Compact Stellarator Simulations Using M3D

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The M3D code is capable of using a 3D mesh, suitable for stellarator studies. Simulations can be initialized with Vmec equilibrium data. M3D is run with resistive dissipation, as well as cross field thermal conduction. Parallel thermal conduction is simulated with the "artificial sound" method.

M3D can be run with a coarse grain parallelization, with poloidal planes of data assigned to different processors. The following equilibrium was calculated with an Origin 2000 shared memory multiprocessor computer.

Initialization of M3D from VMEC

Vmec provides a parametrization of magnetic surfaces

$$R(s, \theta, \phi), Z(s, \theta, \phi)$$

which is used to construct the M3D grid, shown in the figures below. 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.

Relaxation of M3D Equilibrium from VMEC

The artificial sound method solves

$$\frac{\partial p}{\partial t} = -\mathbf{v} \cdot \nabla p - (\gamma - 1) p \nabla \cdot \mathbf{v} + \nabla_{\|} v_{a\|}$$

$$\frac{\partial v_{a\|}}{\partial t} = -\frac{1}{\tau_a} v_{a\|} + c_a^2 \nabla_{\|} p$$

to relax towards a state with

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

Source terms $J_{\phi 0}, p_0$: are included to maintain the toroidal current and pressure.

$$E_\phi + (\mathbf{v} \times \mathbf{B})_\phi = \eta (J_\phi - J_{\phi 0})$$

$$\frac{\partial p}{\partial t} = \ldots + \nabla \cdot \kappa \nabla (p - p_0)$$

Kinetic energy is removed by viscous damping.

Simulations were done with $2000 - 5000$ poloidal meshpoints, and $20 - 36$ toroidal meshpoints, using an 8 processor SGI Origin 2000 computer at NYU, as well as on workstations. Better resolution, with larger grids, will be obtained by running on a large O2000 shared memory computer at Princeton University. High resolution will be achieved with parMHD, a massively parallel implementation.

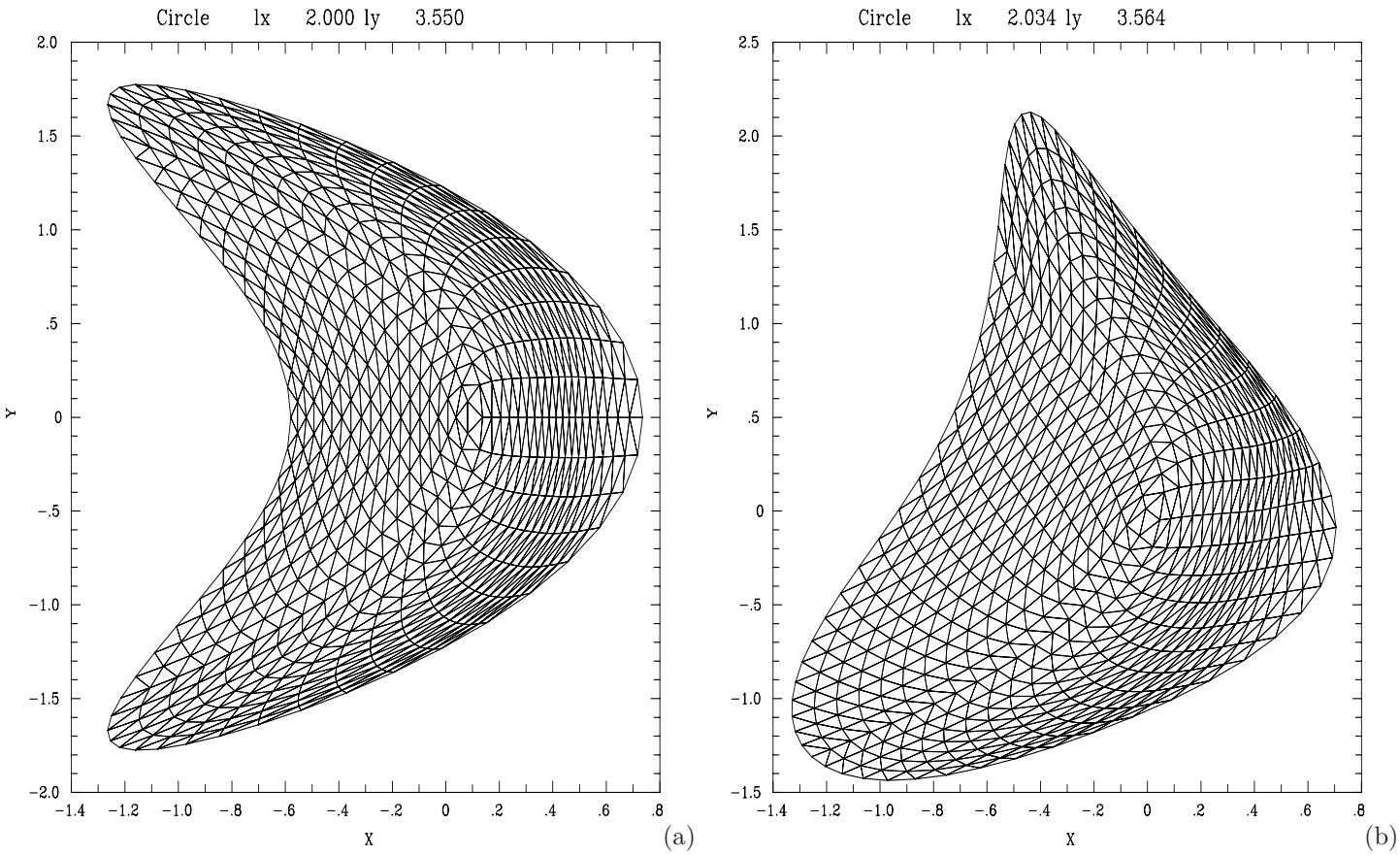


Figure 1: The computational mesh has about 4 times as many points as in these figures. (a) mesh in poloidal plane $\phi = 0$. (b) mesh in poloidal plane $\phi = \pi/6$.

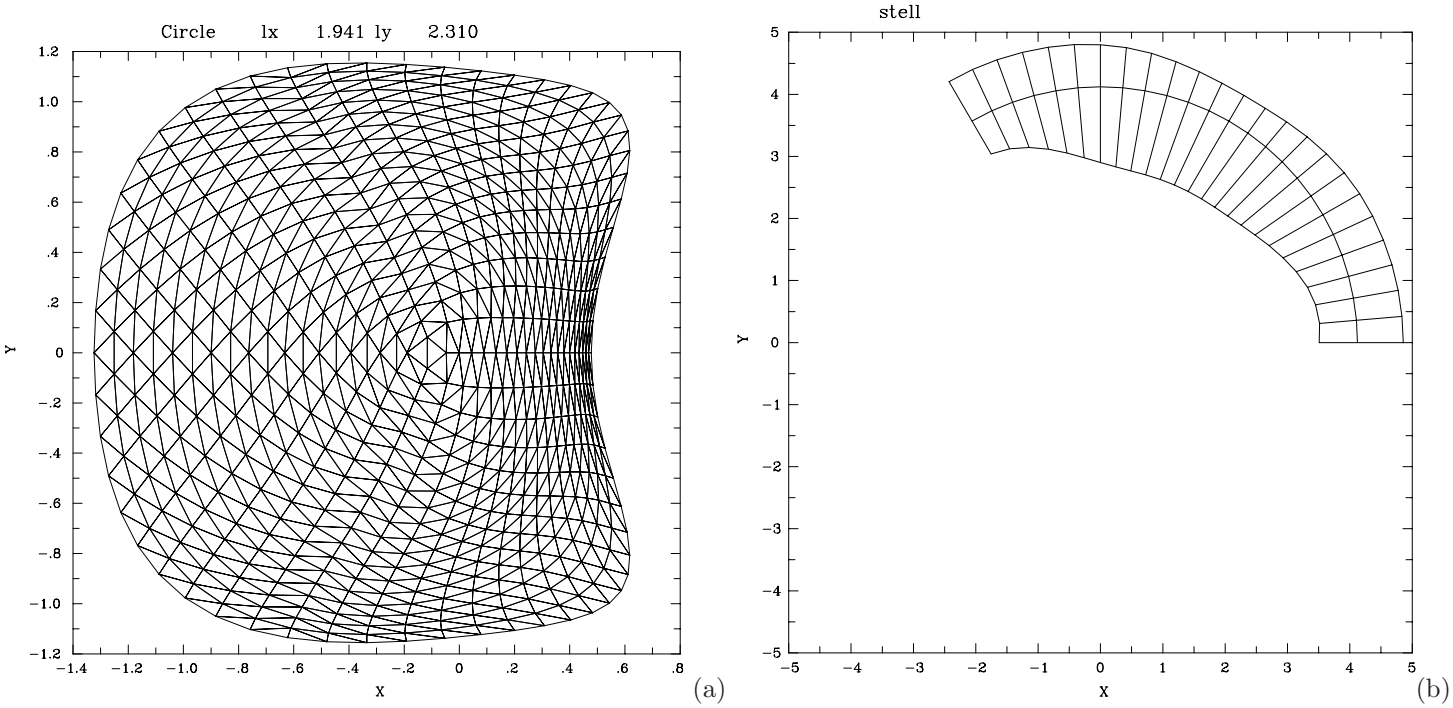
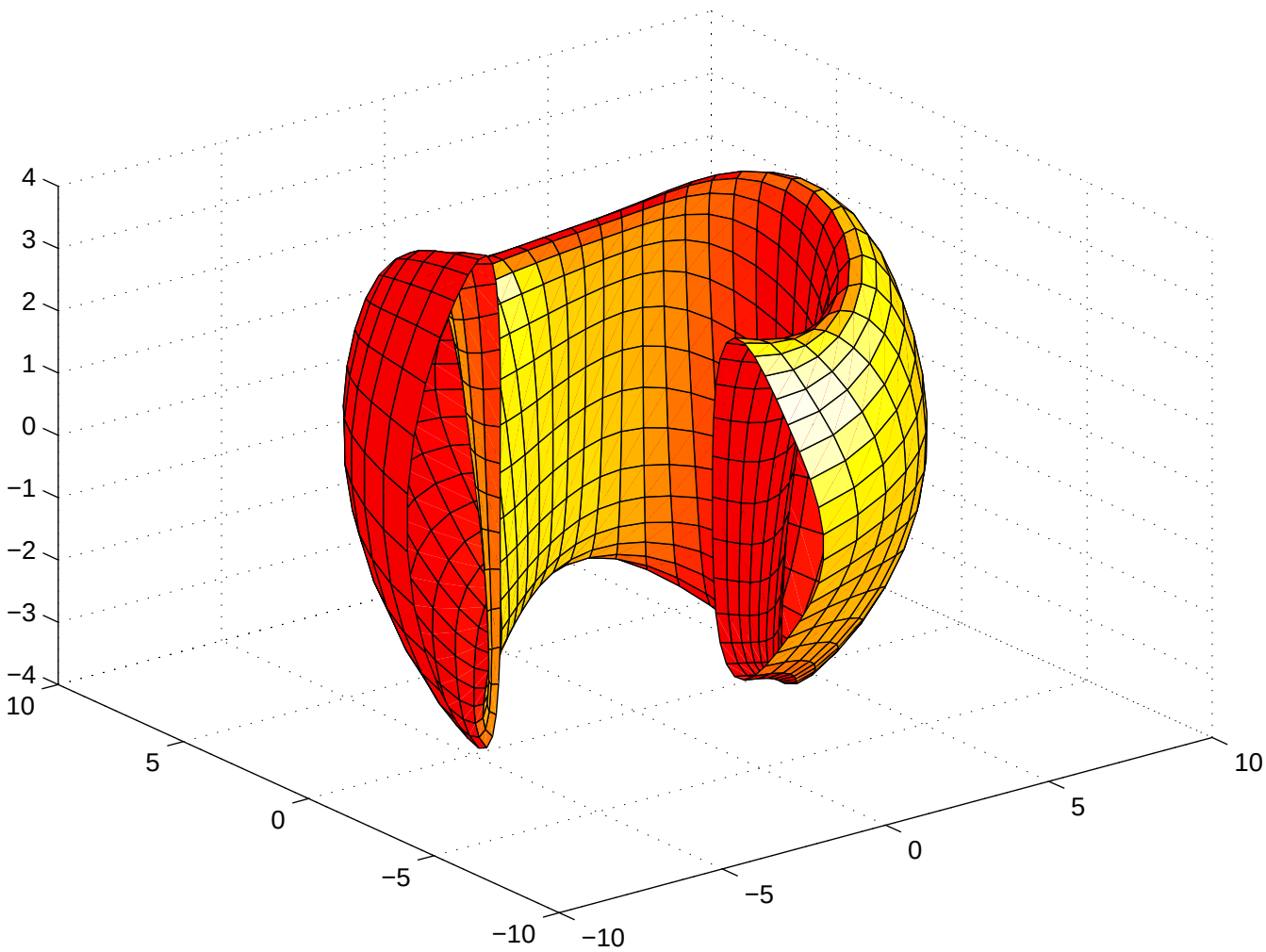
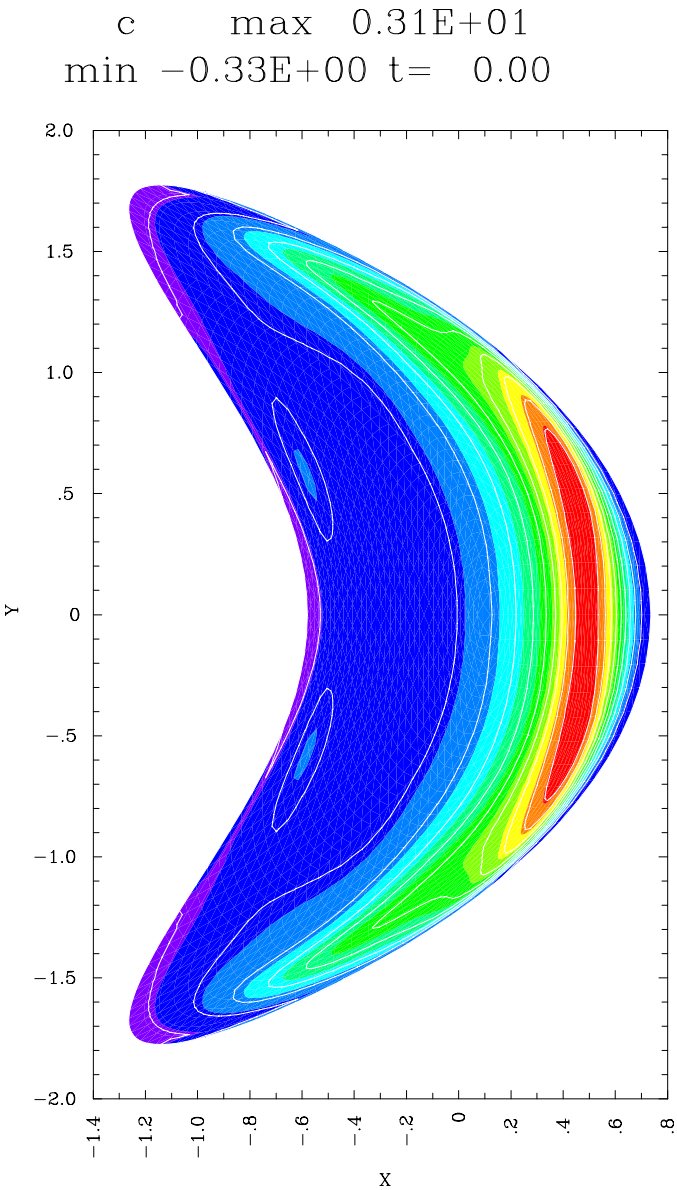


Figure 2: (a) mesh in poloidal plane $\phi = \pi/3$. (b) toroidal mesh


4
3
2
1
0
−1
−2
−3
−4
10
5
0
−5
−10
−10
−5
0
5
10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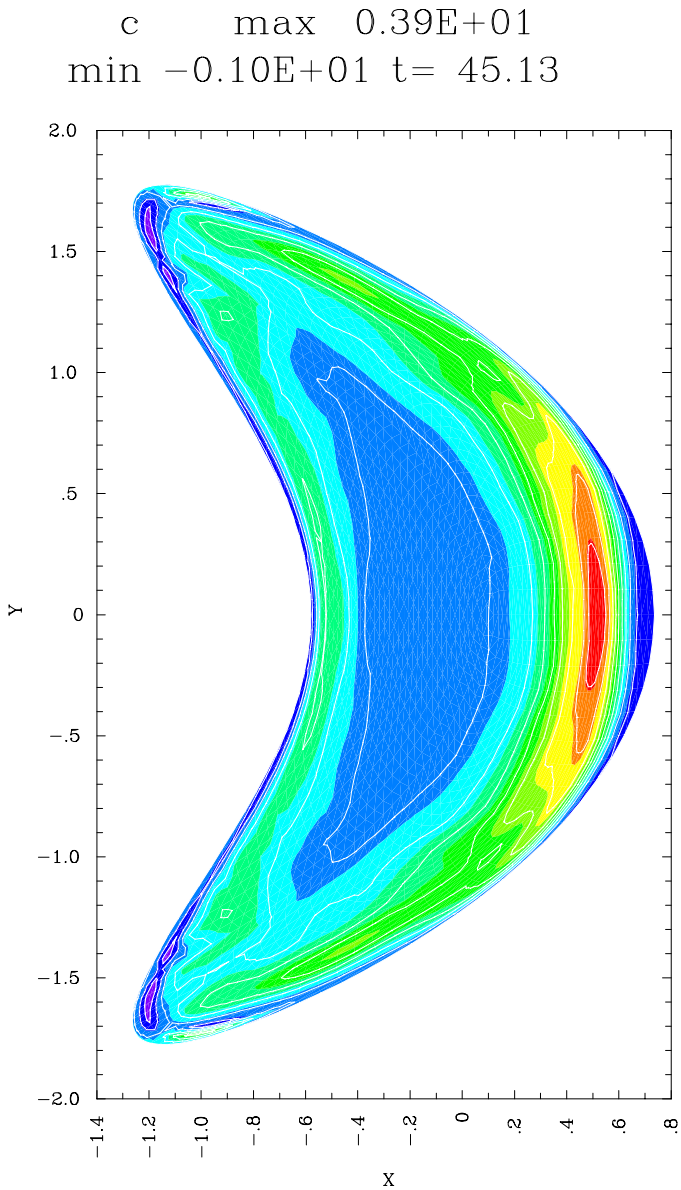
2.0
1.5
1.0
.5
0
−.5
−1.0
−1.5
−2.0
Y
−1.4
−1.2
−1.0
−.8
−.6
−.4
−.2
0
.2
.4
.6
.8
X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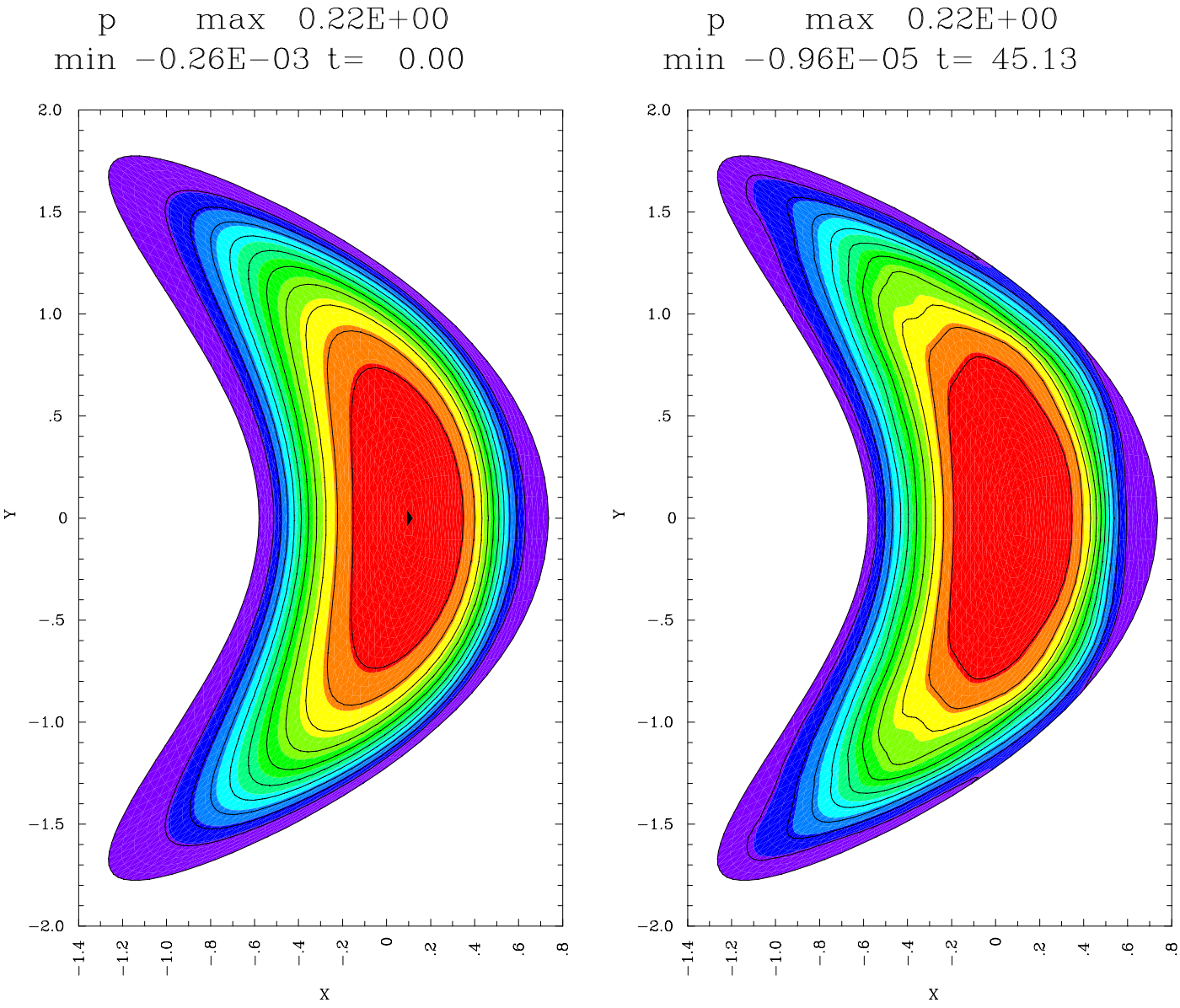
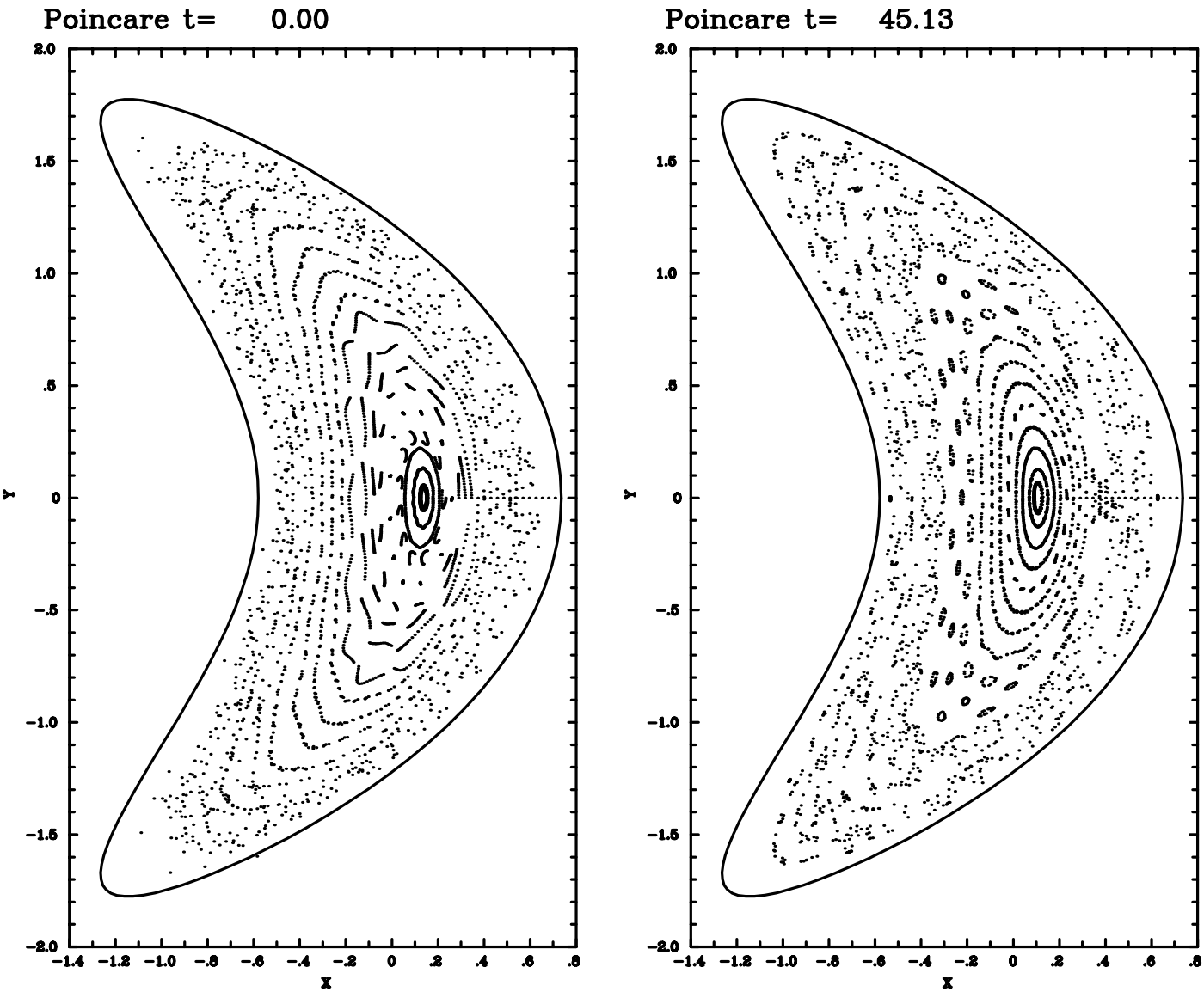
min −0.10E+01 t= 45.13
2.0
1.5
1.0
.5
0
−.5
−1.0
−1.5
−2.0
Y
−1.4
−1.2
−1.0
−.8
−.6
−.4
−.2
0
.2
.4
.6
.8
X

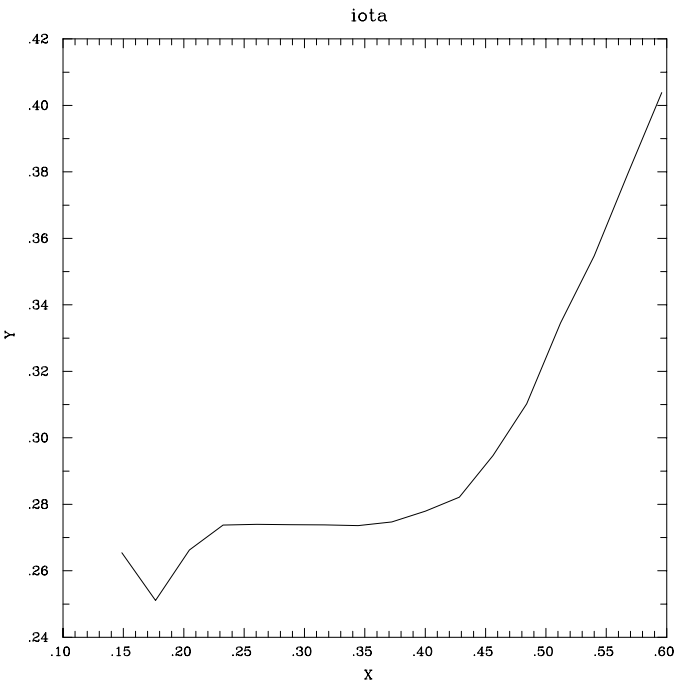
2 ϕ 0, t 0, t .

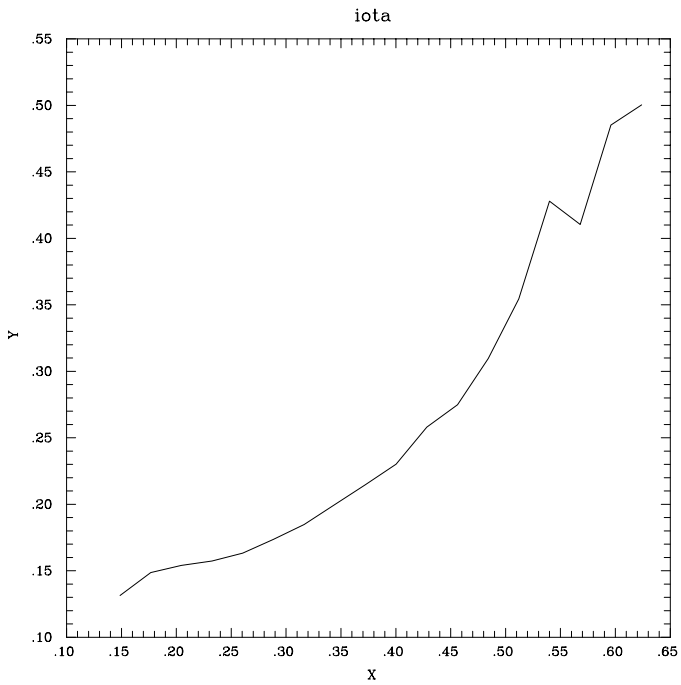

p max 0.22E+00
min −0.26E−03 t= 0.00
p max 0.22E+00
min −0.96E−05 t= 45.13
Y
X
2.0
1.5
1.0
.5
0
−.5
−1.0
−1.5
−2.0
−1.4
−1.2
−1.0
−.8
−.6
−.4
−.2
0
.2
.4
.6
.8

ϕ 0, t 0, t .

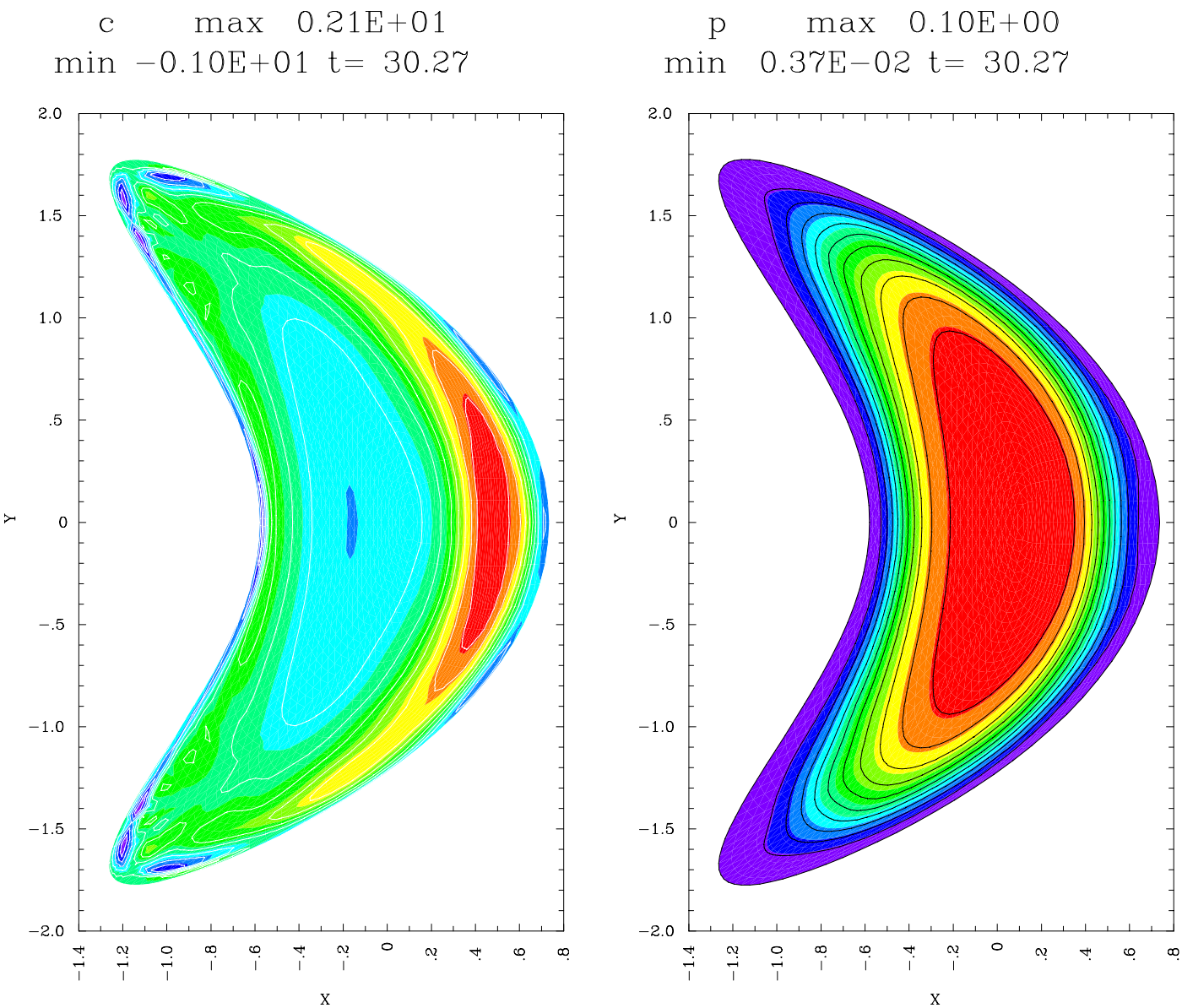

Poincare t= 0.00
Poincare t= 45.13
Y
X
2.0
1.5
1.0
.5
0
−.5
−1.0
−1.5
−2.0
−1.4
−1.2
−1.0
−.8
−.6
−.4
−.2
0
.2
.4
.6
.8

$t \quad 0, \quad .$


iota
Y
X
.42
.40
.38
.36
.34
.32
.30
.28
.26
.24
.10
.15
.20
.25
.30
.35
.40
.45
.50
.55
.60


iota
Y
X
.55
.50
.45
.40
.35
.30
.25
.20
.15
.10
.10
.15
.20
.25
.30
.35
.40
.45
.50
.55
.60
.65

$t \quad 0, \quad .$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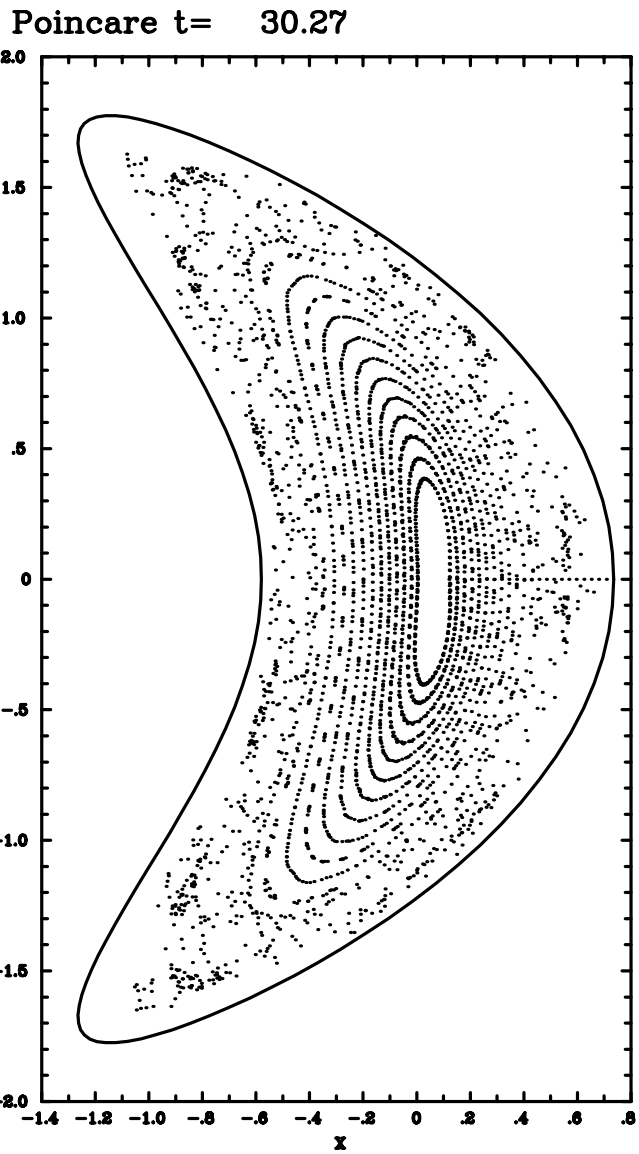
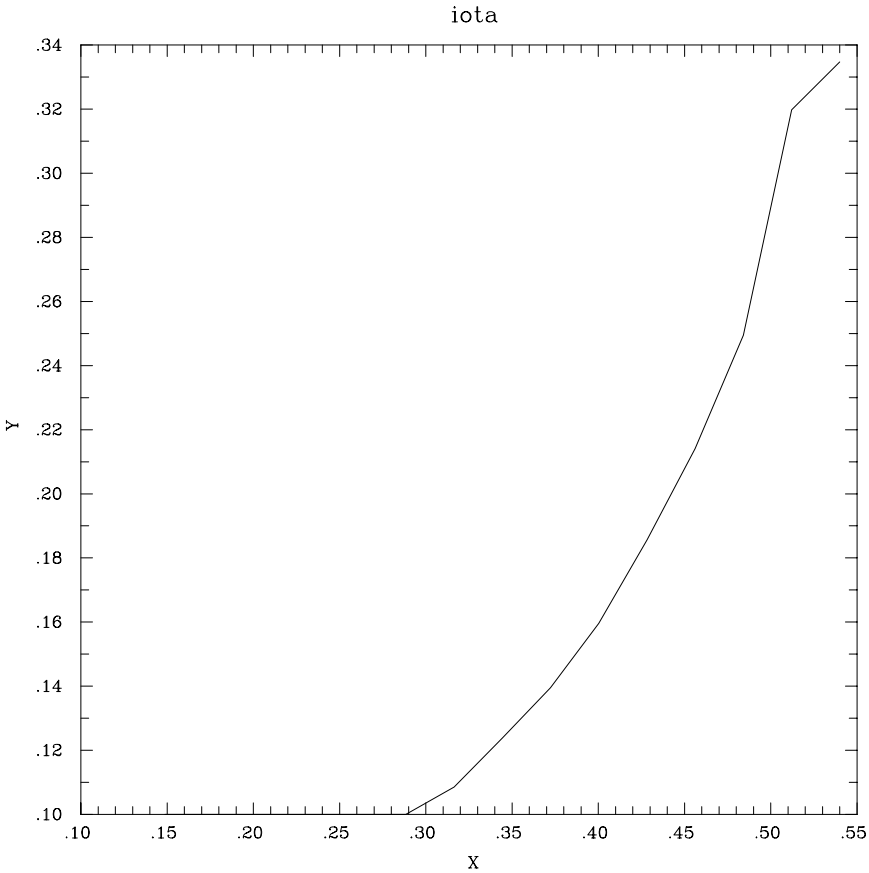
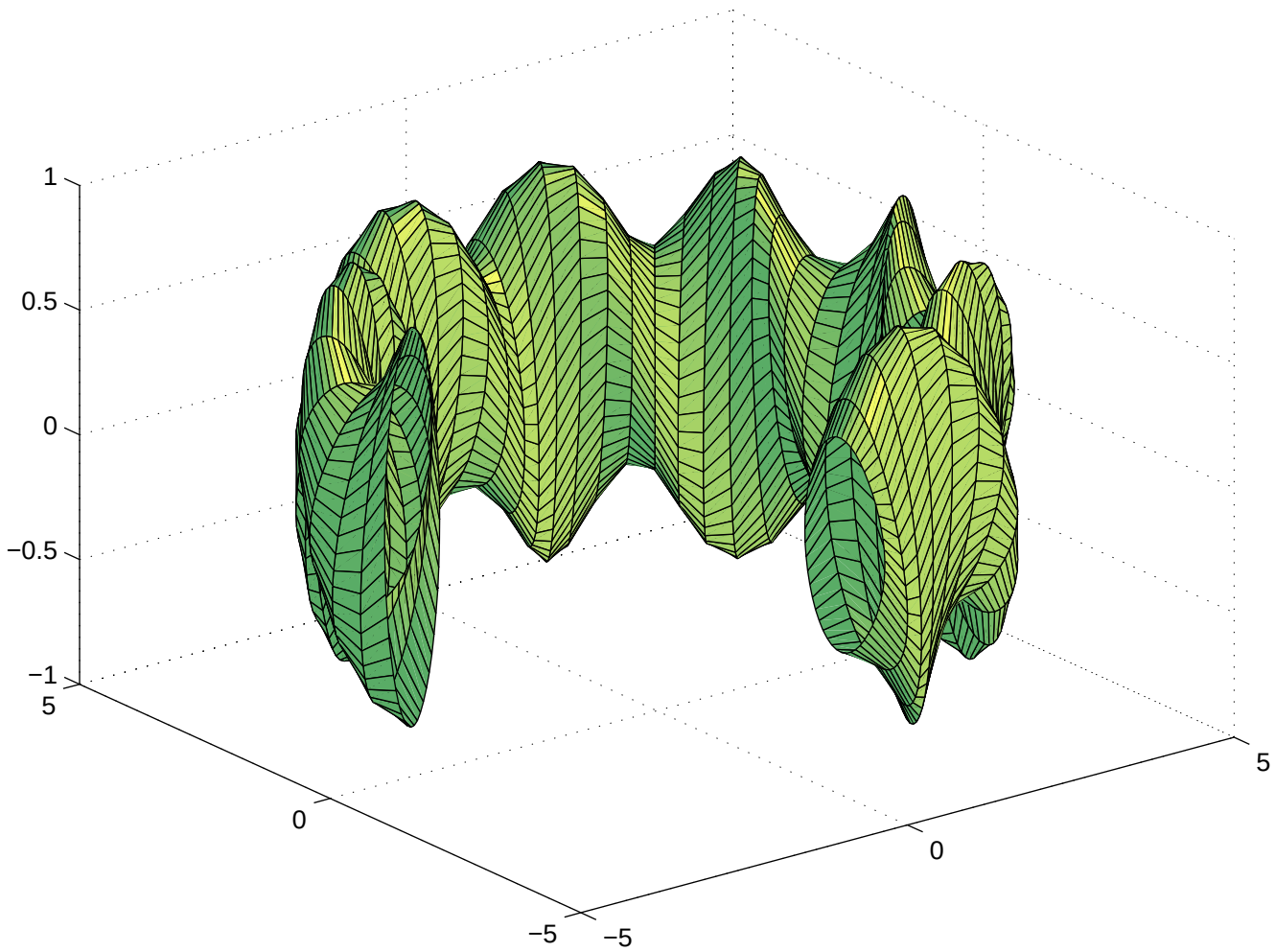
min −0.10E+01 t= 30.27
p max 0.10E+00
min 0.37E−02 t= 30.27
Y
X

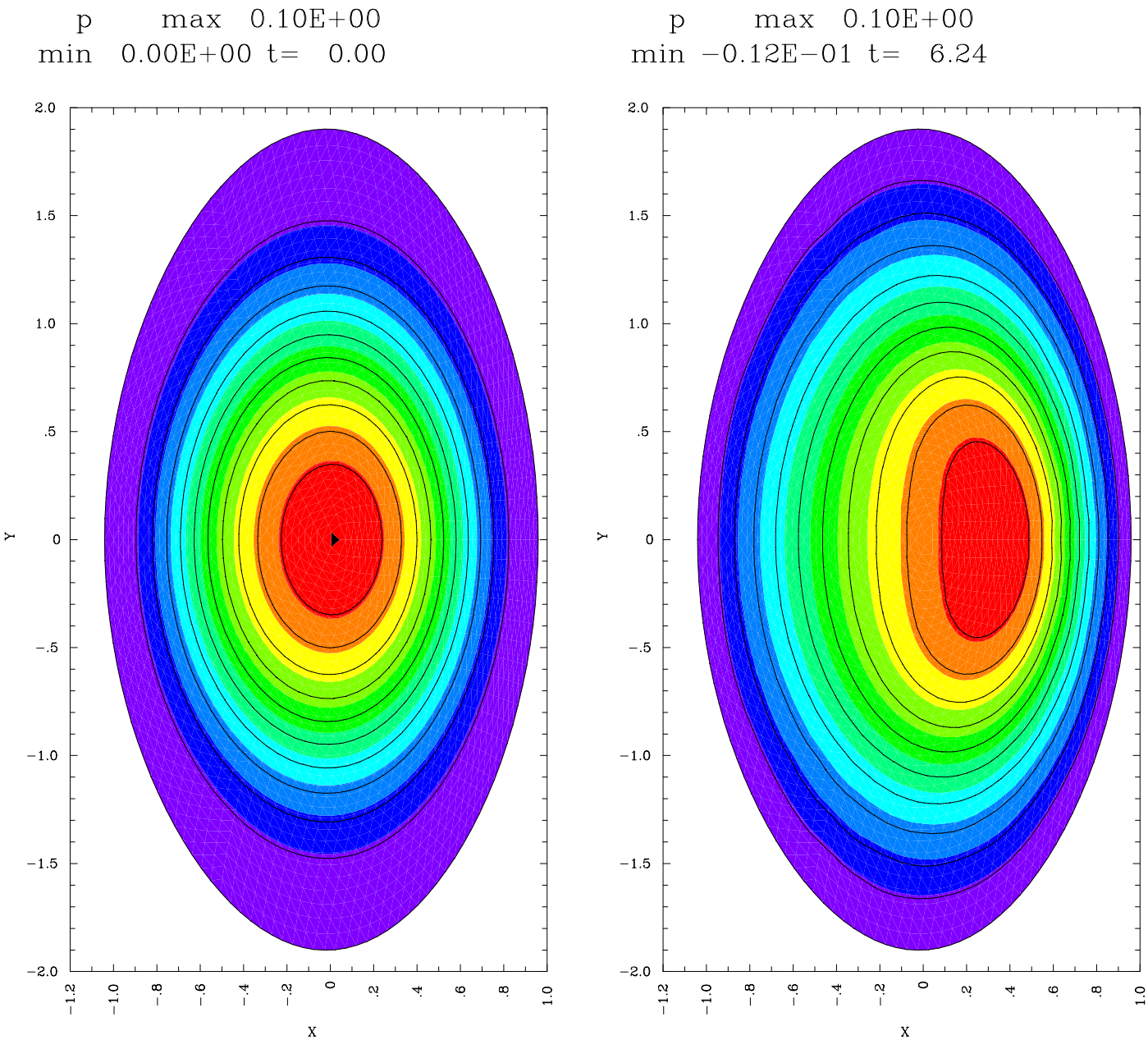
ϕ $0, t$ 0.2 .


Poincare t= 30.27
2.0
1.5
1.0
.5
0
-.5
-1.0
-1.5
-2.0
-1.4 -1.2 -1.0 -.8 -.6 -.4 -.2 0 .2 .4 .6 .8
X

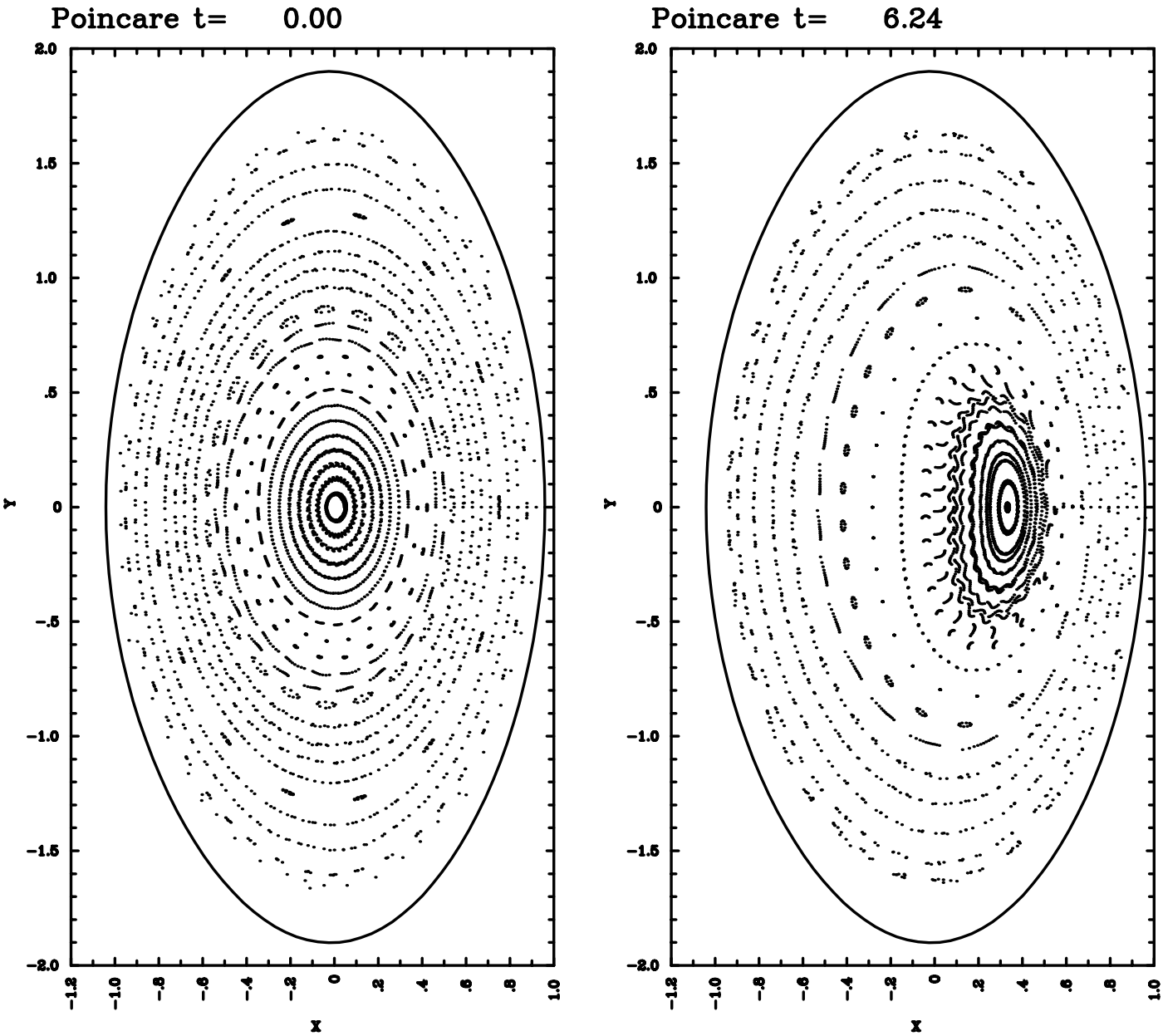

iota
.34
.32
.30
.28
.26
.24
.22
.20
.18
.16
.14
.12
.10
Y
.10 .15 .20 .25 .30 .35 .40 .45 .50 .55
X

2 t 0.2

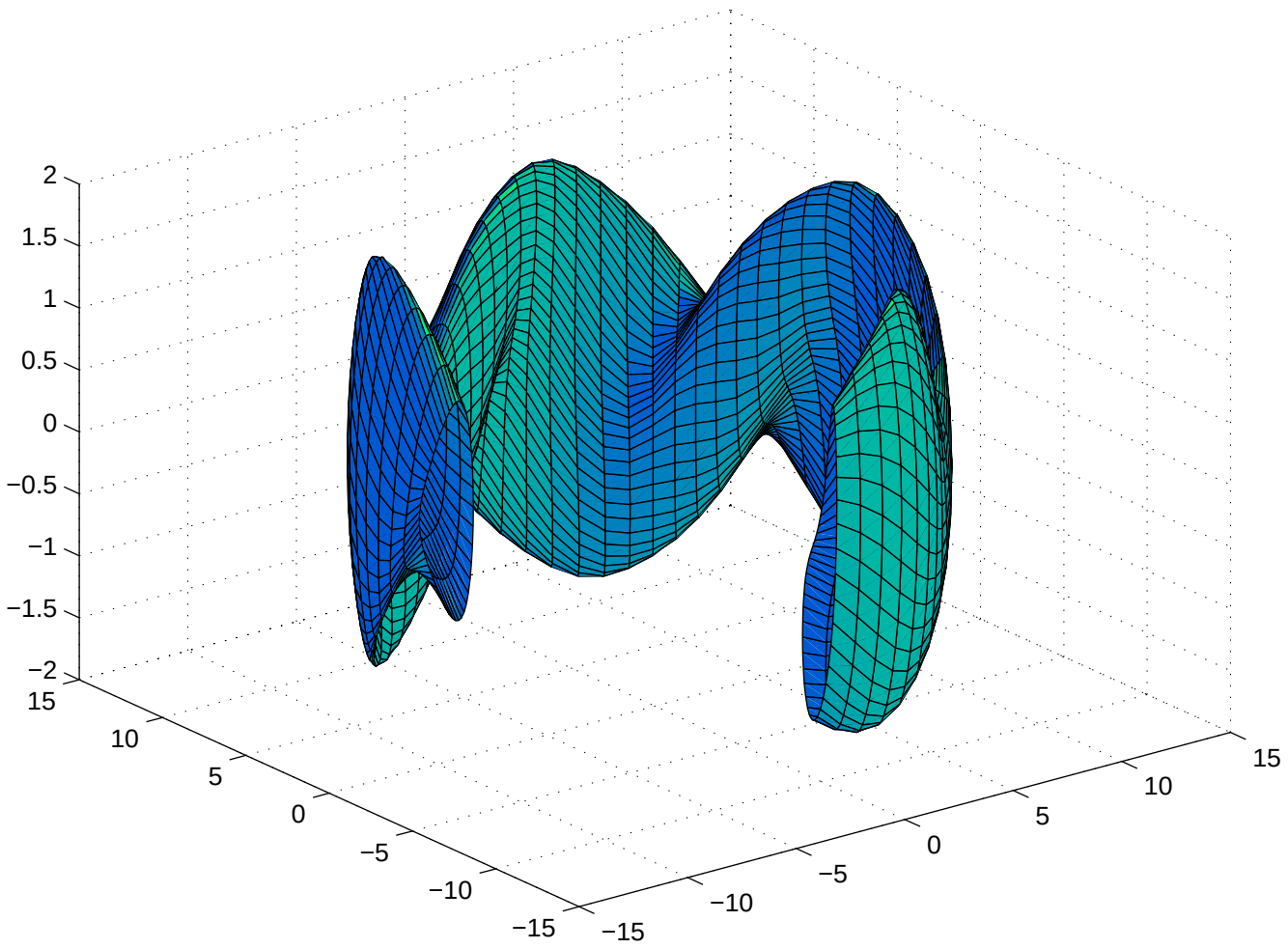

1
0.5
0
−0.5
−1
5
0
−5
−5
0
5

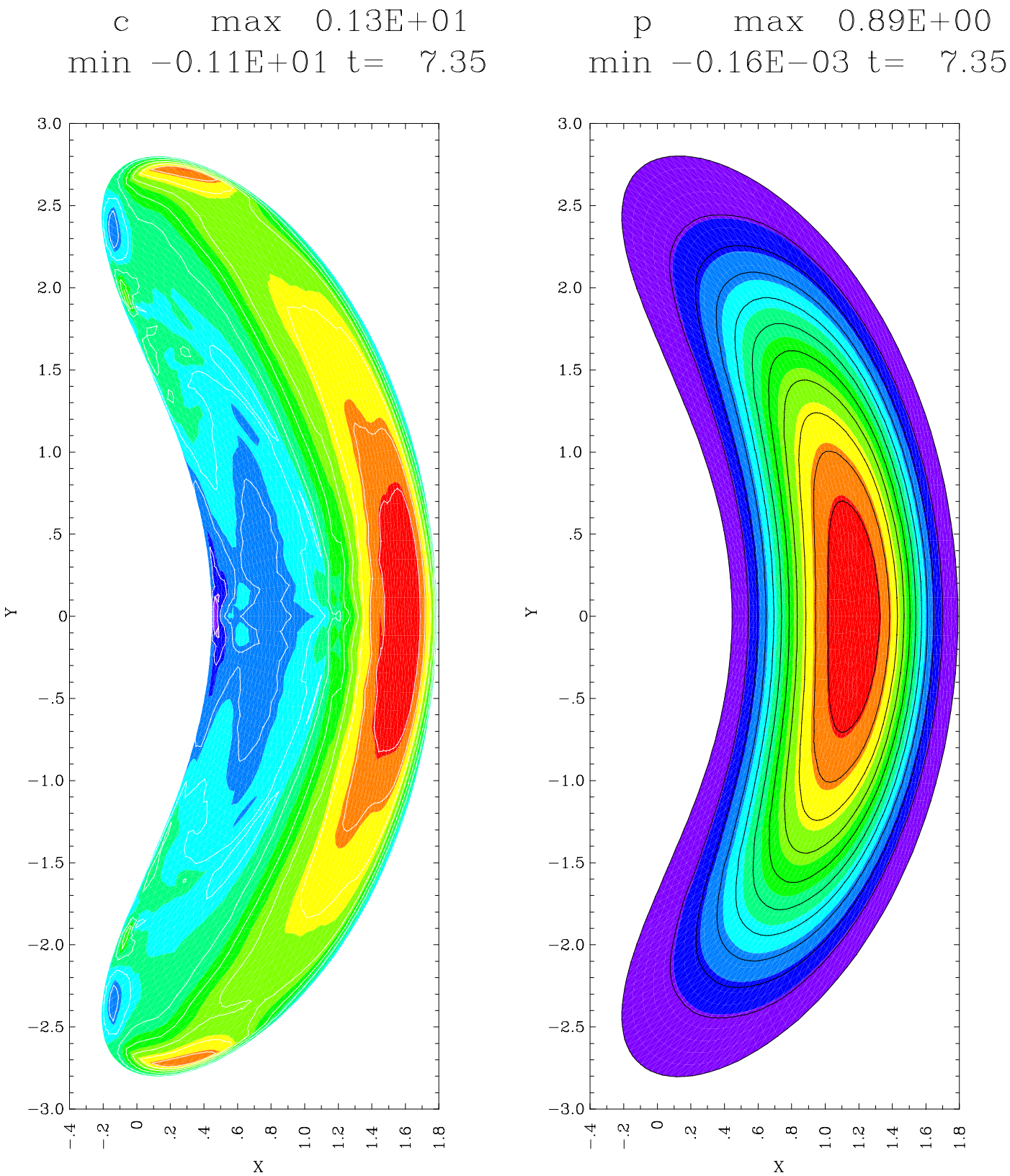


2 ϕ 0, t 0 t .2



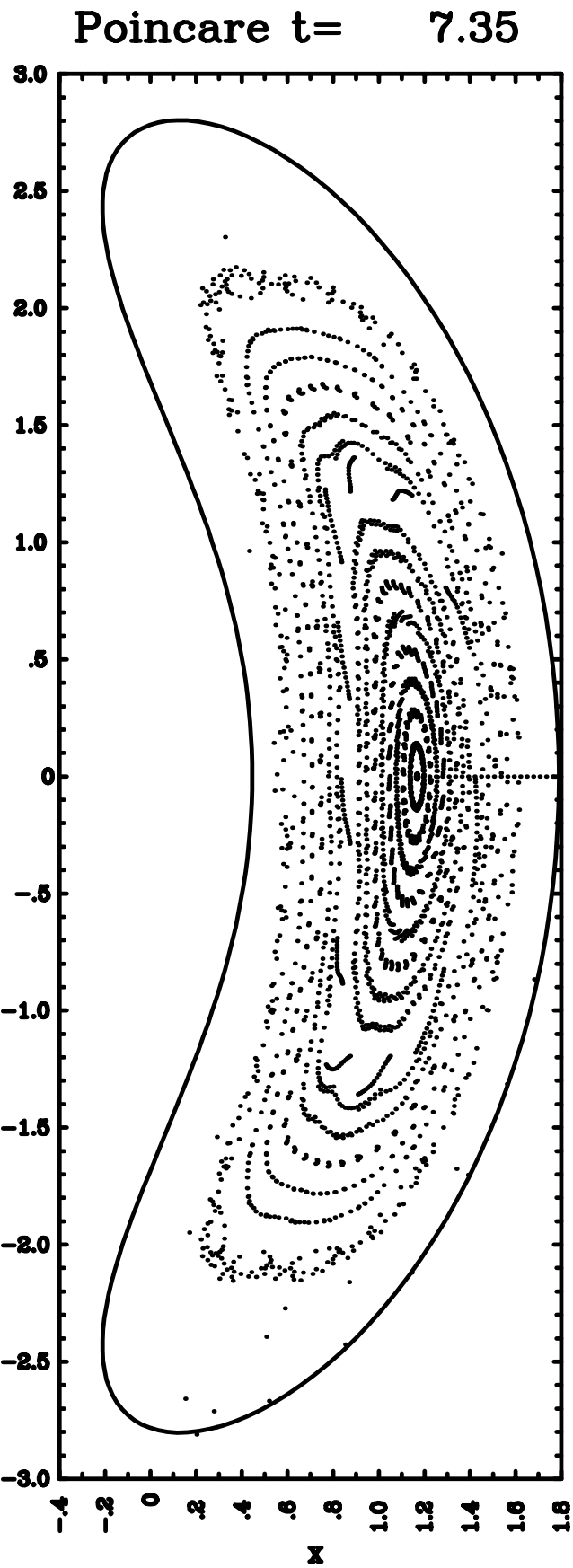
$t \quad 0, \ .2$

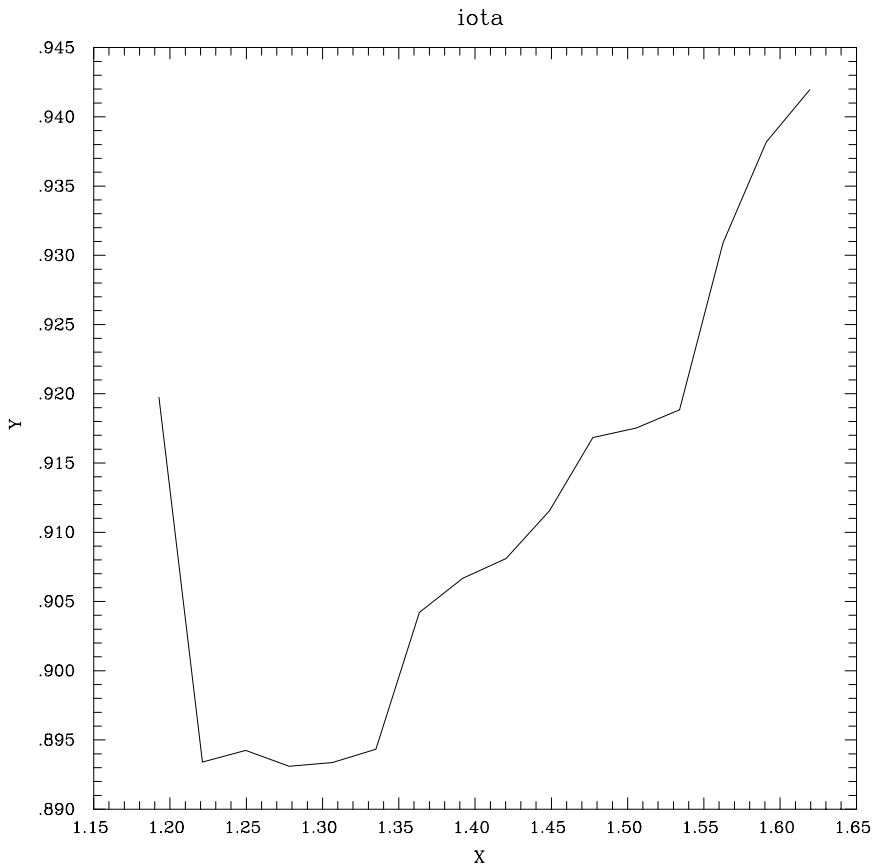

2
1.5
1
0.5
0
−0.5
−1
−1.5
−2
15
10
5
0
−5
−10
−15
−15
−10
−5
0
5
10
15


c max 0.13E+01
min −0.11E+01 t= 7.35
p max 0.89E+00
min −0.16E−03 t= 7.35
3.0
2.5
2.0
1.5
1.0
.5
0
−.5
−1.0
−1.5
−2.0
−2.5
−3.0
Y
−.4
−.2
0
.2
.4
.6
.8
1.0
1.2
1.4
1.6
1.8
X

2

ϕ $0, t$ . .


Poincare t= 7.35
3.0
2.5
2.0
1.5
1.0
.5
0
−.5
−1.0
−1.5
−2.0
−2.5
−3.0
−.4
−.2
0
.2
.4
.6
.8
1.0
1.2
1.4
1.6
1.8
X


iota
.945
.940
.935
.930
.925
.920
.915
.910
.905
.900
.895
.890
Y
1.15
1.20
1.25
1.30
1.35
1.40
1.45
1.50
1.55
1.60
1.65
X

t .