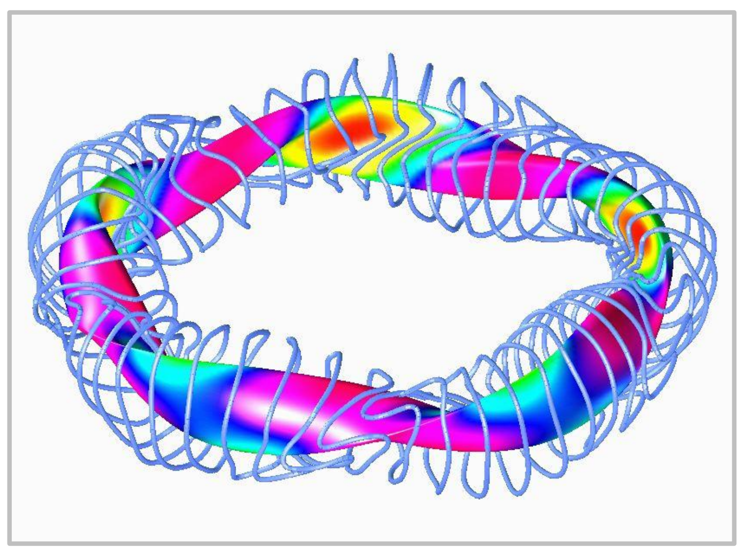
Critical behaviour in toroidal plasma confinement

Mathew McGann[1], Robert Dewar[1], Stuart Hudson[2]
[1]Theoretical Physics / Plasma Research Laboratory (PRL), RSPE, ANU
[2]Theoretical Physics, Princeton Plasma Physics Laboratory (PPPL), NJ

Fusion



Confine a plasma of temperature 10^8 C by making magnetic field lines wrap around a toroid, the charged particles in the plasma follow the field lines and are confined.

Scale Free interaction

The plasma gyrates around the field lines (scale: 10^{-9} - 10^{-10}m, 10^{-10} s).

Field lines get tangled (fractal, all scales)

Zonal flows are also observed.(scale: 10^{-6} - 10^{-1} m, 10^{-7} - 10^{-1} s) .

The field lines rotate around the plasma. (scale: 10^{-3} - 10^{1}m, 10^{-4} - 10^{-1} s) .

Magnetic field affects the plasma on a great range of time and length scales. Devices have interacting scales of a factor of anywhere between 10^4 to 10^{10}!

Sandpile behaviour of ELMs

Edge Localised Modes (ELMs) can violently throw plasma out the sides of the device.

Major cause of loss of confinement.

They have been showed to follow the sand pile distribution often found in complex systems. [1]

Current experimental goal: excite chaotic behaviour at the edge of the plasma to leak plasma slowly so it does not disrupt violently.

Magnetic field line Hamiltonian

Theory

$\theta =$ angle short way round torus.

$\zeta =$ angle long way round torus.

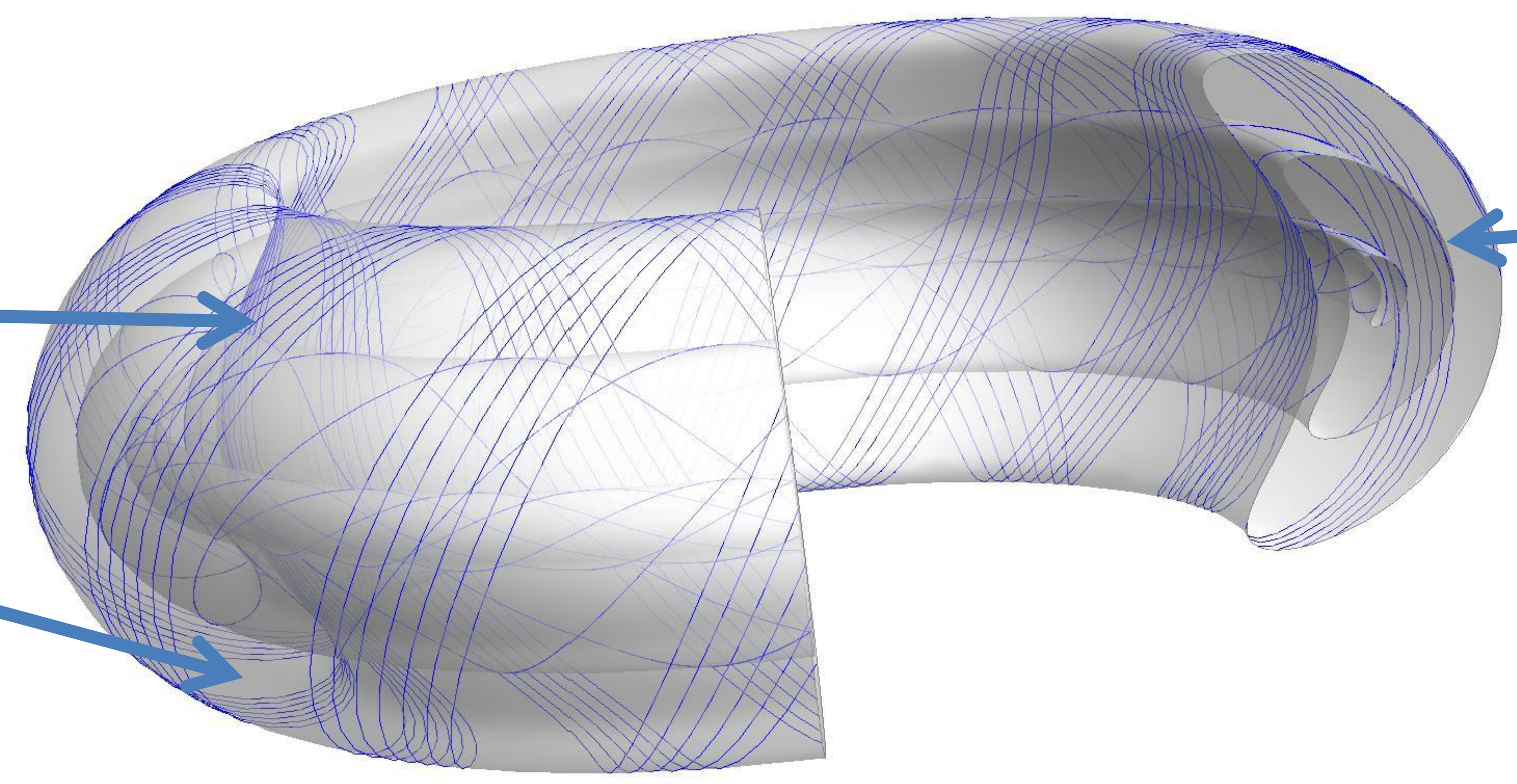
The magnetic field within a plasma volume can be written as
$\mathbf{B} = \nabla\psi_t \times \nabla\theta + \nabla\zeta \times \nabla\psi_p$

using $\frac{d\mathbf{r}}{d\zeta} = \mathbf{B}$ gives [2] $\frac{d\theta}{d\zeta} = \frac{\partial\psi_p}{\partial\psi_t}$, $\frac{d\psi_t}{d\zeta} = \frac{\partial\psi_p}{\partial\theta}$ which are of Hamiltonian form.

Use

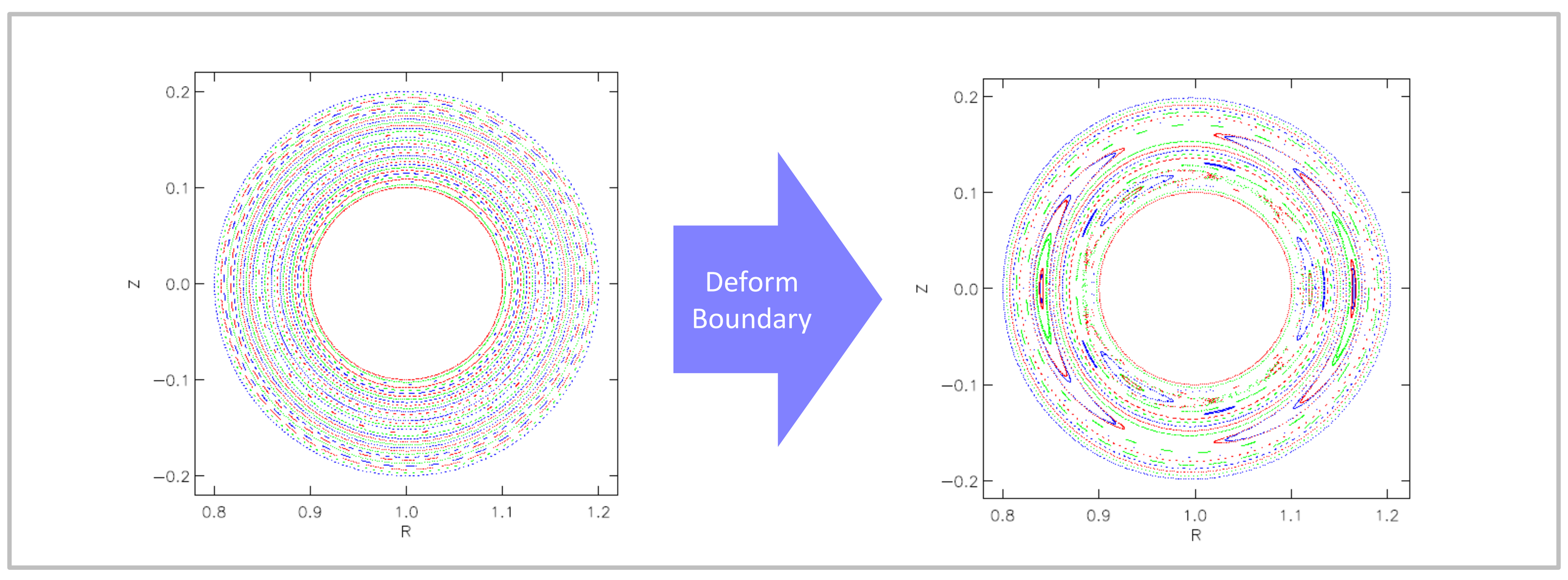
Trajectories of the field line Hamiltonian are the field lines that permeate the plasma.

If the field lines lie on a torus, they draw out a flux surface, which can act as a barrier to transport.



Existence

Increasing deformation tends to destroy flux surfaces.



Pressure jump Hamiltonian

Theory

Consider flux surface has finitely different pressure either side.

The condition of force balance due to pressure discontinuity is [3]

$$\left[\!\left[p + \frac{B^2}{2} \right]\!\right] = 0$$

Which can be shown to be a Hamiltonian Jacobi Equation with Hamiltonian

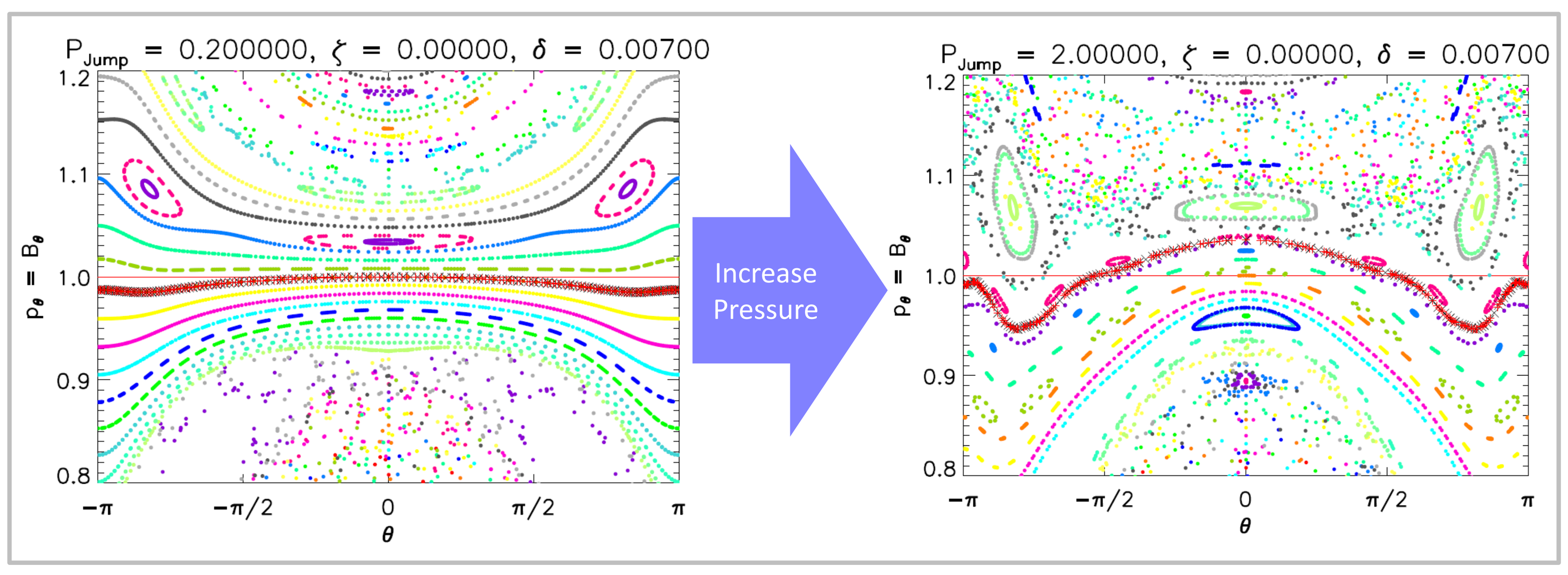
$$H = \sum_{i,j\in[\theta,\zeta]} \frac{1}{2} g^{ij} p_i p_j + V(\theta,\zeta)$$

Use

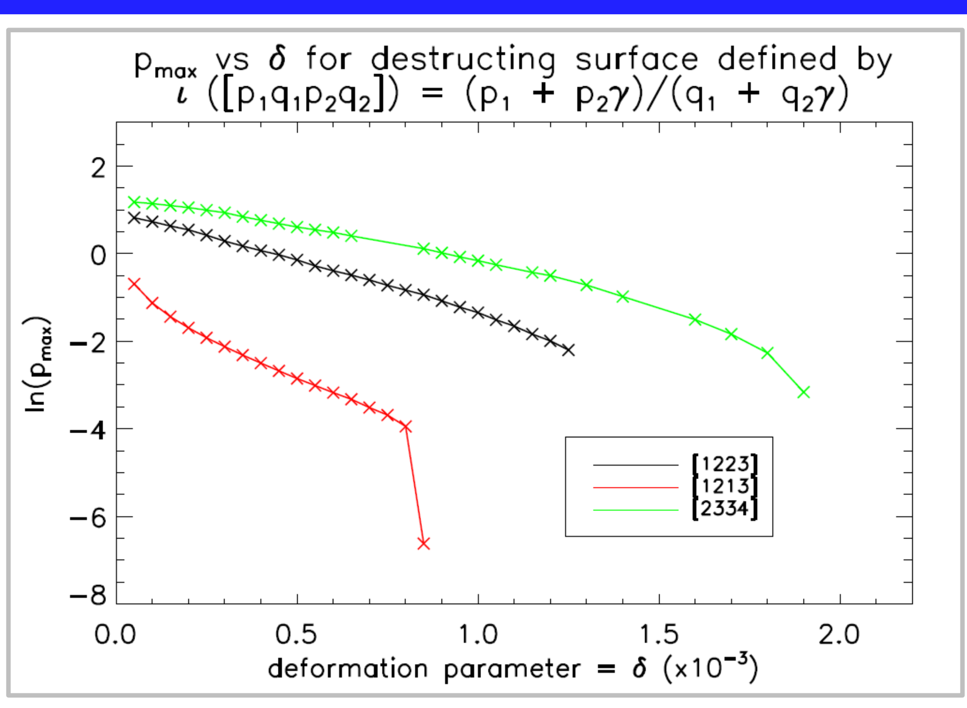
Trajectories of the pressure jump Hamiltonian correspond to the field lines on a given surface that survive a given pressure discontinuity.

Existence

Increasing pressure tends to destroy flux surfaces.



Combine



While MFLH destroys surface, PJH tests it for the maximum pressure discontinuity it can withstand.

Highly dependent on form of deformation and twist of field line.

Different flux surfaces support different pressure for different deformations.

Future Work

Is resilience to pressure shared between classes of surfaces?

Find more natural deformation parameter.

References

[1] Greenhough J, *et al.* *Plasma Phys. Control. Fusion* 45 2003 747

[2] S. Hudson. *Phys Plasmas* 11 2004 p.667

[3] S. Hudson, M. Hole, R. Dewar. *Phys Plasmas* 14 2007 052505