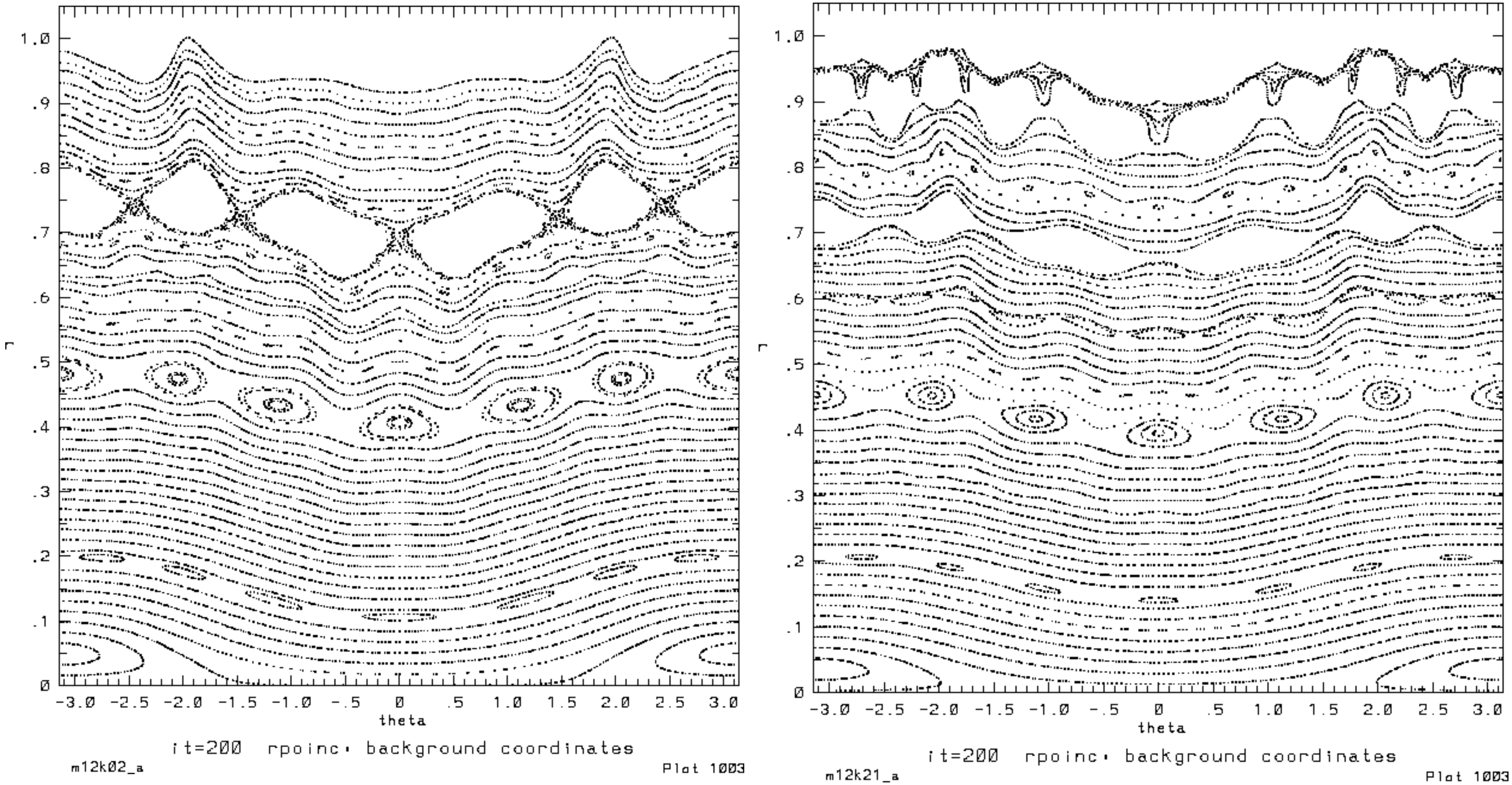


Flux surfaces from reference M12 coils (left) and current modified M12 that reduces 1/5 resonance Boozer Jacobian by a factor of 10 in VMEC solution (right), after 100 iterations with blend=0.99.

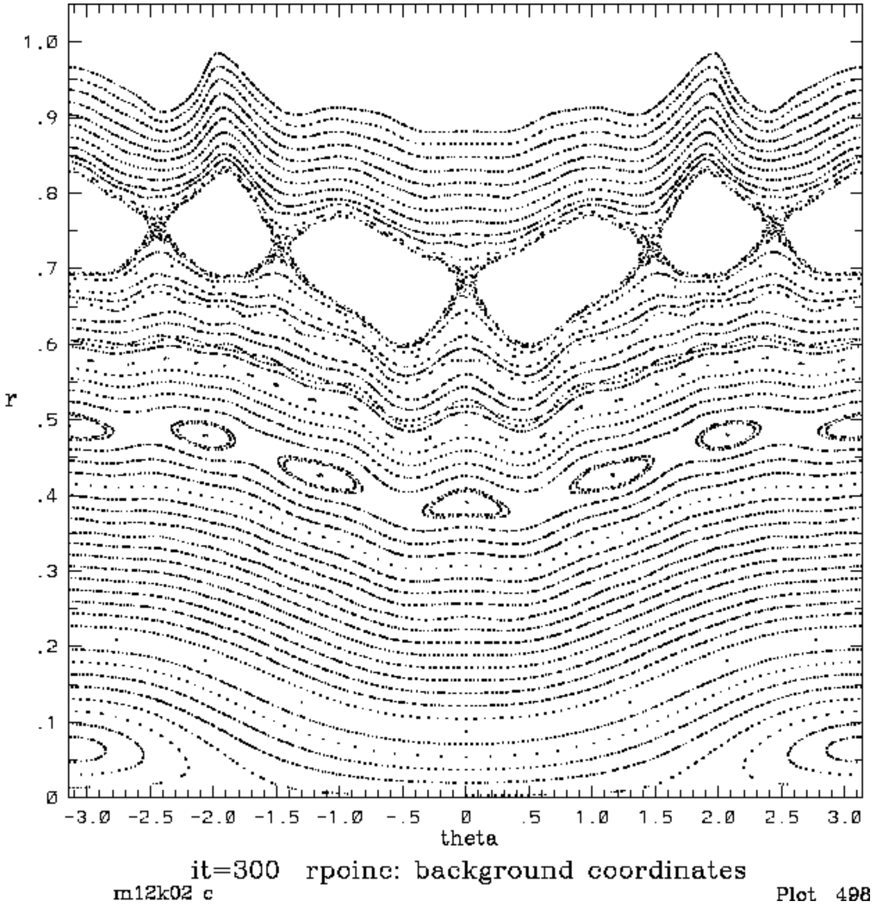


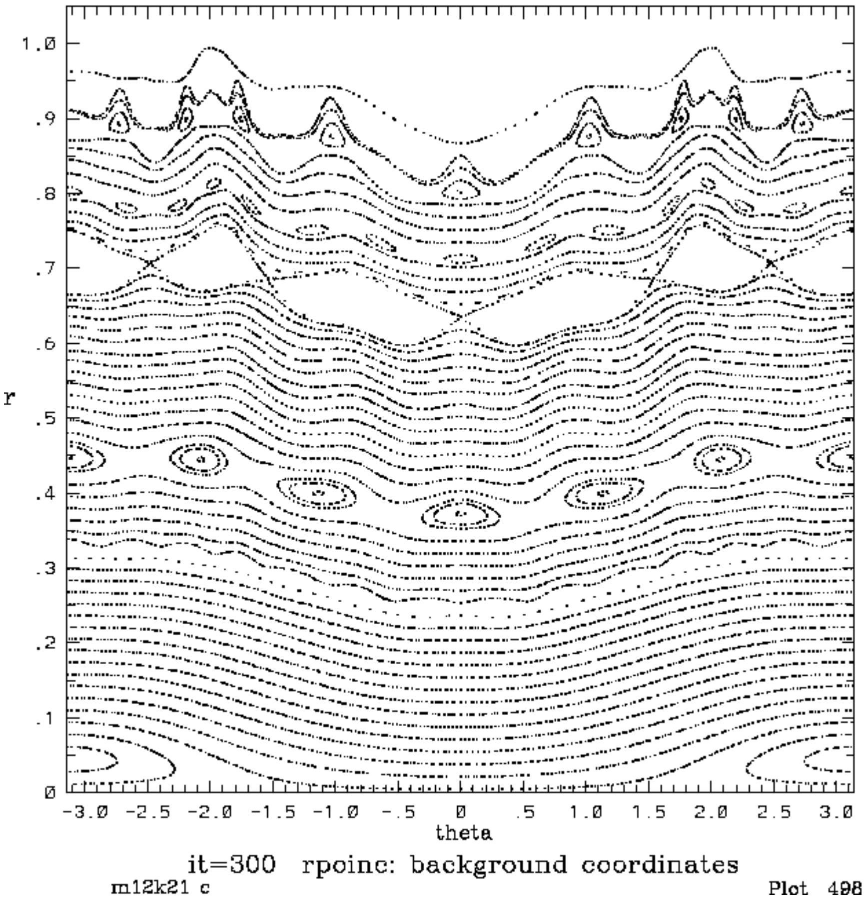


Flux surfaces from reference M12 coils (left) and current modified M12 that reduces 1/5 resonance Boozer Jacobian by a factor of 10 in VMEC solution (right), after 200 iterations with blend=0.99.

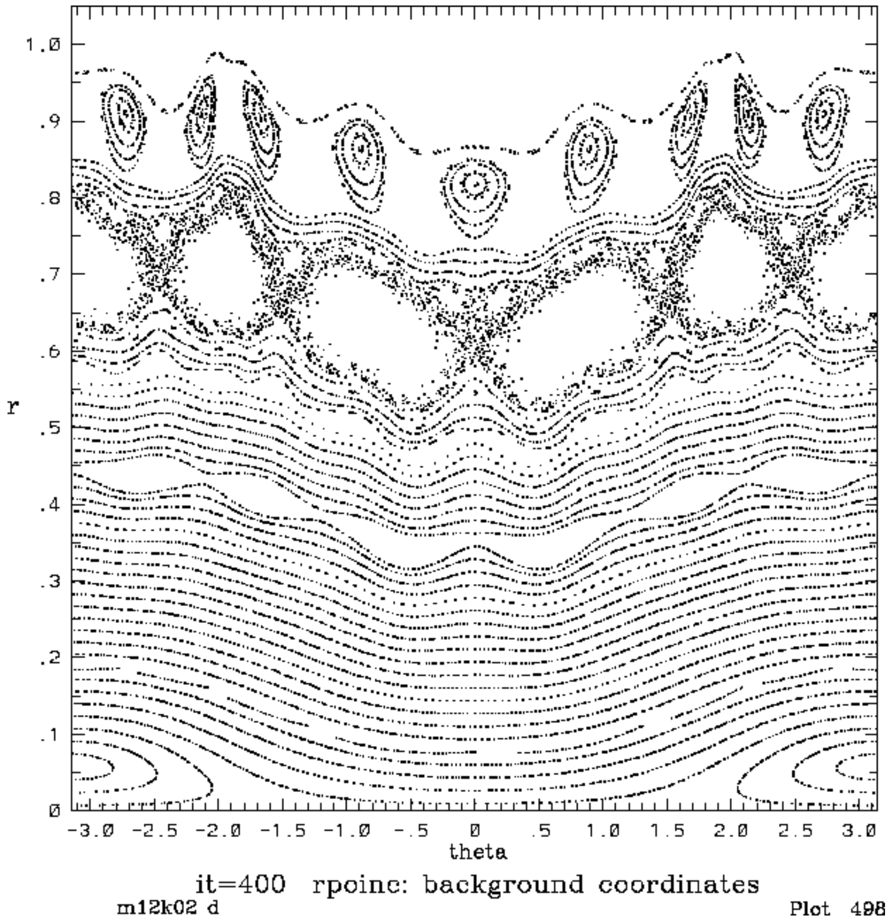


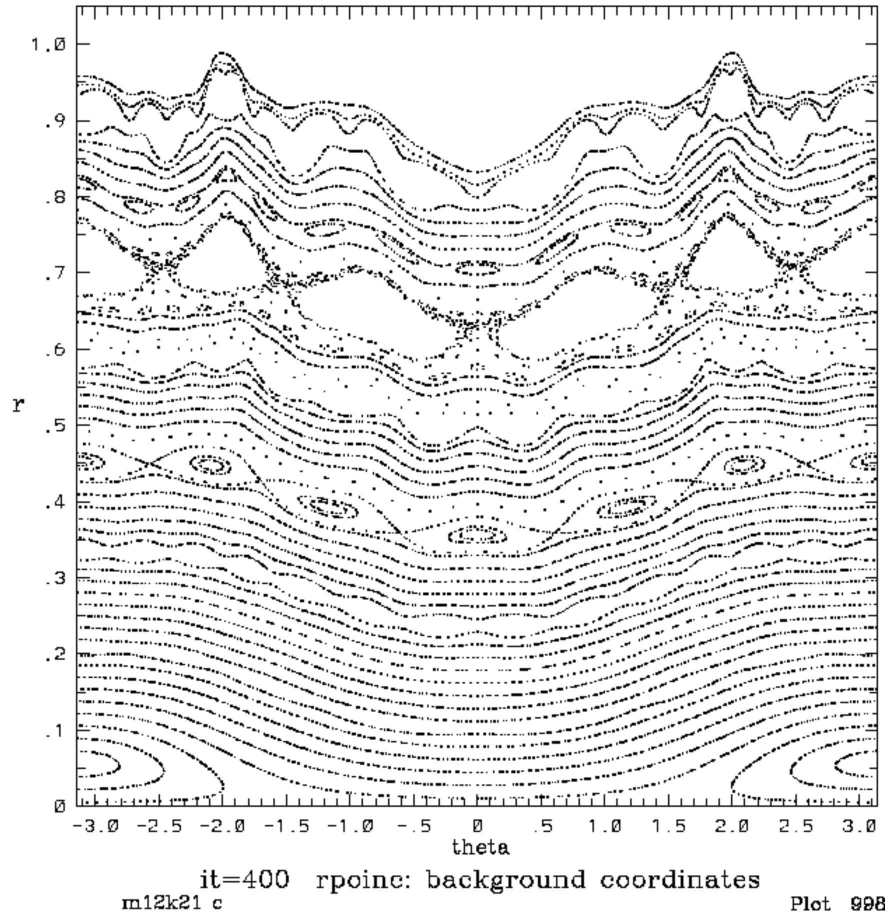
Flux surfaces from reference M12 coils (left) and current modified M12 that reduces 1/5 resonance Boozer Jacobian by a factor of 10 in VMEC solution (right), after 300 iterations with blend=0.99.



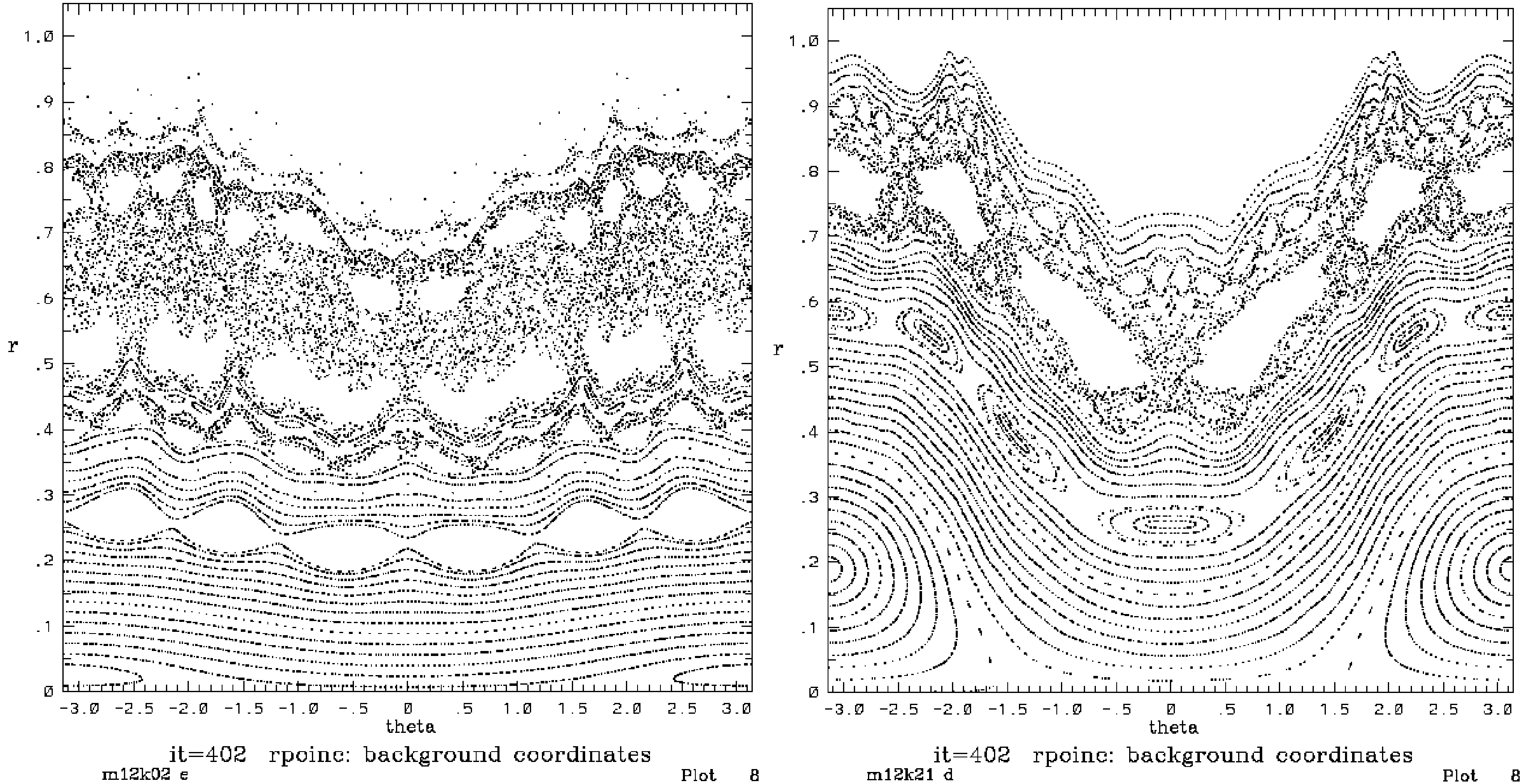


Flux surfaces from reference M12 coils (left) and current modified M12 that reduces 1/5 resonance Boozer Jacobian by a factor of 10 in VMEC solution (right), after 400 iterations with blend=0.99.





Flux surfaces from reference M12 coils (left) and current modified M12 that reduces 1/5 resonance Boozer Jacobian by a factor of 10 in VMEC solution (right), after 400 iterations with blend=0.99 and two more iterations without blending.



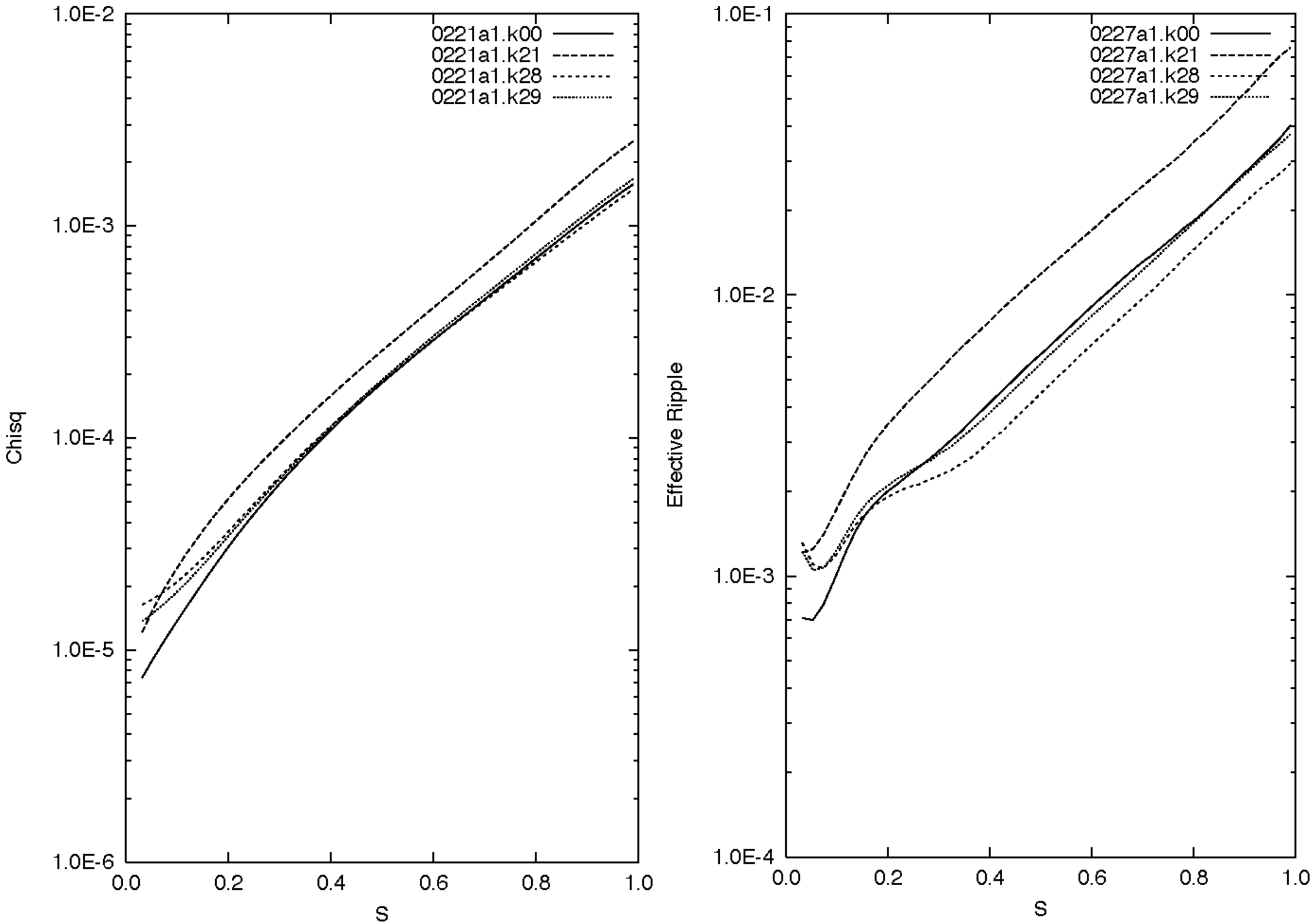
- The “non-hudson” approach, although helpful, does not give us the flux surface quality that deems acceptable.

- Island healing via iterative PIES calculation and coil modification needs to be carried out FIRST before we can analyze the stability and transport properties of the reconstructed plasmas.

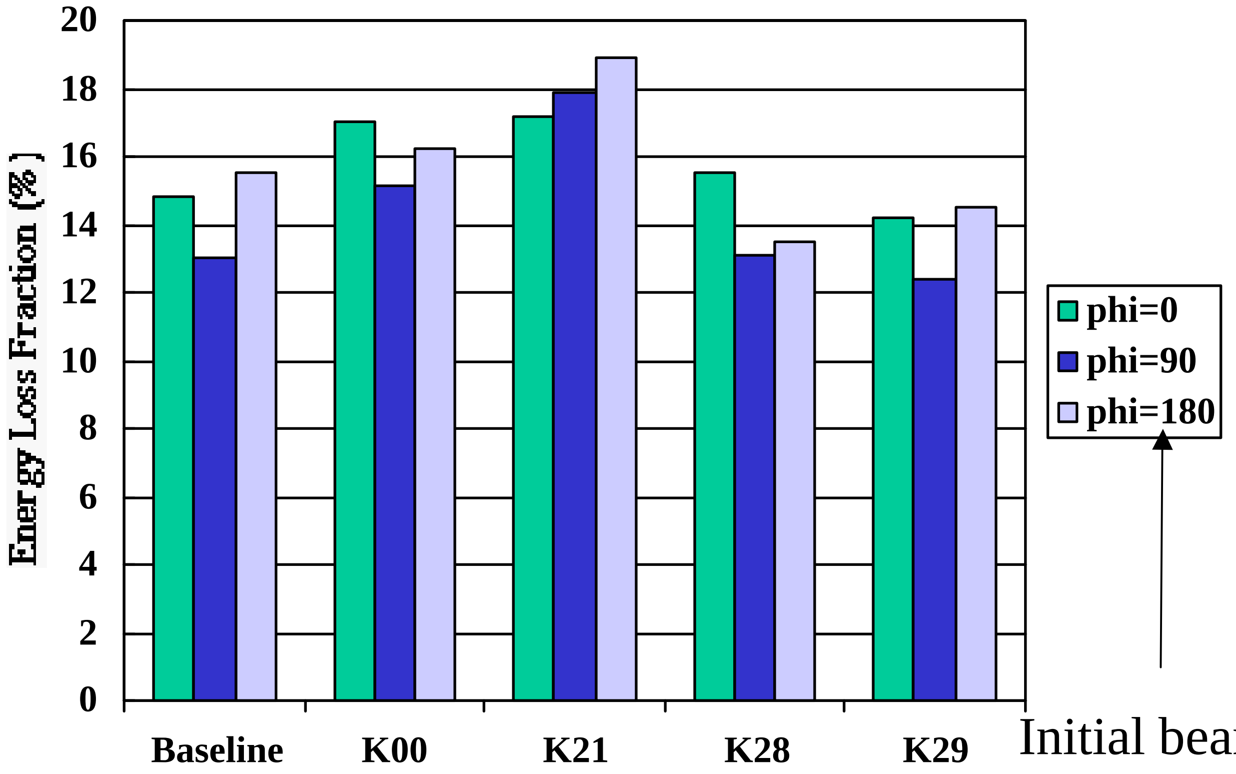
- Plasma performances can be improved by optimizing coil current alone (without changing coil geometry).
  - Single objective can be achieved at the expense of some other properties (M2.3.z07, M7.3.k11).
  - Careful balance the weight of different objectives in the optimization may allow us to find an overall better solution.

- For M12
  - M12.3.k21: Jac(1,5) lowered by x10, ballooning stable, kink stable with new modified 91 mode table, β=5.4%.
  - M12.3.k28: effective ripple improved and NB loss ~ reference LI383 plasma. Kink eigenvalue~1.5×10^{-4}
  - M12.3.k29: recovered almost all the properties of the reference plasma, except somewhat larger effective ripple in the region r/a<0.5.
  - All of these are achieved without using additional coils, and the modifications of coil currents are modest.

Comparison of residual non-axisymmetric fields and effective ripple for three modified cases of M12.



NB energy losses for K28 and K29 are no worse than the baseline LI383.

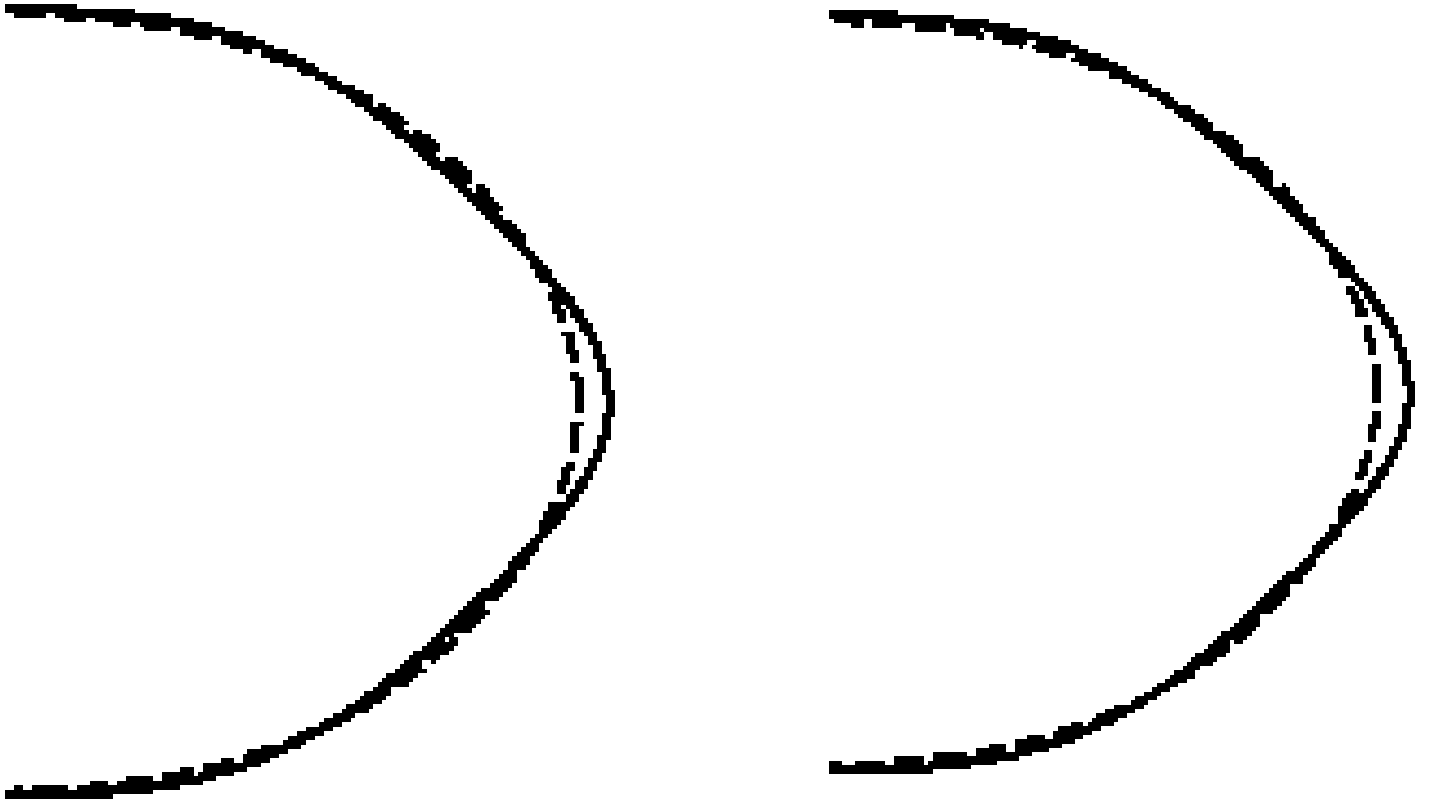


Initial beam toroidal angle

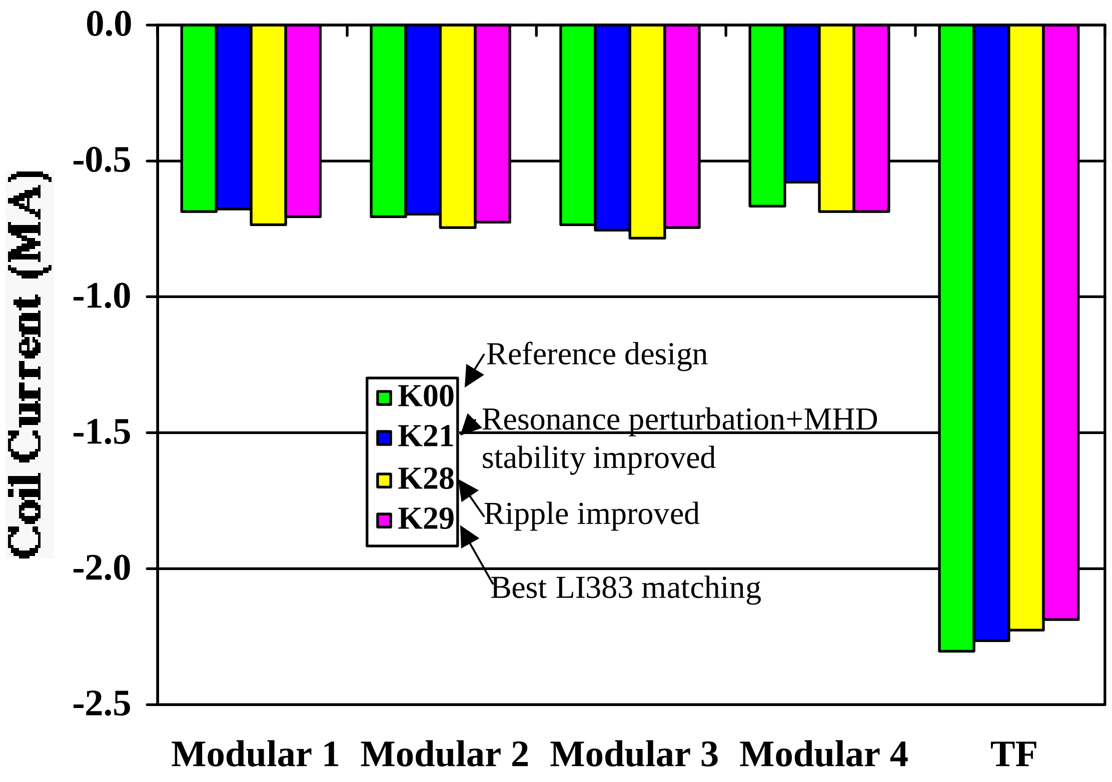
40 keV H beam @ 2T. $R_{tan}=R_{maj}$

Cross Section at v=0 for the reference M12 (left) and current modified M12.K29 (right), in comparison to the baseline LI383 plasma

Cross Section at v=1/2 for the reference M12 (left) and current modified M12.K29 (right), in comparison to the baseline LI383 plasma



Modest modification of M12 coil currents can improve plasma performance of different emphasis



R_{maj}=1.7 m, B_{edge}=2 T

M12 appears to be a good candidate for the reference coil, provided that islands can be healed and its ability to access other regions of operating space ascertained.