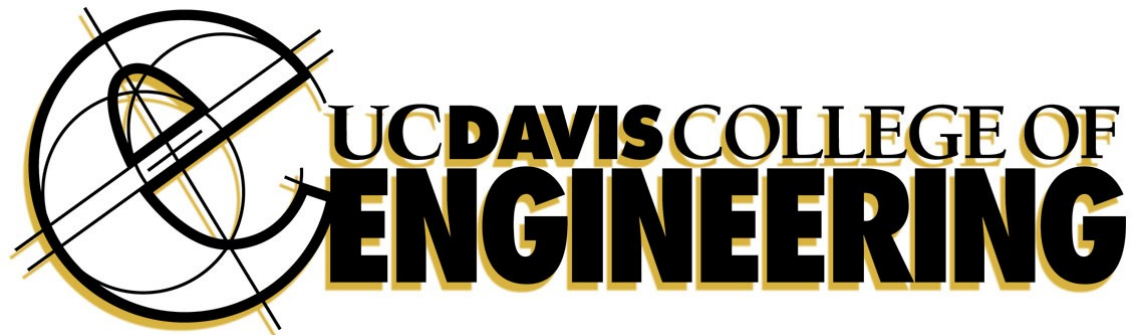


# Chaotic Streamlines Inside Droplet

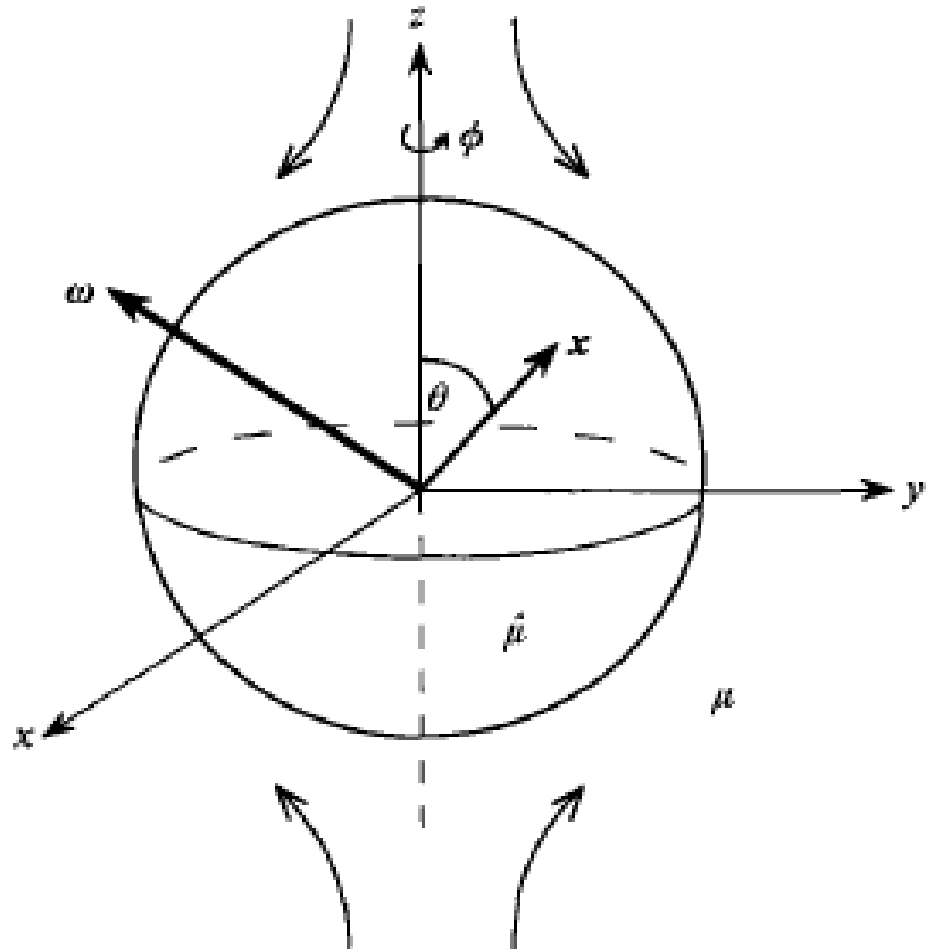
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**Radoslav Bozinoski**



# System

- Neutrally Buoyant
  - External Flow
    - Vorticity
    - Rate of Strain Tensor
    - Linear
  - Internal Flow
    - Nonlinear
    - Chaotic Streamlines



# Flow field

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- Coordinate system moving with center-of-mass.
- Inter-boundary tension is sufficiently large to maintain a spherical drop shape.
- Far from the drop the fluid is assumed to undergo a steady linear motion

# Governing Equations

$$u^\infty(x) = U + \frac{1}{2} w \times x + E \cdot x$$

$$u(x) = \frac{1}{2} [(5r^2 - 3) E \cdot x - 2 x x \cdot E \cdot x] + \frac{1}{2} w \times x$$

$$E = \begin{pmatrix} 1/(1+a) & 0 & 0 \\ 0 & a/(1+a) & 0 \\ 0 & 0 & -1 \end{pmatrix} \quad a = \frac{E_{22}}{E_{11}}$$

# Simplifications

$$x \rightarrow y, y \rightarrow x, a \rightarrow \frac{1}{a}$$

$$w = (w_x, w_y, w_z) \rightarrow (-w_y, -w_x, -w_z)$$

$$0 \leq a \leq 1$$

$$x \rightarrow -x, w_y \rightarrow -w_y, w_z \rightarrow -w_z$$

$$w_z \geq 0$$

$$z \rightarrow -z, w_x \rightarrow -w_x, w_y \rightarrow -w_y$$

$$w_y \geq 0$$

# Parameters of interest

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- $a = 1$  - Axisymmetric
- $\omega = (\omega_x, 0, \omega_z)$ 
  - $\omega = 0$
  - $\omega$  - inline with z-axis
  - $\omega$  - oriented off z-axis

$$\omega = 0$$

$$a = 1.0$$

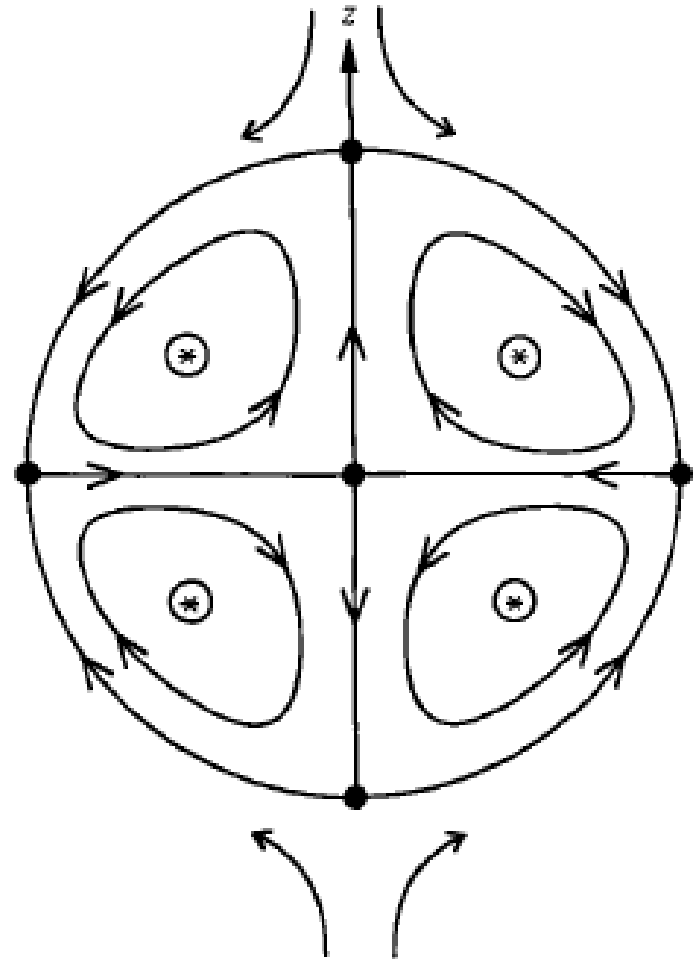
$$w = (0,0,0)$$

$$\text{LCE} = (0,0,-)$$

Dot - Saddle fixed points

Asterisks – Elliptic fixed points

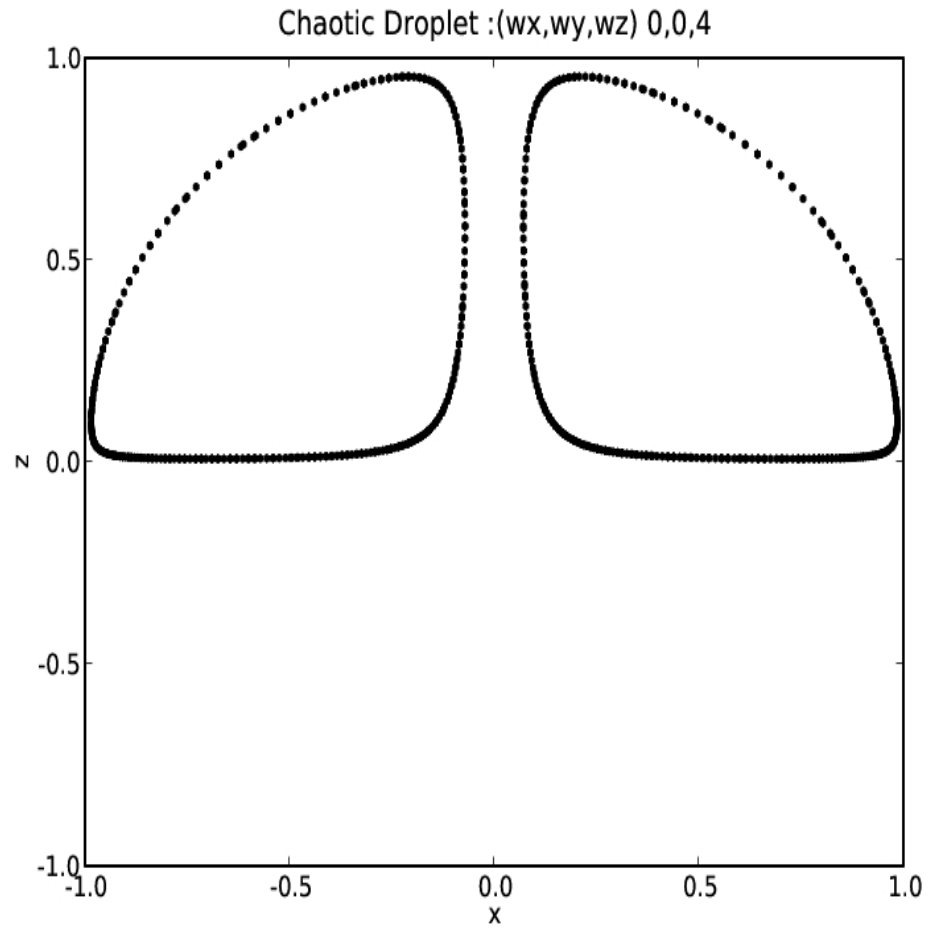
$\psi = 0$  -Nested family of tori



# $\omega$ - inline with z-axis

- $\psi$  exists

$$\phi(t) = \omega t + \phi_0$$





# $\omega$ – oriented off z-axis

- Chaotic Streamlines

- Fixed orientation ( $36^\circ$ )

- Fixed  $\omega$  magnitude

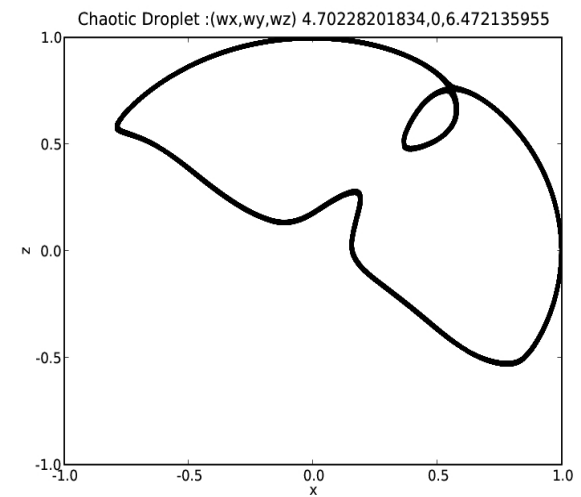
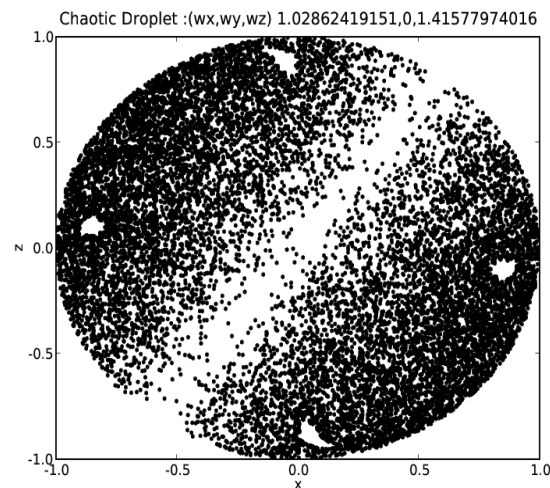
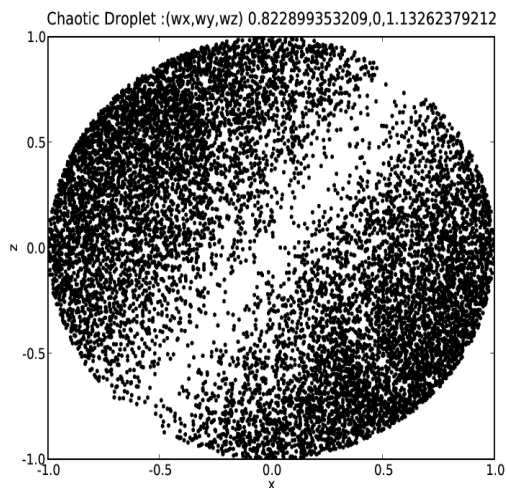
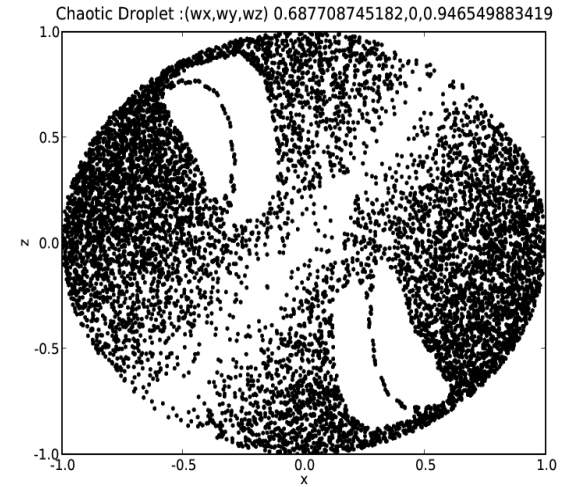
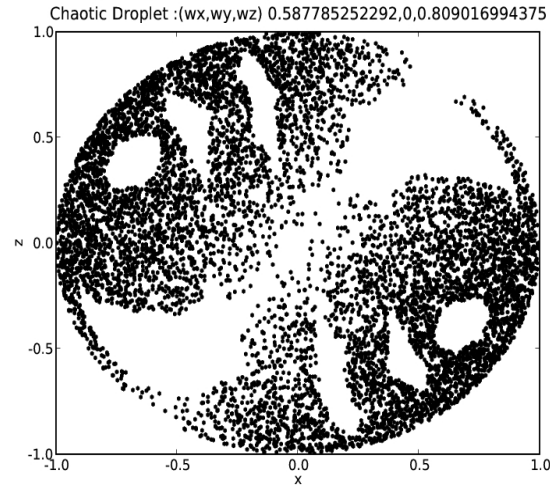
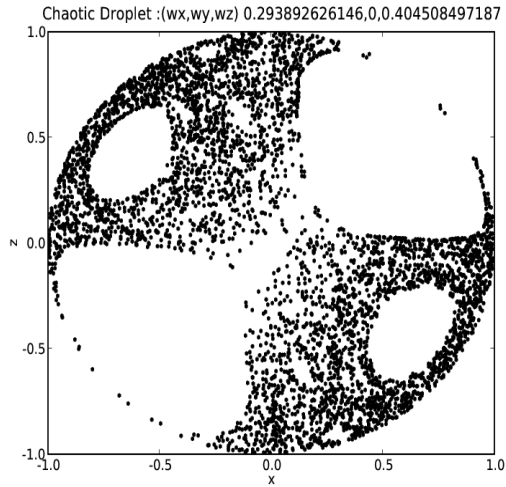
- $\omega = 0.1$

- $\omega = 2.0$

- $a = 1.0$

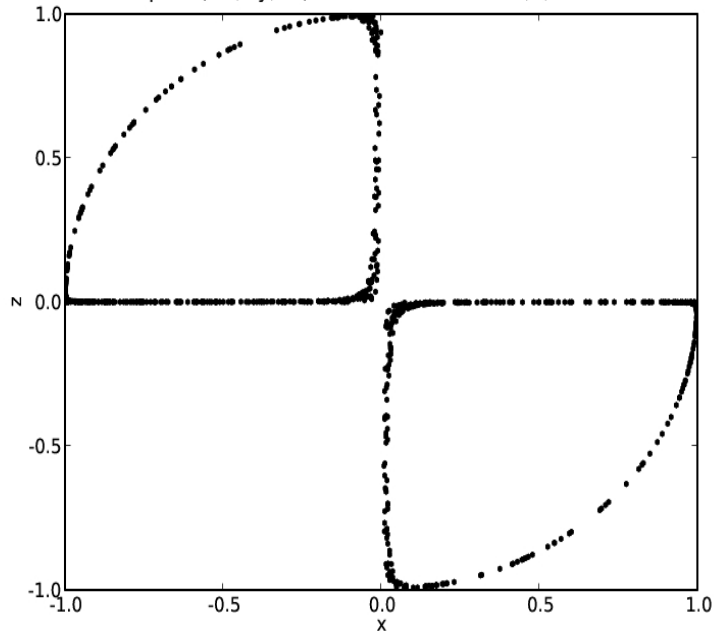
- $\omega = (w_x, 0, w_z)$

# Theta = 36°

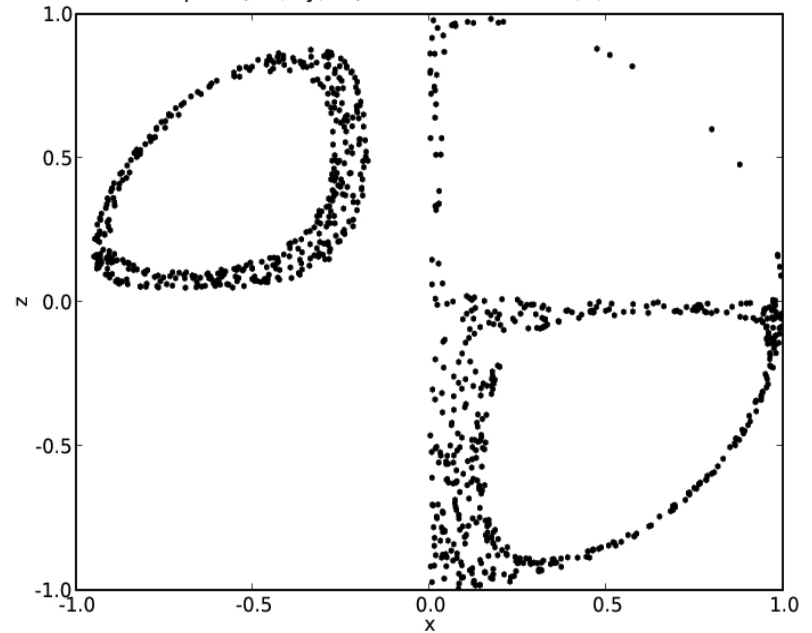


$$\omega = 0.1$$

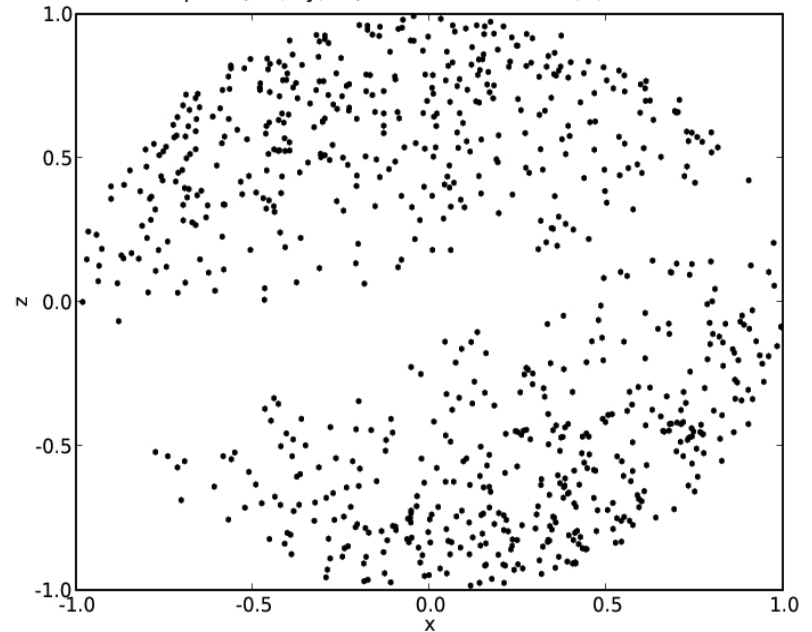
Chaotic Droplet : (wx,wy,wz) 0.000314158748588,0,0.0999995065202



Chaotic Droplet : (wx,wy,wz) 0.0309016994375,0,0.0951056516295

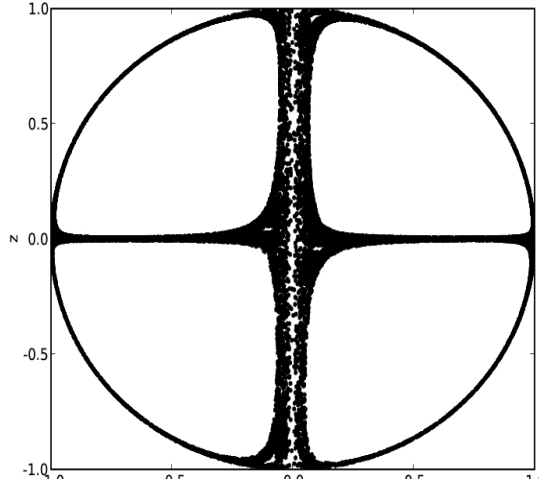


Chaotic Droplet : (wx,wy,wz) 0.0951056516295,0,0.0309016994375

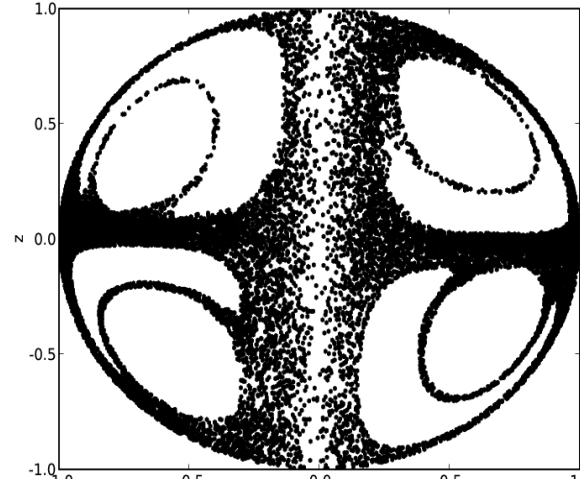


$$\omega = 2.0$$

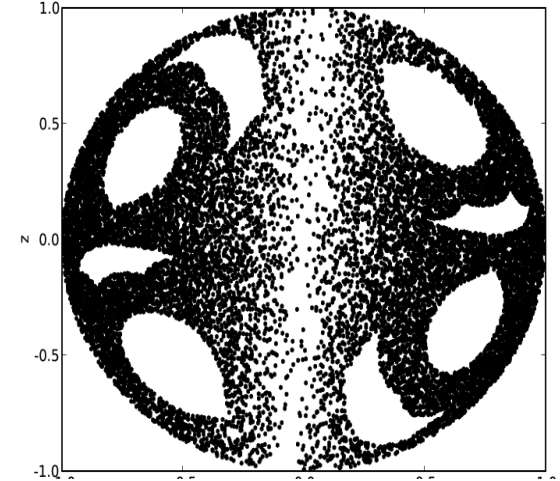
Chaotic Droplet : (wx,wy,wz) 0.00628317497176,0,1.9999901304



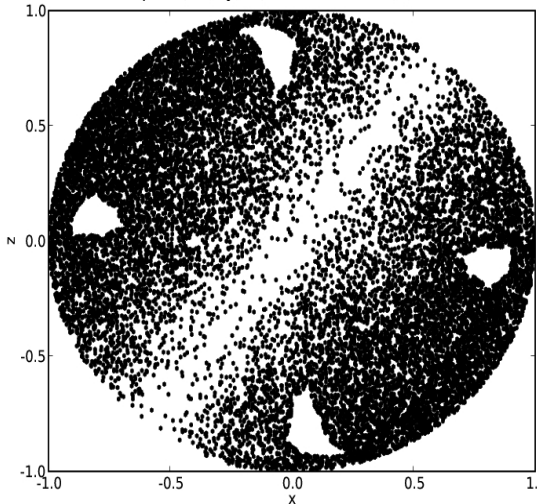
Chaotic Droplet : (wx,wy,wz) 0.0420942331134,0,1.99955696982



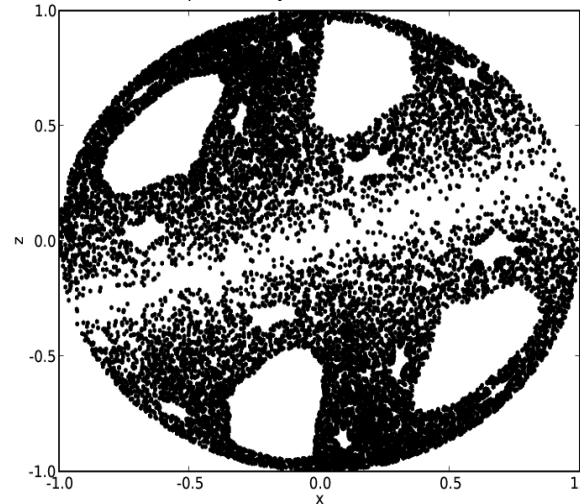
Chaotic Droplet : (wx,wy,wz) 0.125581039059,0,1.99605345686



Chaotic Droplet : (wx,wy,wz) 1.17557050458,0,1.61803398875



Chaotic Droplet : (wx,wy,wz) 1.902113,0,0,0.618033988



Chaotic Droplet : (wx,wy,wz) 1.99605345686,0,0.125581039059

