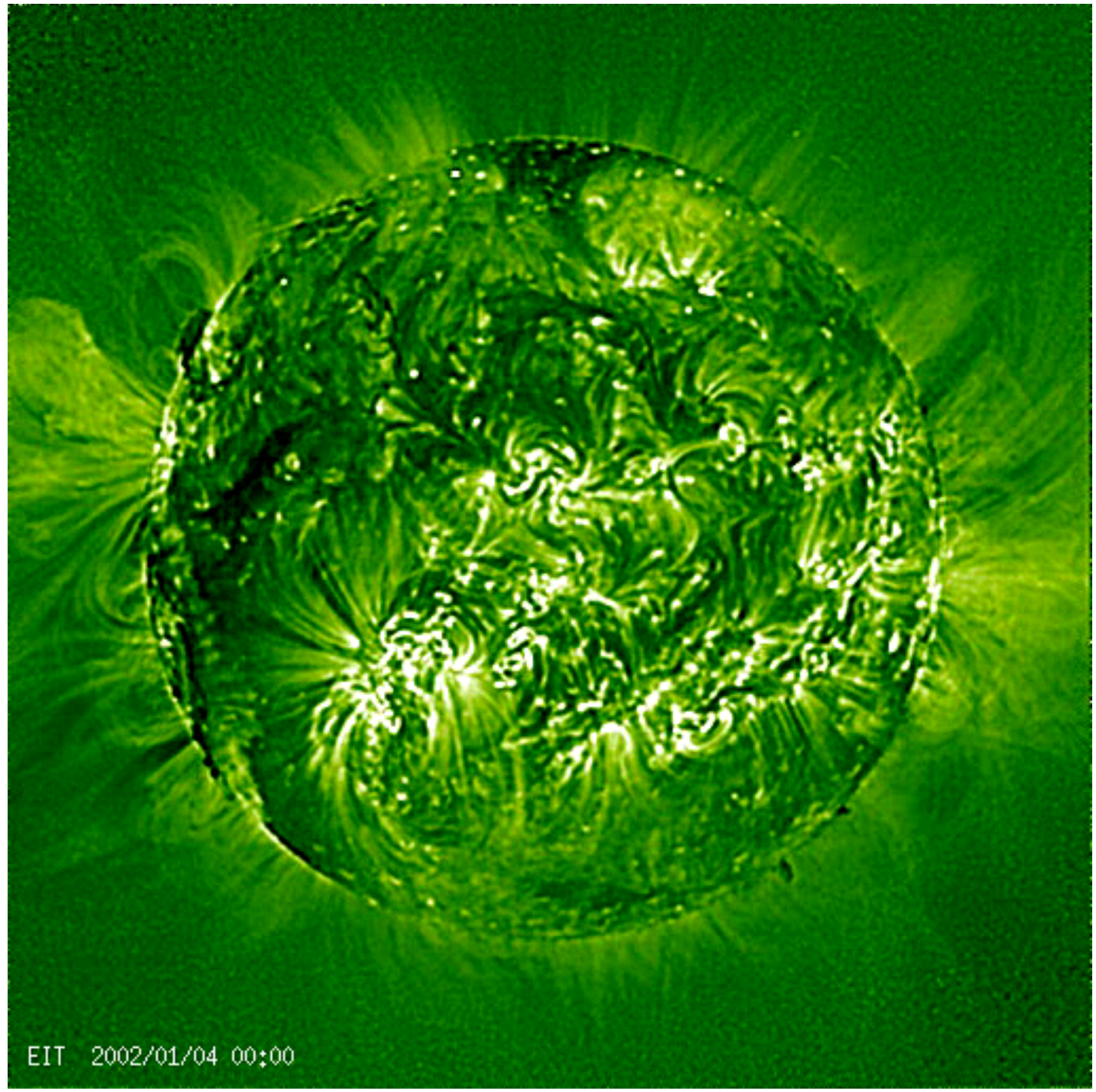
The Onset of Magnetic Reconnection

- Magnetic reconnection often occurs in explosive events.
- Examples includes the Corona at all scales

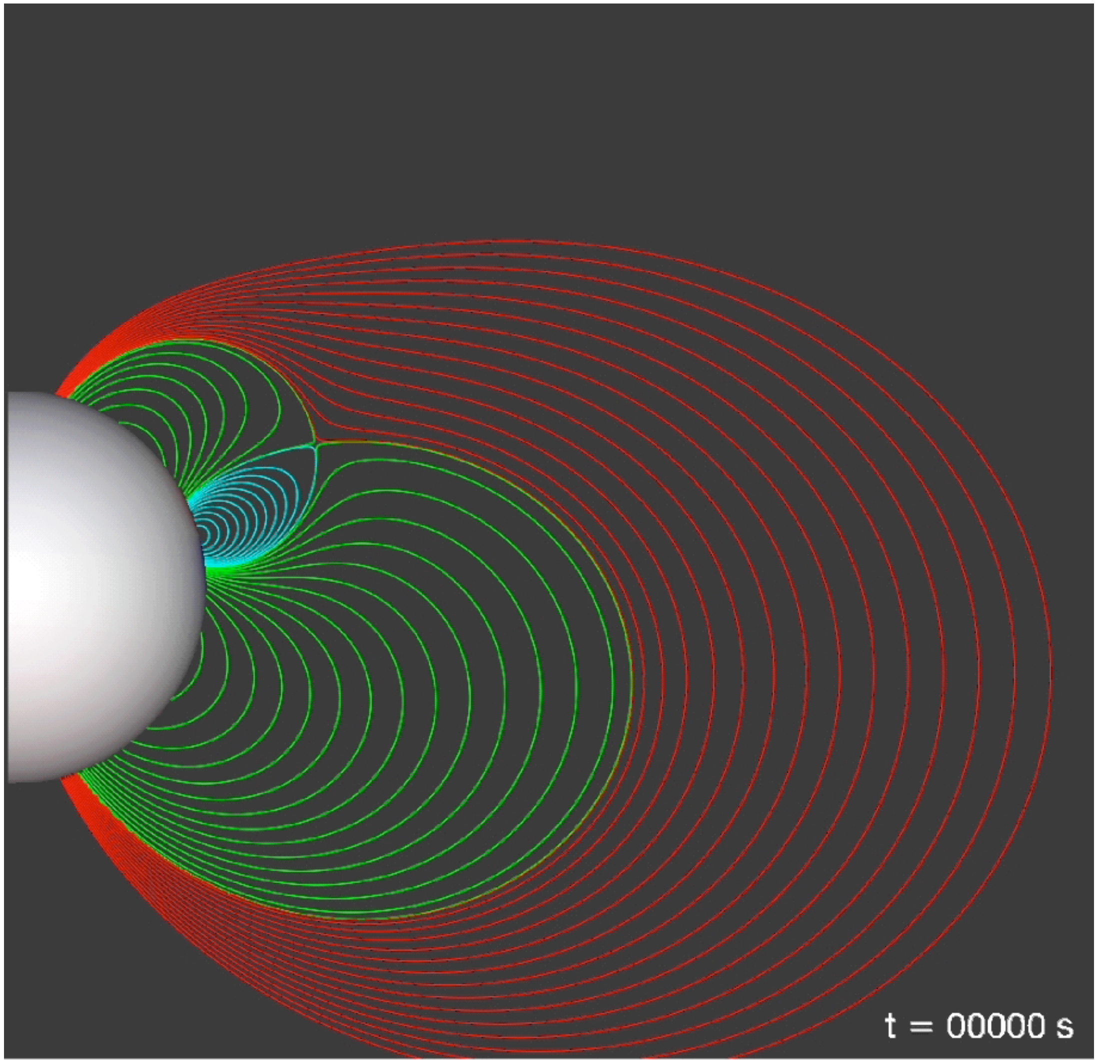


Reconnection Driven Solar Activity

- Coronal energy injected quasi-statically due to slow photospheric stressing
- Reconnection initially suppressed (or slow) until free energy builds up to large levels, $E \sim 10^{28} - 10^{33}$ ergs
- Reconnection switches on and stays on enabling large energy decrease
- Explosive energy release depends critically on rapid onset

Example: 3D Breakout CME Model

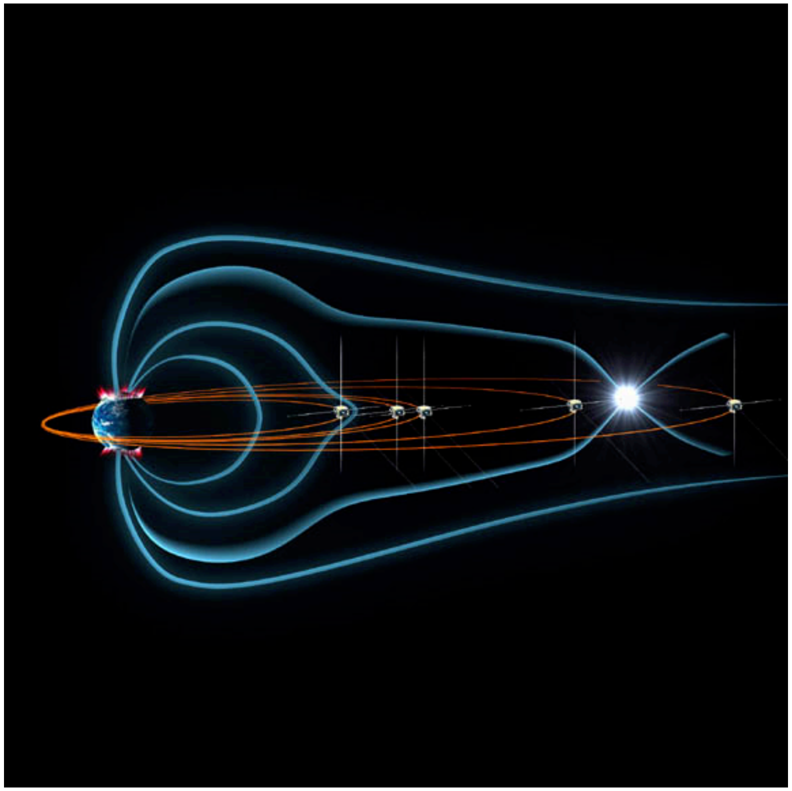
- Initial potential field with multipolar topology and coronal null
- Drive system by slow photospheric shear
- Reconnection onset above at deformed null initiates eruption
- Reconnection onset below at flare current sheet produces fast acceleration



From Lynch et al. 2009, ApJ, 697, 1918

THEMIS: Substorms in the Earth's Magnetotail Triggered by Reconnection

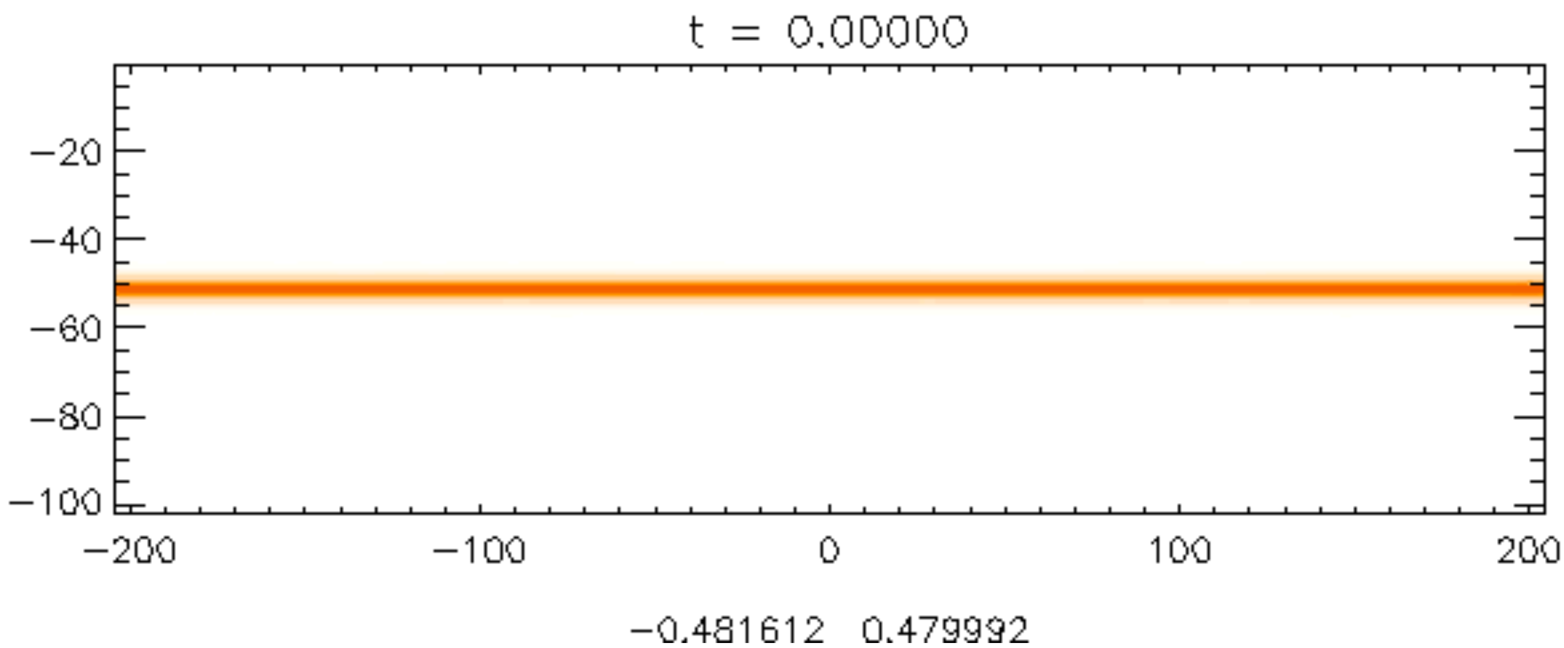
- Observations by THEMIS show that magnetic substorms can be triggered by reconnection in the midtail.
- Meanwhile, reconnection at the magnetopause and in the solar wind is often quasi-steady.



V. Angelopoulos, et. al, Science **321**, 931 (2008)

2D Simulations Address the Onset Problem

P Cassak et. al. (2005), Transition from slow to fast



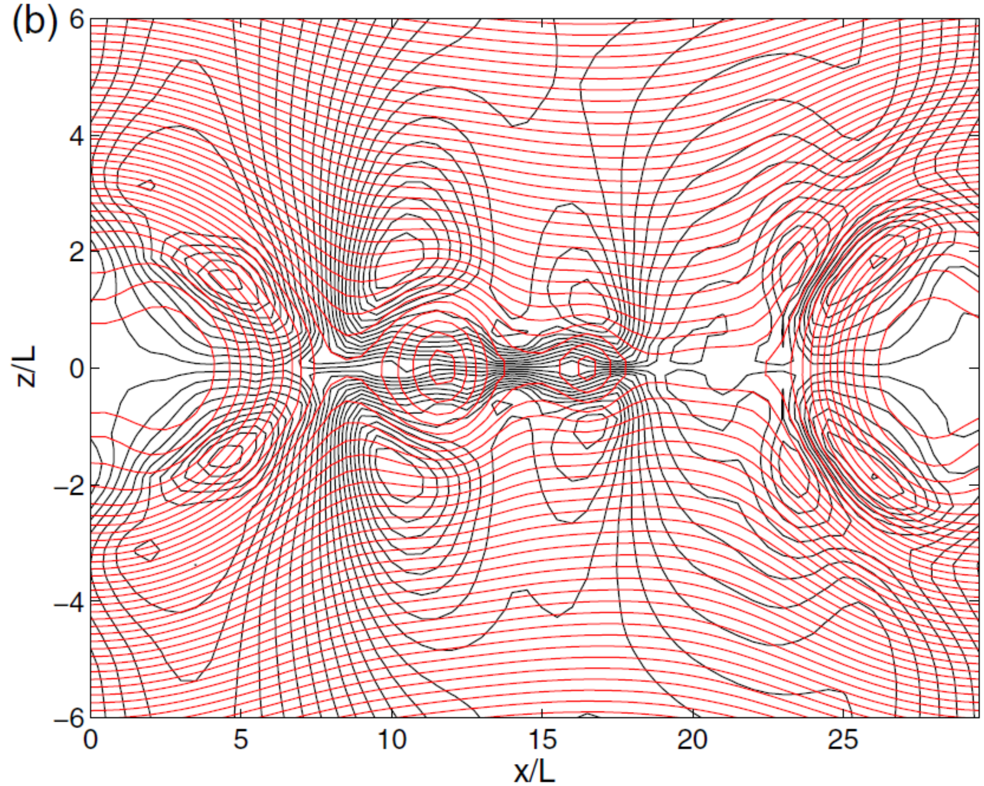
The transition from resistive to fast Hall reconnection occurs when the width of the current sheet approaches ρ_s or d_i.

Resistive Reconnection Fast at Large Lundquist Numbers (Island formation)

- At large Lundquist numbers the Sweet-Parker layer can break up and multiple islands are formed.

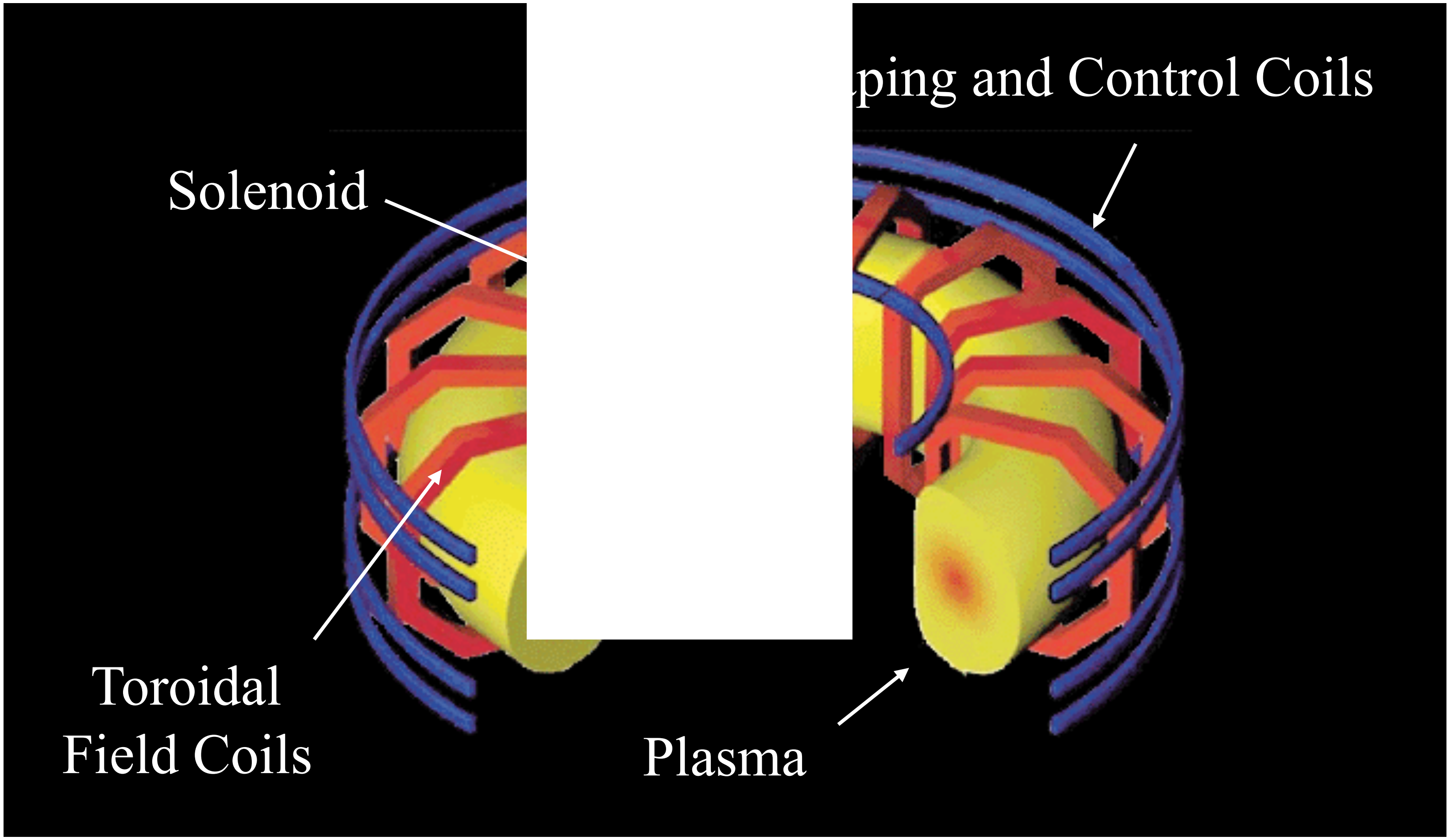
- A number resent studies show that this yields fast reconnection in purely resistive systems (no Hall Term required)

From G. Lapenta, PRL 100, 235001 (2008)

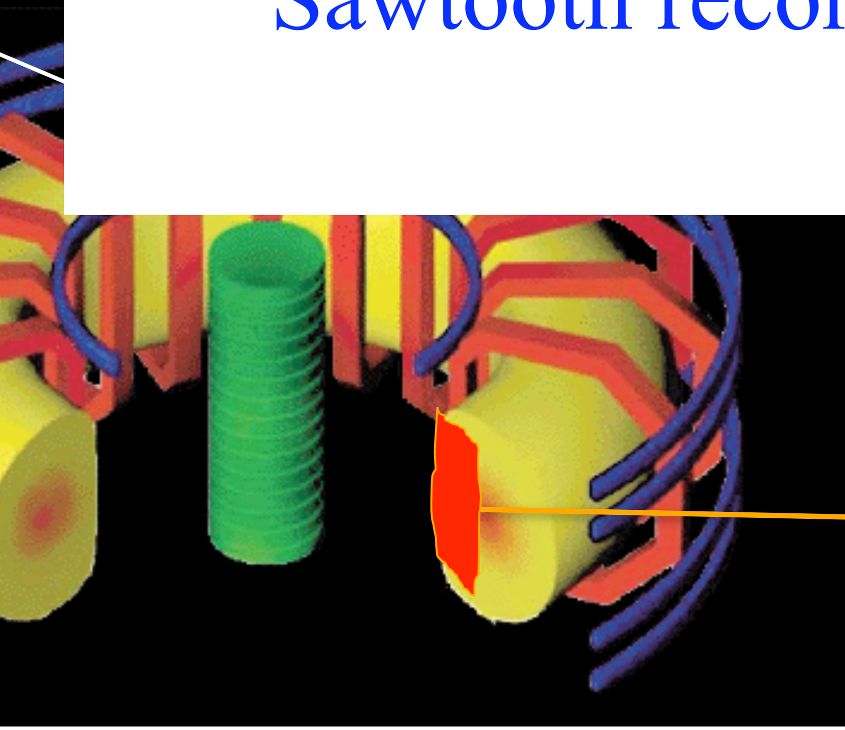


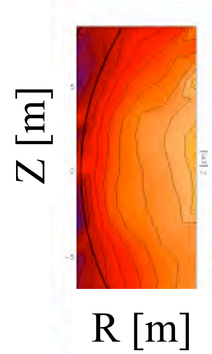
Red lines: Magnetic flux contours
Black lines: Plasma stream function

Sawtooth reconnection in Tokamaks: 3D

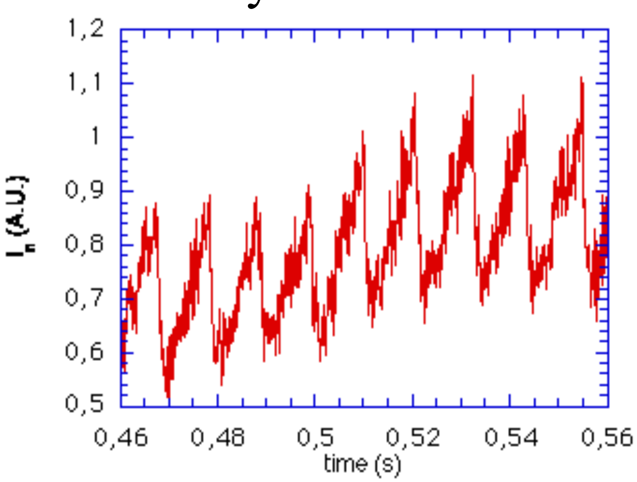


Sawtooth reconnection in Tokamaks: 3D

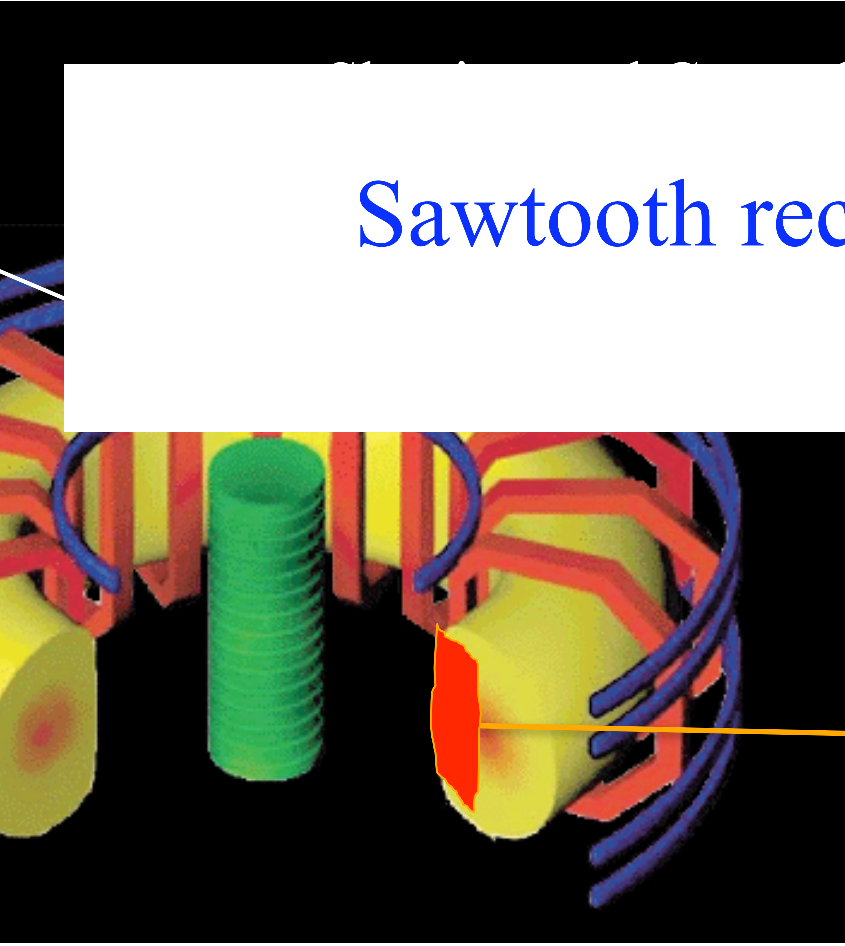


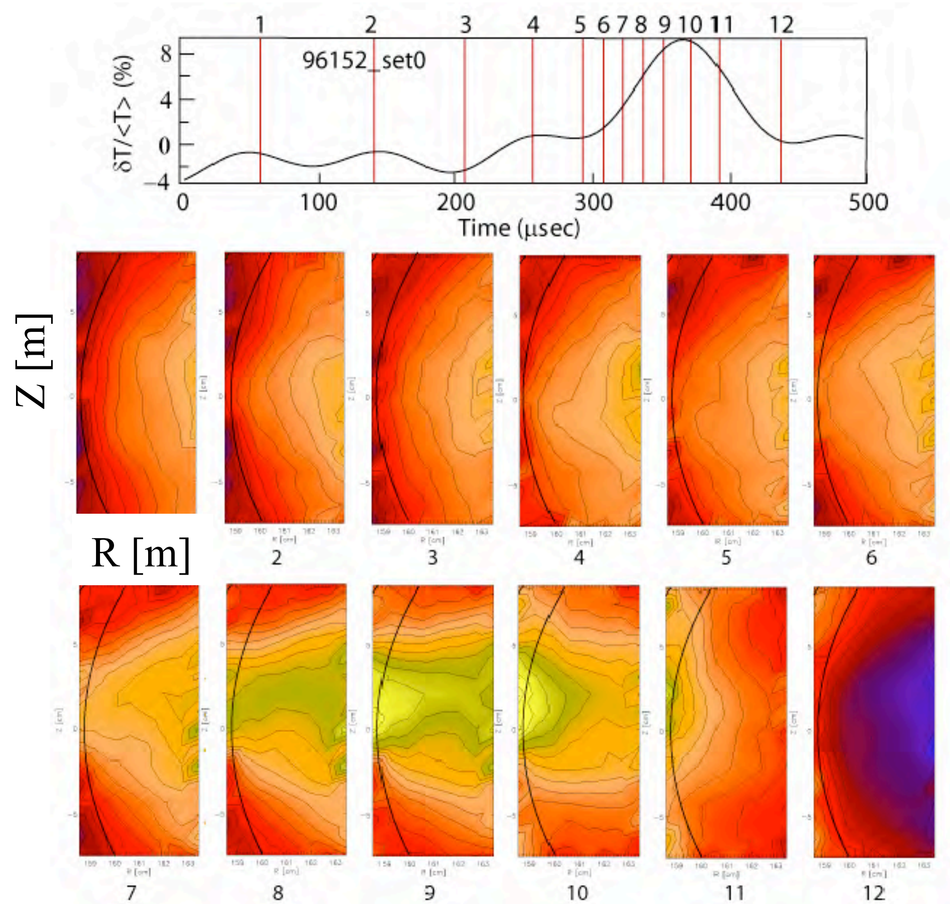


Neutron yield in a tokamak



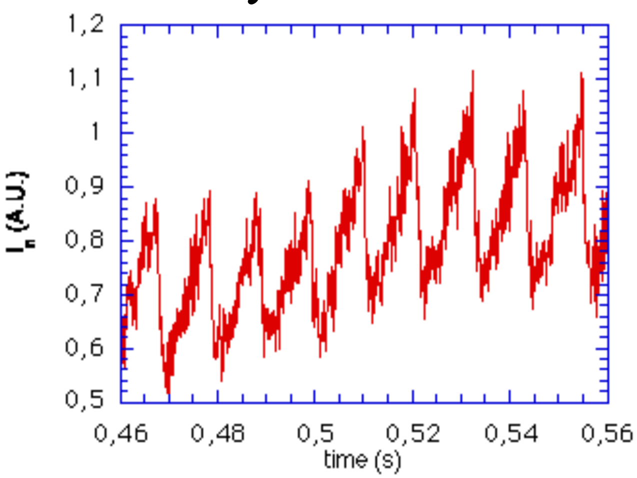
Sawtooth reconnection in Tokamaks





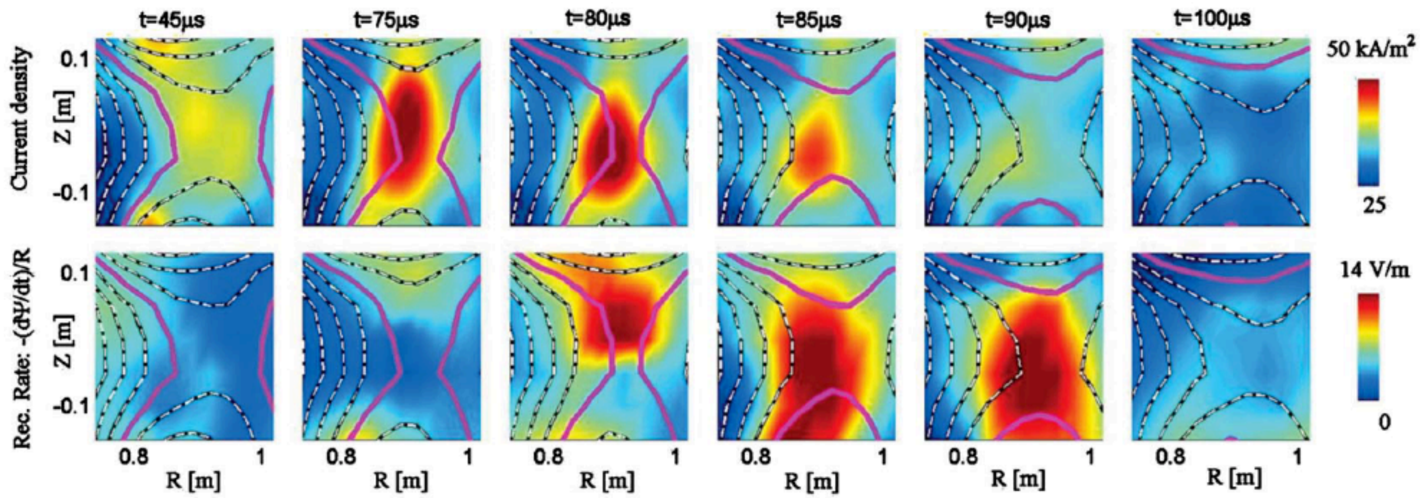
H Park, PRL 2005: localized reconnection

Neutron yield in a tokamak

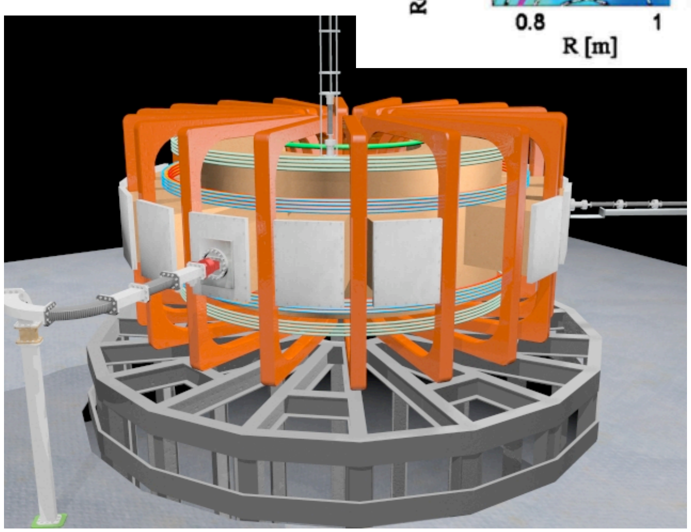


3D Onset Observed in the Laboratory

Spontaneous onset of reconnection occurs when current sheet width approach ρ_s



VTF at MIT



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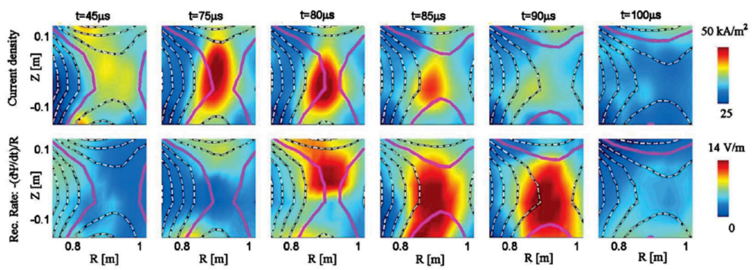

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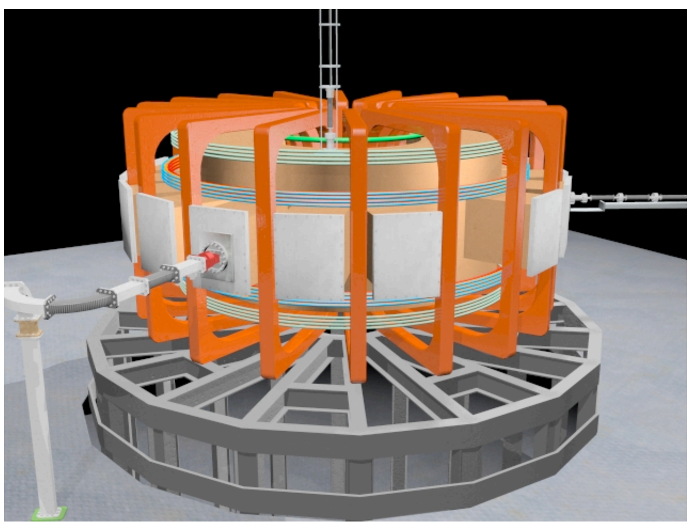

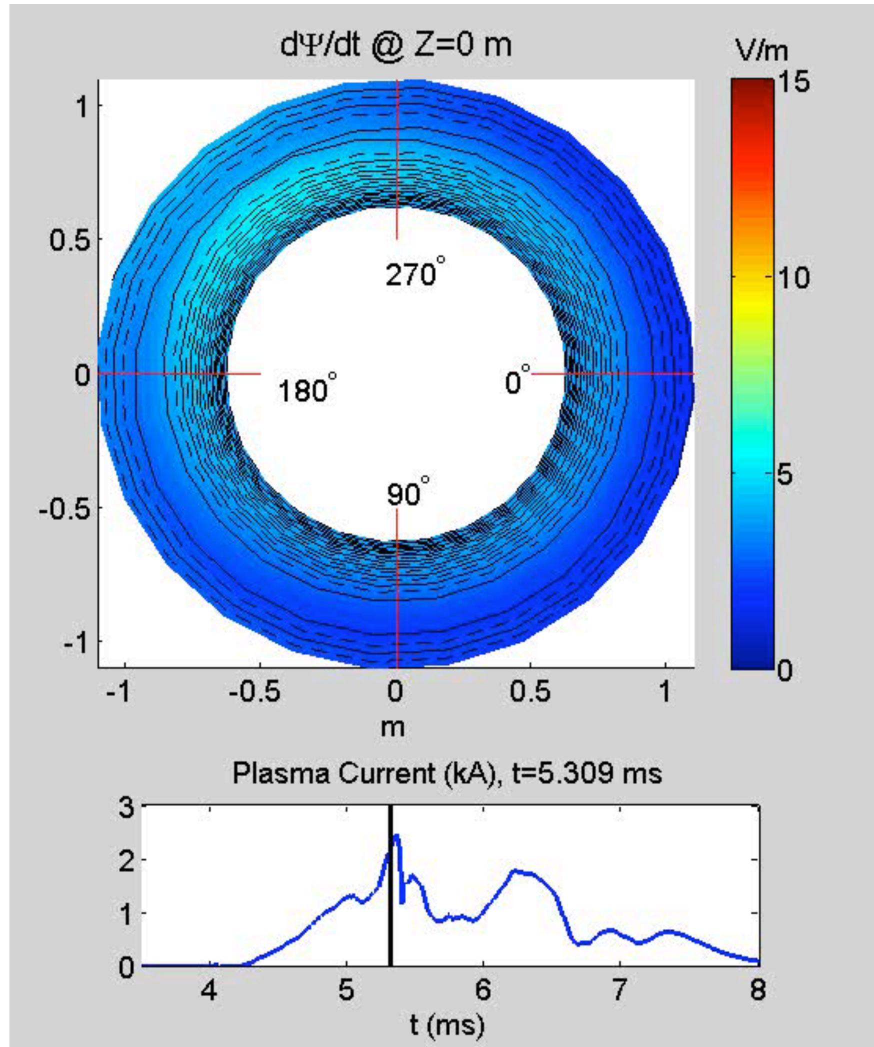

Questions that need to be addressed

1) Why does reconnection often occur as an explosion (flares, substorms, sawteeth and disruptions in the laboratory) while appearing steady at the Earth's magnetopause and in the solar wind?

2) Is reconnection onset locally determined or a consequence of global dynamics?

3) Are 3D effects fundamental to the onset of reconnection in nature?

4) What physical processes control the onset of collisionless reconnection? Are wide current sheets in collisionless plasma always stable?

5) Do ambient pressure gradients impact stability, particularly in plasmas with beta of order unity (e.g., the solar wind)?

6) Does the transition from Sweet-Parker (collisional) to Hall (collisionless) reconnection control onset during flares?

7) What is the role of turbulence?

Tools available for onset study

1) Observations from the sun:
   - Provides global view of dynamics.
   - Does not resolve the reconnection regions.

3) Spacecraft observations in the Solar Wind and Earth's magnetosphere
   - Provides detailed local information about the fields and plasma properties.
   - A global overview of the 3D geometry can rarely be established.

4) Fully kinetic simulations
   - Retains the kinetic effects of the electrons and ions.
   - Spatial scales of simulations are small and limited to 2D.

5) Fluid simulations
   - Large systems can be simulated.
   - Kinetic effects of the electrons and ions are not included.

6) Dedicated reconnection experiments
   - Retains all kinetic effects and allow for 3D dynamics under repeatable and controllable conditions. Microscopic and global view can be obtained.
   - Spatial scales of present experiments are small (in dimensionless units)

➔ Need strong collaboration and larger experimental facilities