THE PLASMA EDGE IN NON-AXISYMMETRIC DIVERTED DISCHARGES

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Overview

- Divergence-free fields
- Magnetic axisymmetric confinement
- Small asymmetries
  - Experimental signatures
  - Modeling approaches
  - Manifolds calculation
- Modeling non-stationary heat patterns

Divergence-free fields

From $\nabla \cdot B = 0 \rightarrow \vec{B} = \nabla \times \vec{A}$

In general, we can specify P in R^3 by three independent scalar functions $P \equiv \{\phi(\vec{r}), \vartheta(\vec{r}), \chi(\vec{r})\}$

Such that $\vec{A}(\vec{r})$ can be expressed as

$$\vec{A}(\vec{r}) = \nabla\chi + \varphi\nabla\vartheta - \psi\nabla\phi$$

And the magnetic field becomes

$$\vec{B} = \nabla\varphi \times \nabla\vartheta - \nabla\psi \times \nabla\phi$$

In this coordinates a line element

$$d\vec{l} = d\varphi\vec{e}_\phi + d\vartheta\vec{e}_\vartheta + d\phi\vec{e}_\phi$$

that is parallel to $\vec{B}(\vec{r})$ everywhere, satisfies

$$\frac{d\vartheta}{d\phi} = \frac{\partial\psi}{\partial\varphi}, \frac{d\varphi}{d\phi} = -\frac{\partial\psi}{\partial\vartheta}$$

Namely, the field lines are a Hamiltonian system.

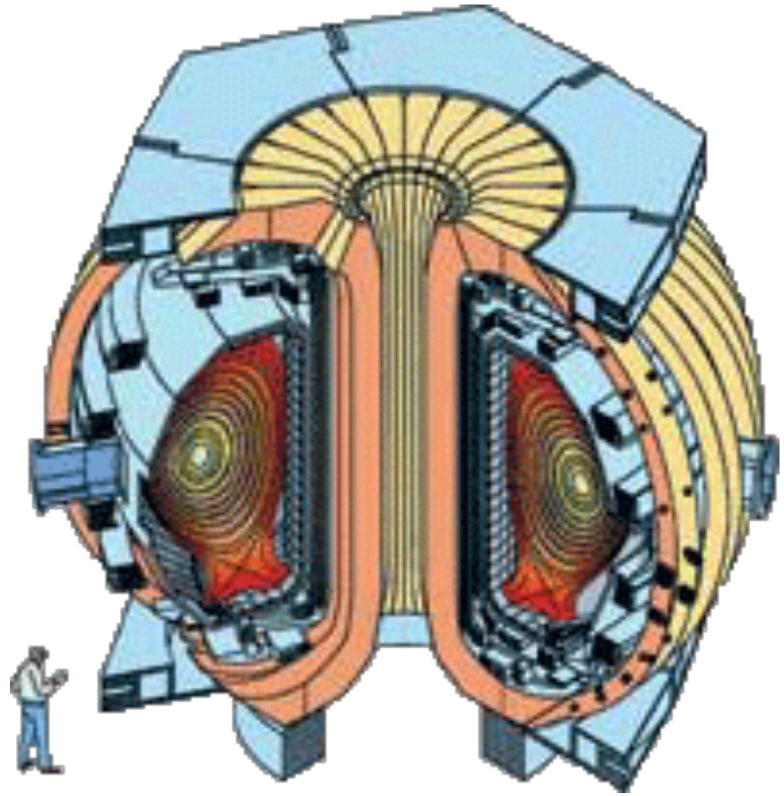
Consequently, any continuous symmetry leads to a conserved quantity and the field lines span continuous surfaces (magnetic surfaces).

Axisymmetric magnetic confinement

The simplest MHD equilibrium consist in balancing magnetic and kinetic forces.

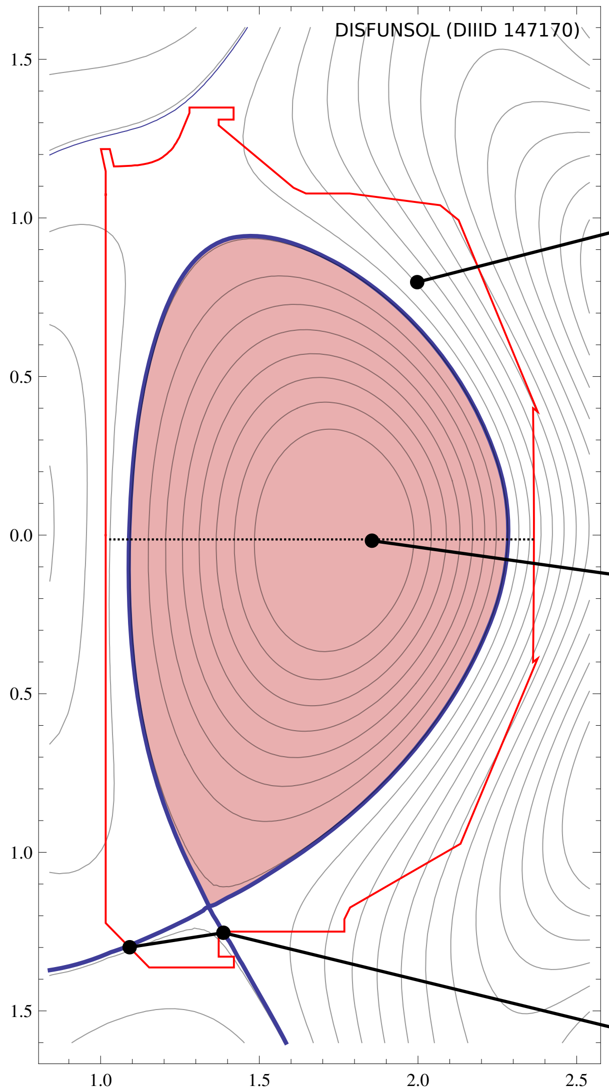
$$\nabla p = \vec{j} \times \vec{B}$$

This requires existence of magnetic surfaces, i.e. the presence of some symmetry.

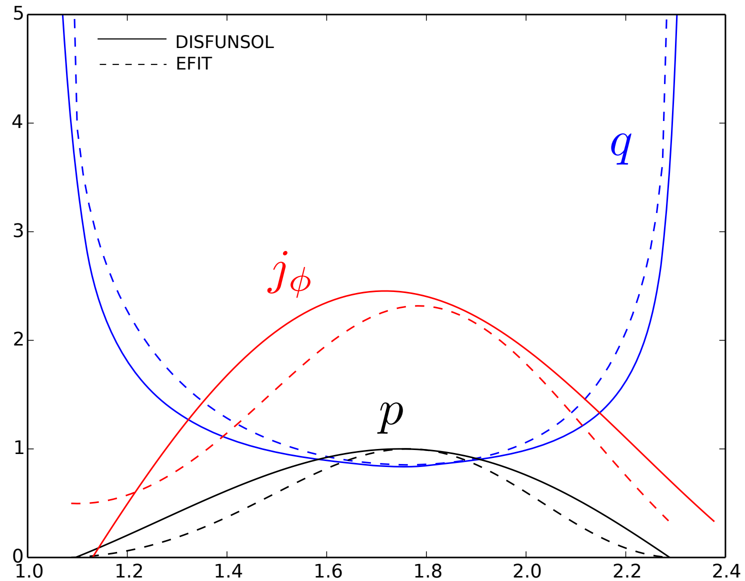


Tokamak devices are designed to create a nearly axisymmetric configuration.

In modern tokamaks the bulk plasma is confined inside a homoclinic magnetic surface.



Open field lines drives the particles to the chamber very quickly.



During the discharge the strike points receive a continuous flux of particles

There is only one problem ... Structural stability.

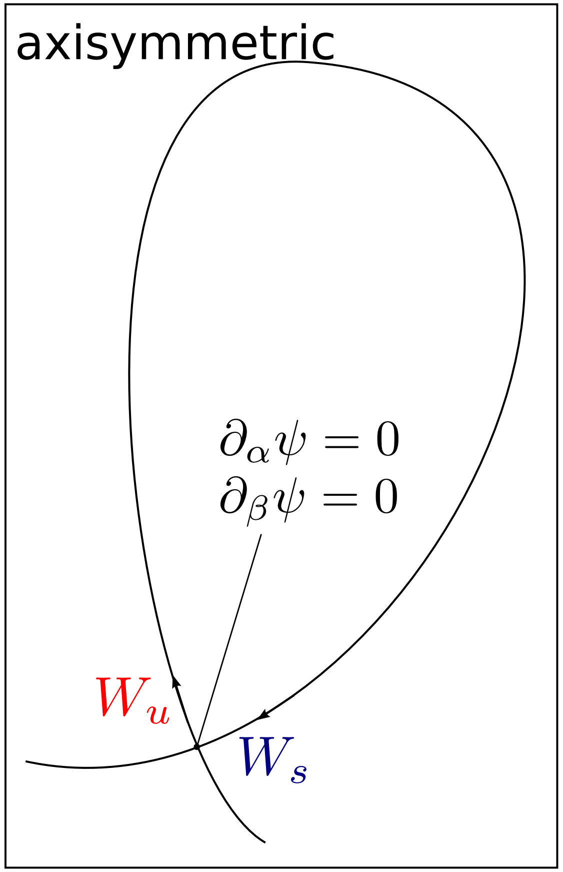
Small asymmetries

There are several sources of asymmetry in a tokamak plasma:

- Error fields (inherit to machine design)
- Resonant Mag. Perturbations (imposed)
- MHD oscillations (inherit to the plasma)

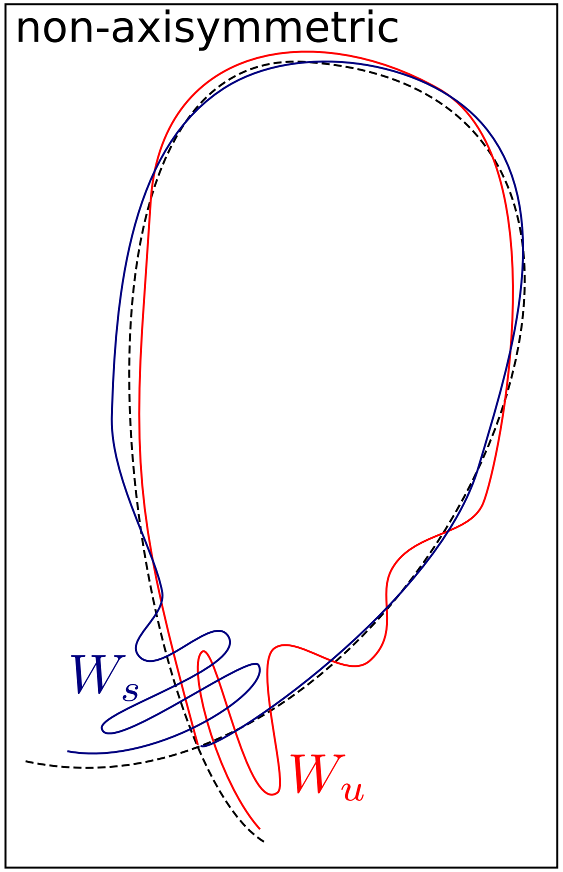
Homoclinic orbits are structurally unstable but the magnetic saddle is stable.

A chaotic region must emerge at the edge



$\psi(\alpha, \beta)$

Stable and Unstable manifolds form a single degenerated structure.



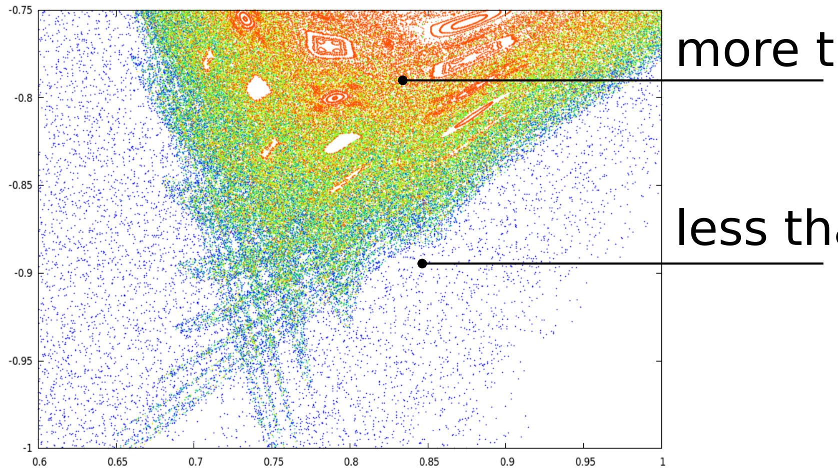
$\psi(\alpha, \beta) = \psi_0(\alpha, \beta) + \psi_1(\alpha, \beta, \gamma)$

Manifolds split and intersect each other infinite times.

The plasma edge now depends on which direction the particle moves.

Experimental signatures

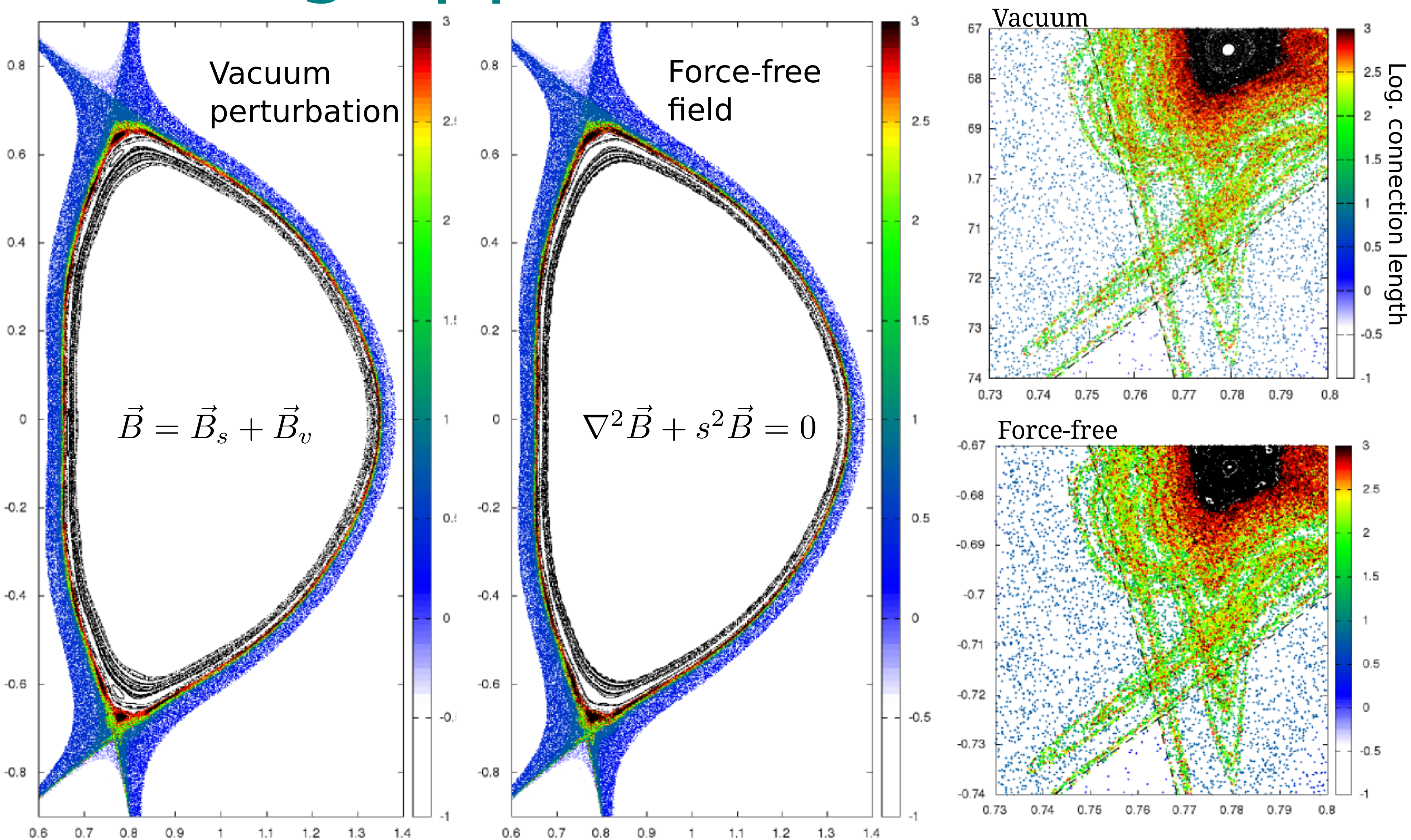
A. Kirk et al, Phys. Rev. Lett. 108, 255003 (2012)



We can observe indirectly the lobes by the connection lengths pattern at the edge region.

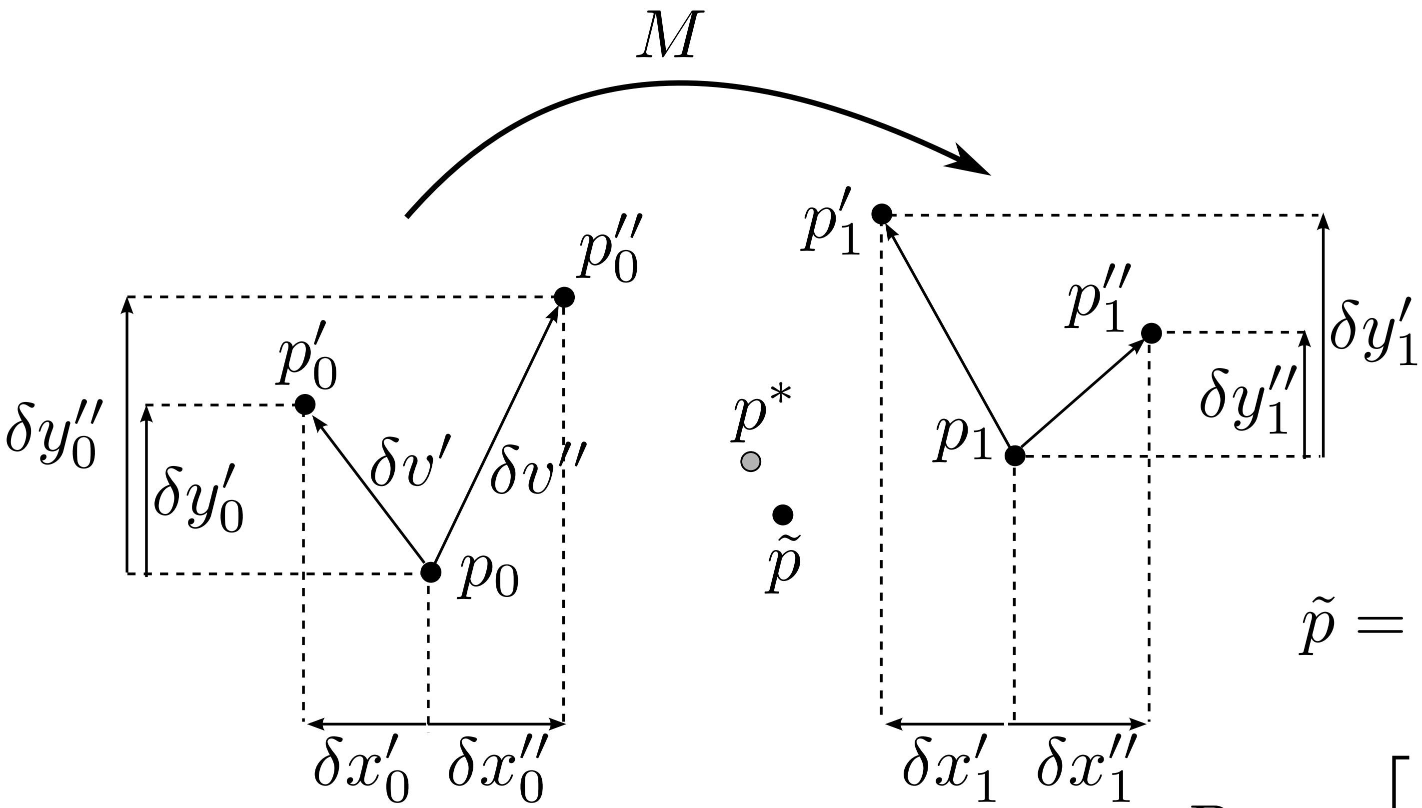
$$\vec{B} = \nabla\psi \times \nabla\phi + F(\psi)\nabla\psi + \vec{B}_v$$

Modeling approaches



Calculating the manifolds

First we need to locate the non-axisymmetric saddle

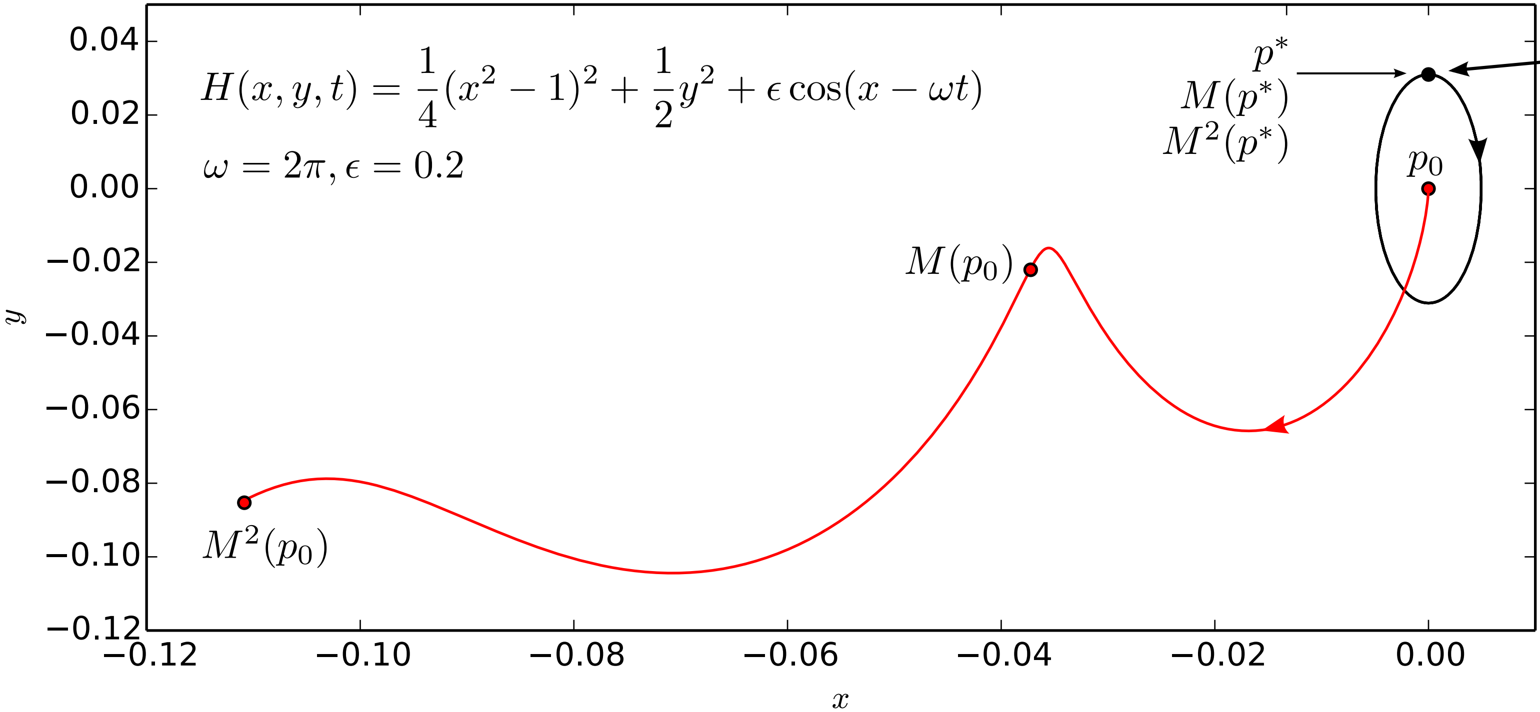


$$\tilde{p} = (I - D_M)^{-1}(p_1 - D_M p_0)$$

$$D_M = \begin{bmatrix} \delta x_1' & \delta x_1'' \\ \delta y_1' & \delta y_1'' \end{bmatrix} \begin{bmatrix} \delta x_0' & \delta x_0'' \\ \delta y_0' & \delta y_0'' \end{bmatrix}$$

For this we introduce the "three-mapping method"

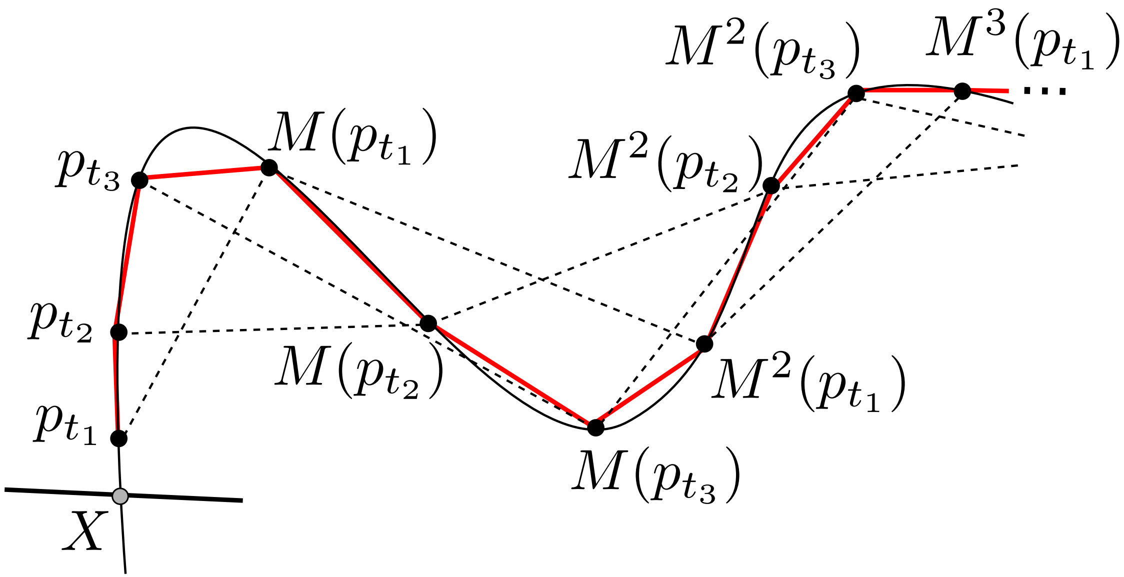
The saddle orbit differs from the curve where the flow vanishes.



Found after five iterations of the three-mapping method.

It is an unstable periodic orbit.

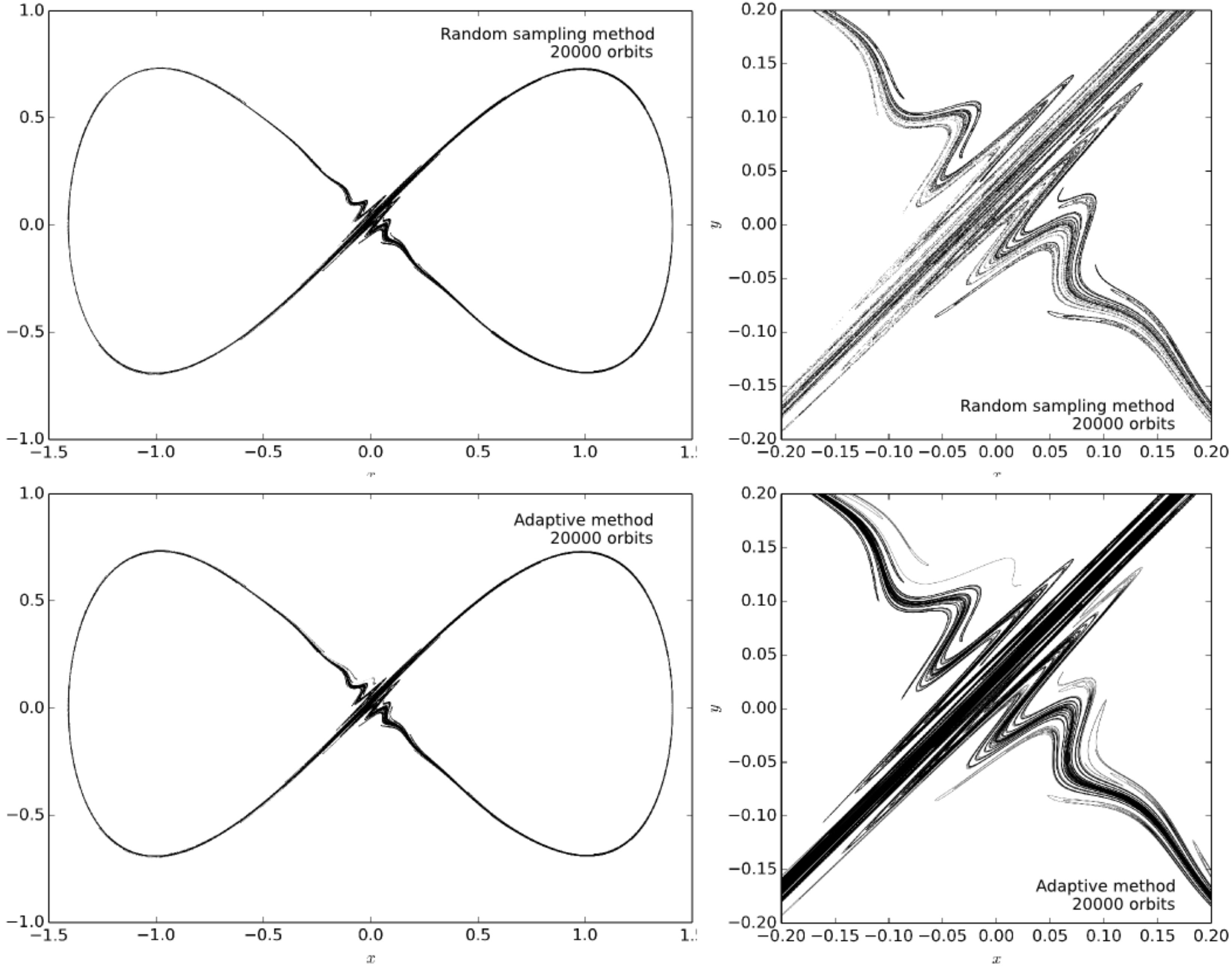
Now we introduce an adaptive calculation of the manifold leading to an ordered high resolution representation



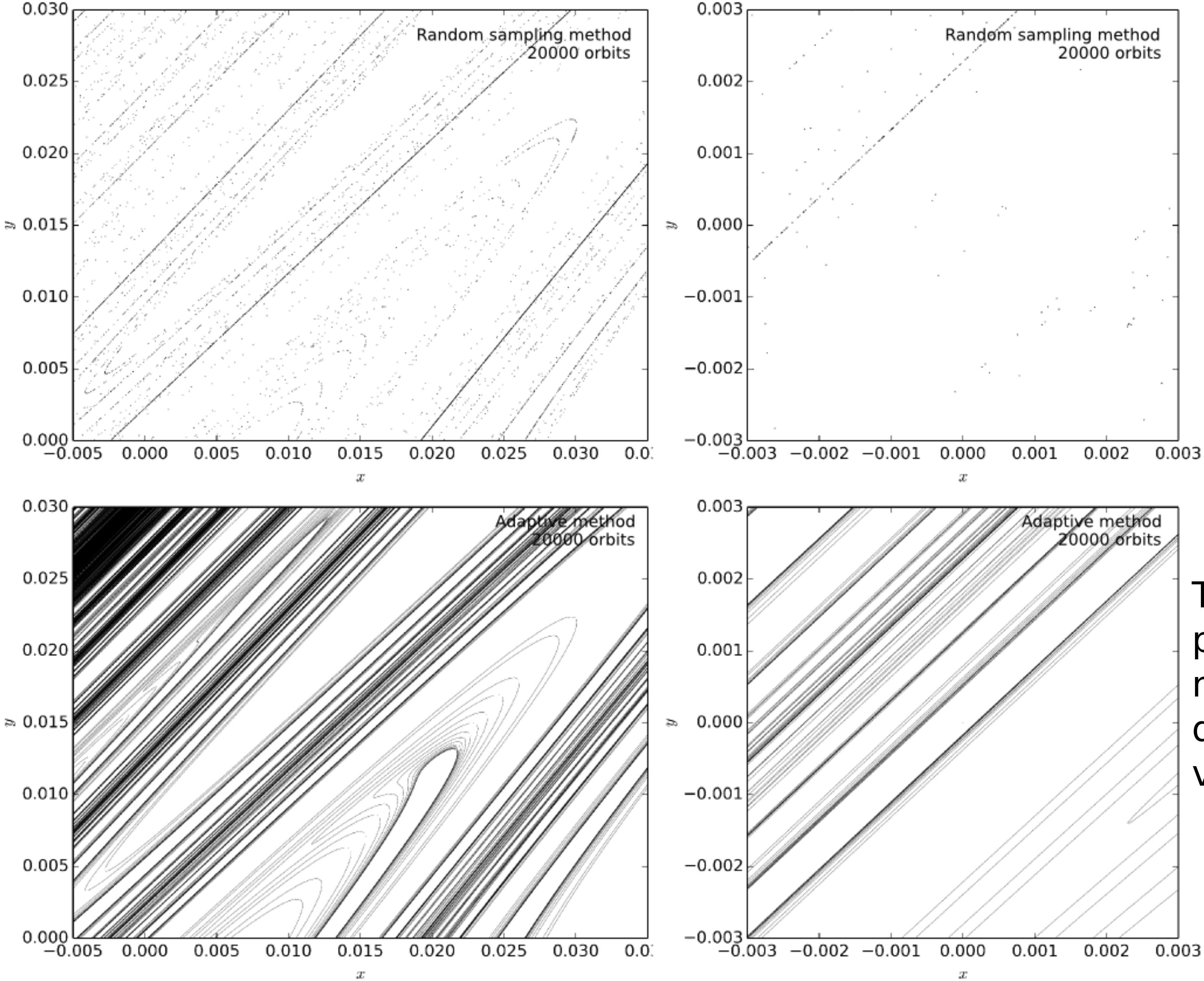
The method locates sparse regions in the manifold and introduces new initial conditions in appropriate locations.

The resulting points are ordered and can be joined smoothly with a continuous line instead of presenting them scattered

Consider a perturbed particle in a quartic potential

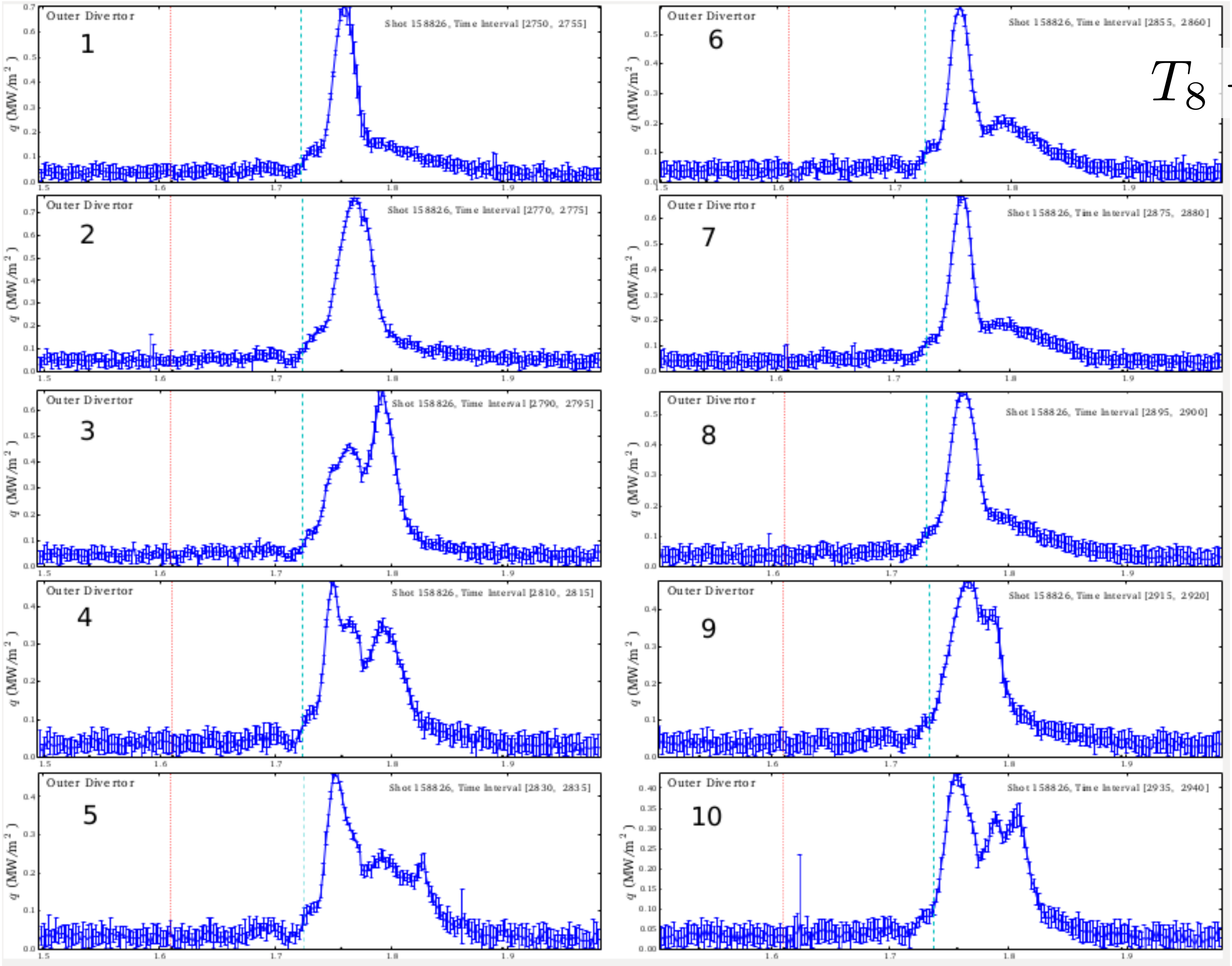


This is the unstable manifold linked to the saddle orbit.

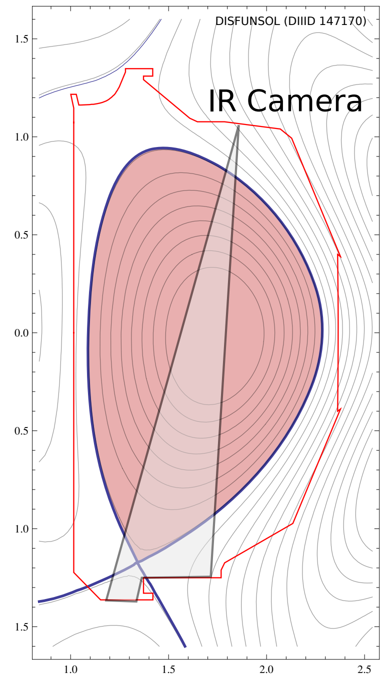


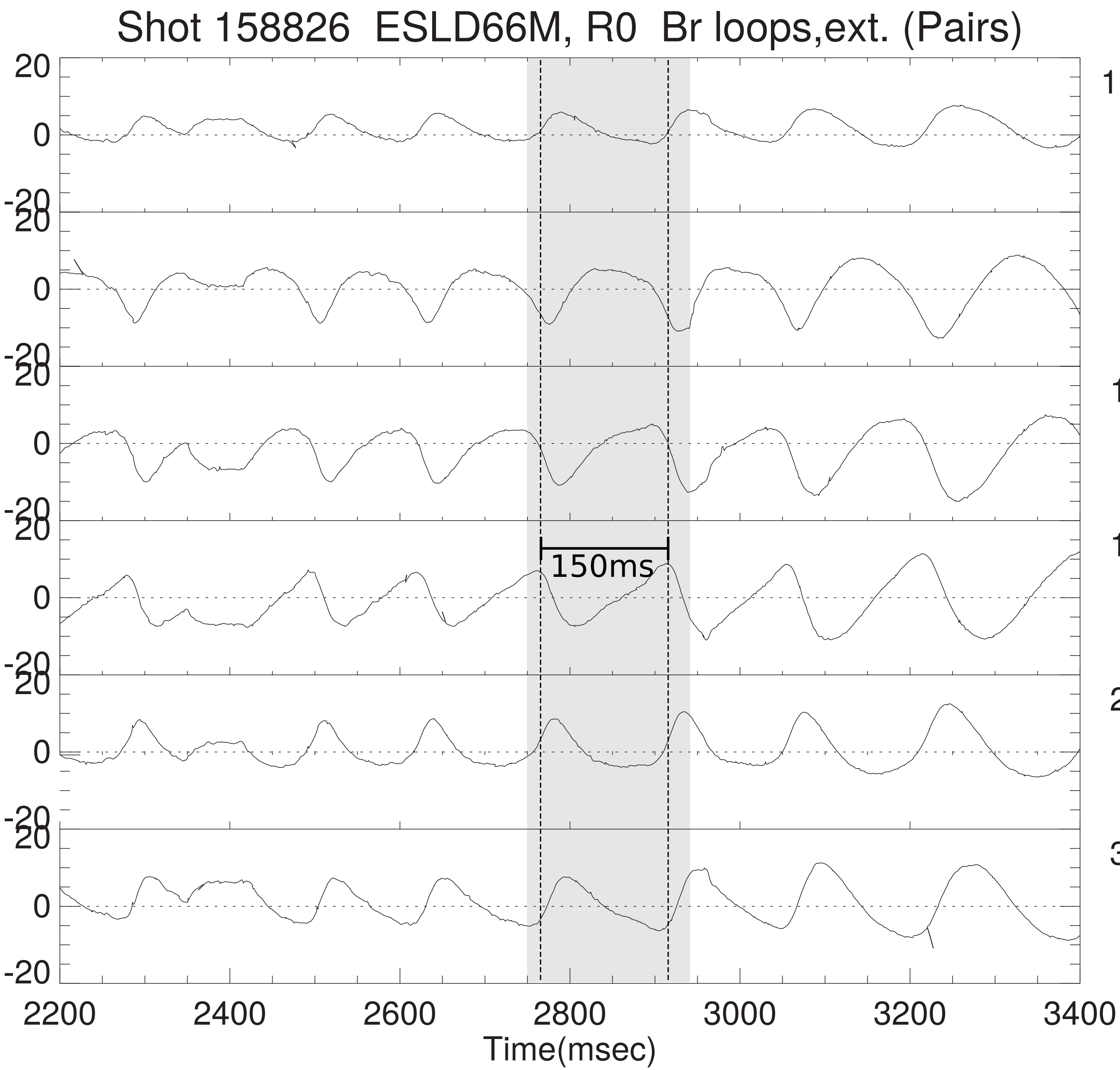
The random sampling technique misses the fine details of the invariant manifold.

Modeling non-stationary heat patterns

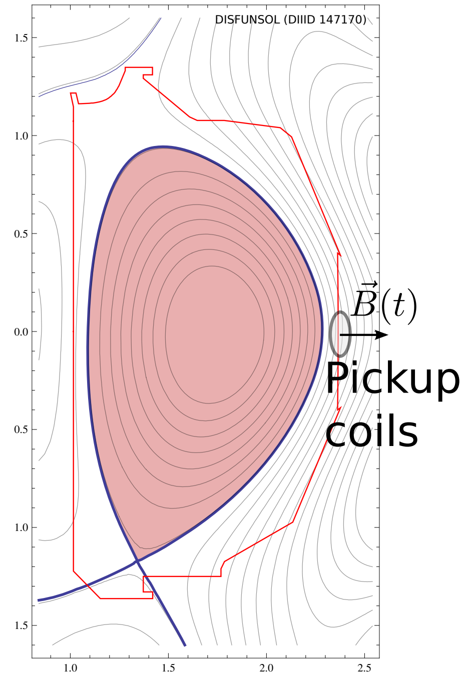


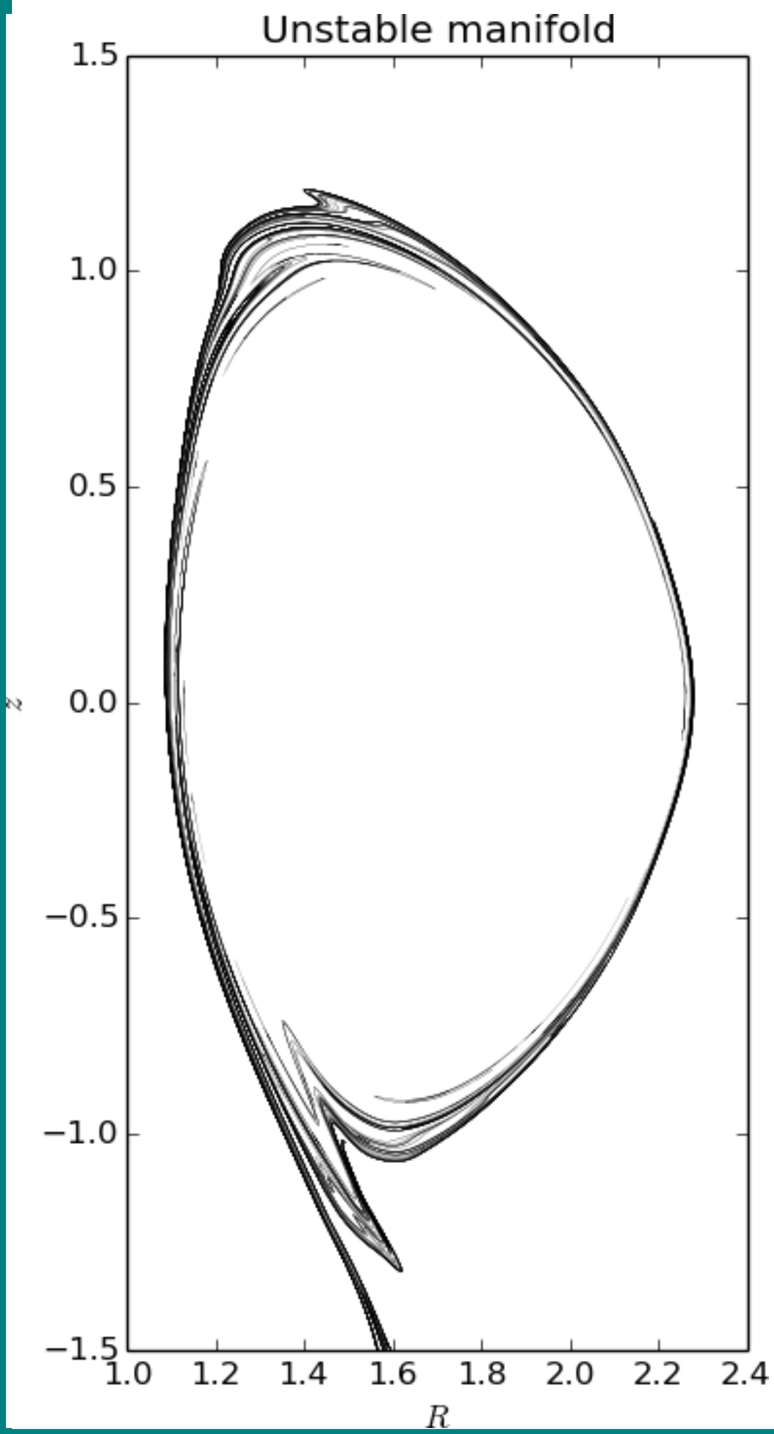
$$T_8 - T_1 \approx 150ms$$

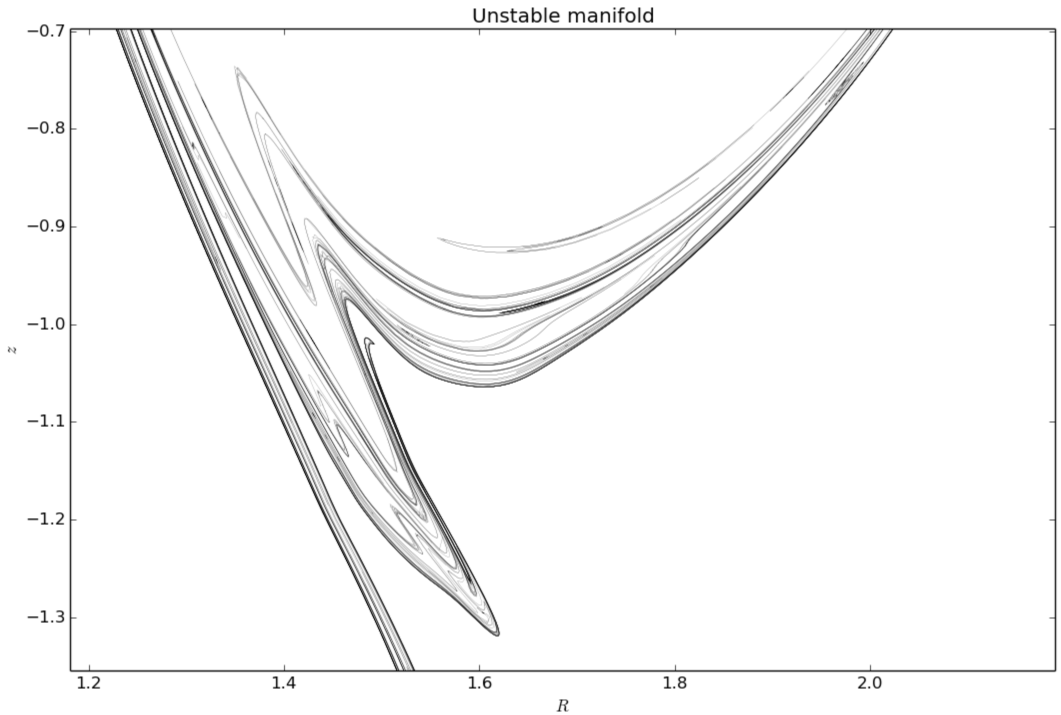




The magnetic signals and heat profile evolution have the same period.



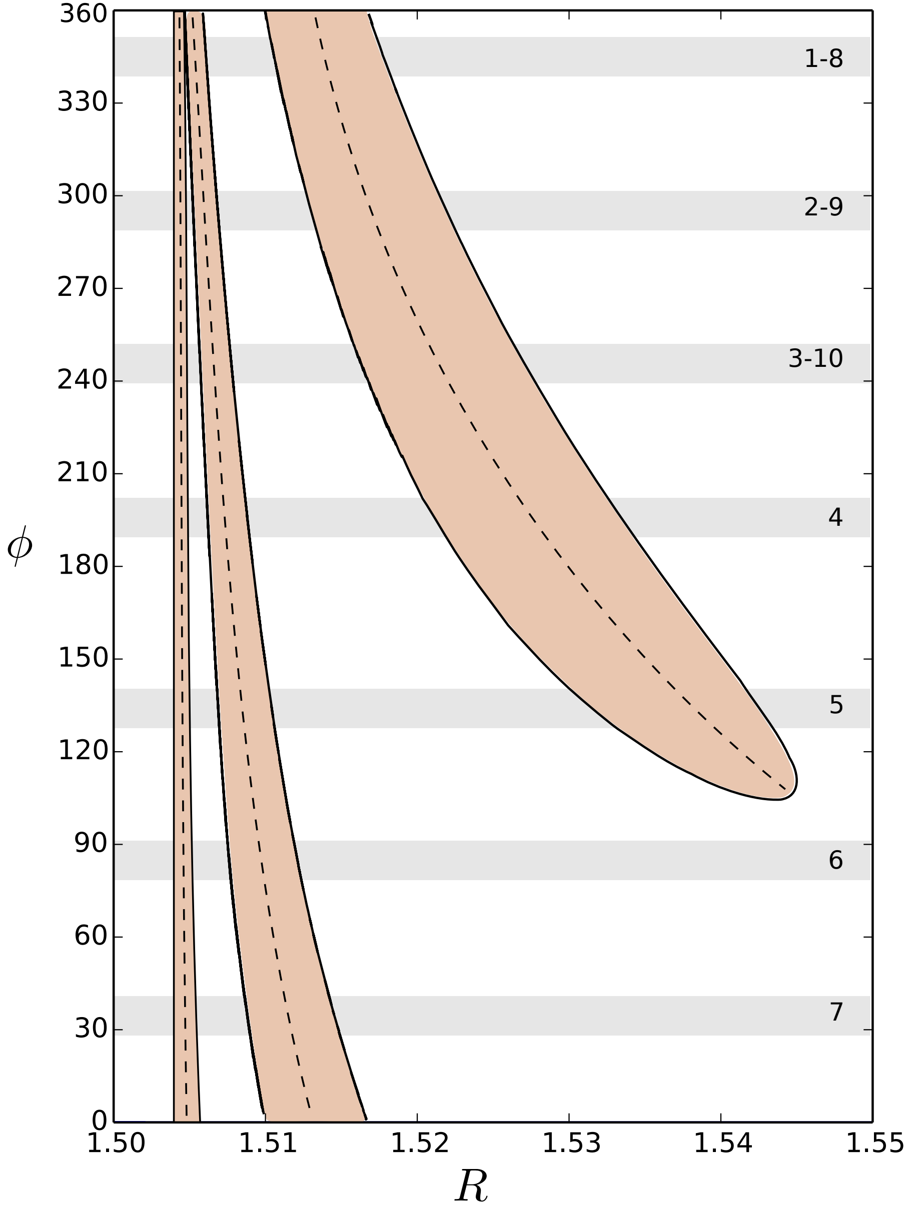


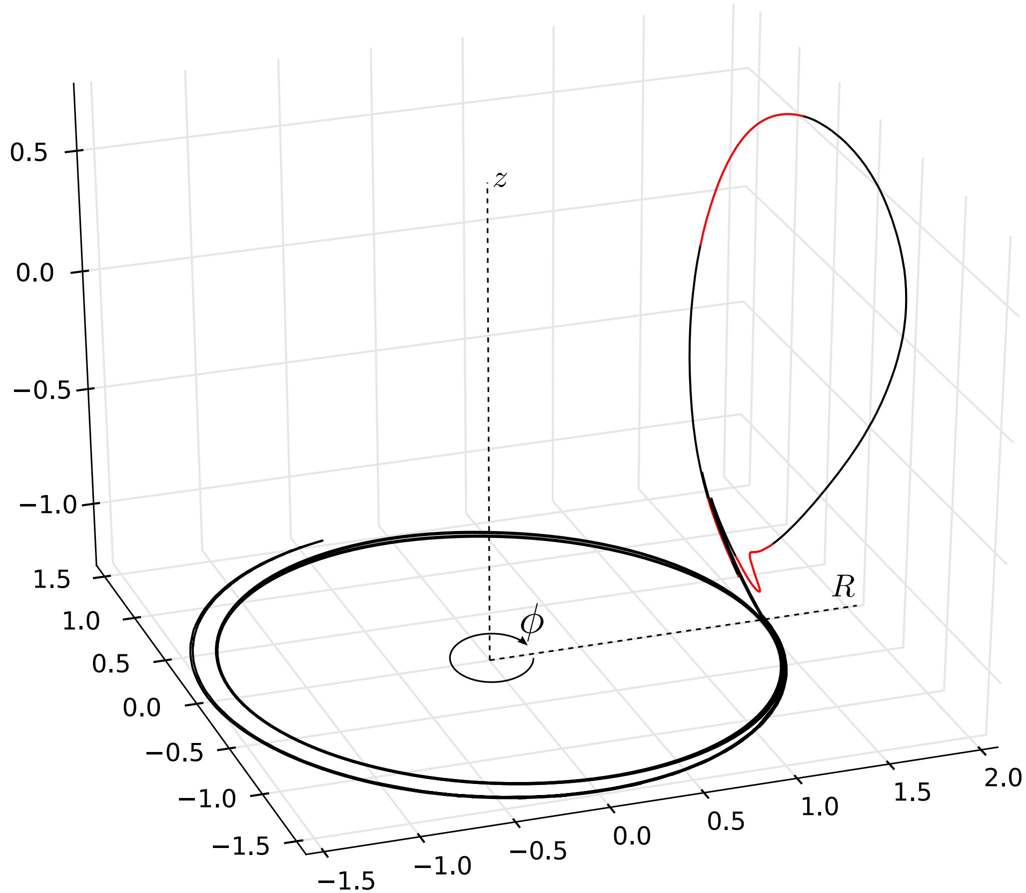


An internal helical current in a rational surface can create a stationary helical lobe.

If the helical current rotates toroidally the unstable manifold will rotate toroidally showing a different cut to the camera every time.

Ongoing work...





The gray regions correspond to the time intervals of the heat measurements and the pink region is the interior of the unstable manifold.

The result matches well with the measurements...

THANKS!

OBRIGADO!