Magnetic Reconnection

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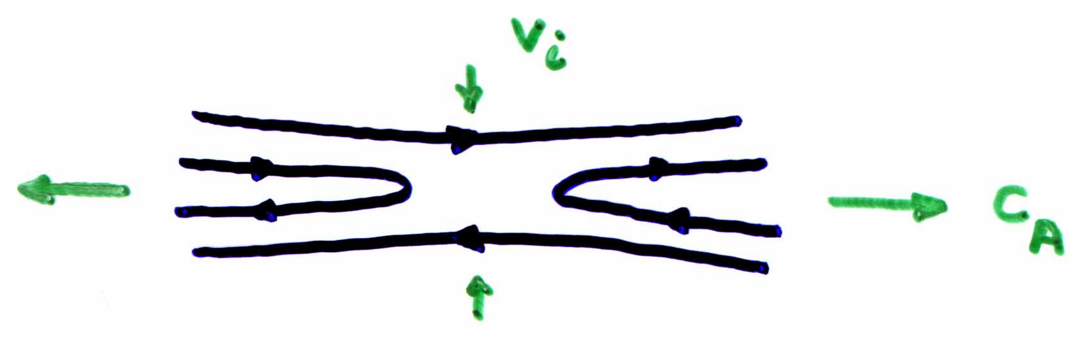
Magnetic Energy Dissipation in the Universe

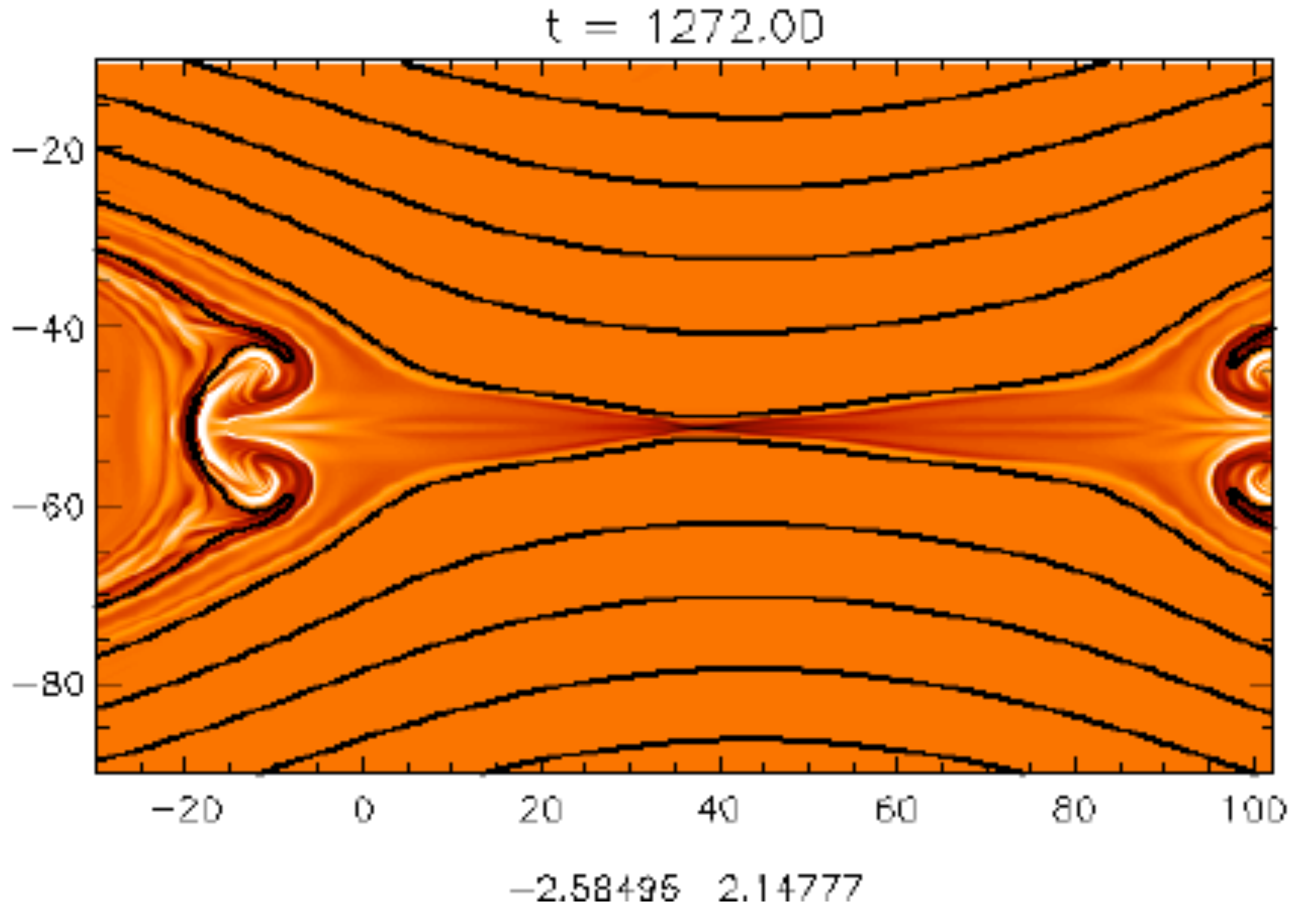
- The conversion of magnetic energy to heat and high speed flows underlies many important phenomena in nature
  - solar and stellar flares
  - energy releases from magnetars
  - magnetospheric substorms
  - disruptions in laboratory fusion experiments
- More generally understanding how magnetic energy is dissipated is essential to model the generation and dissipation of magnetic field energy in astrophysical systems
  - accretion disks
  - stellar dynamos
  - supernova shocks
  - Jets and radio lobes

How magnetic reconnection works



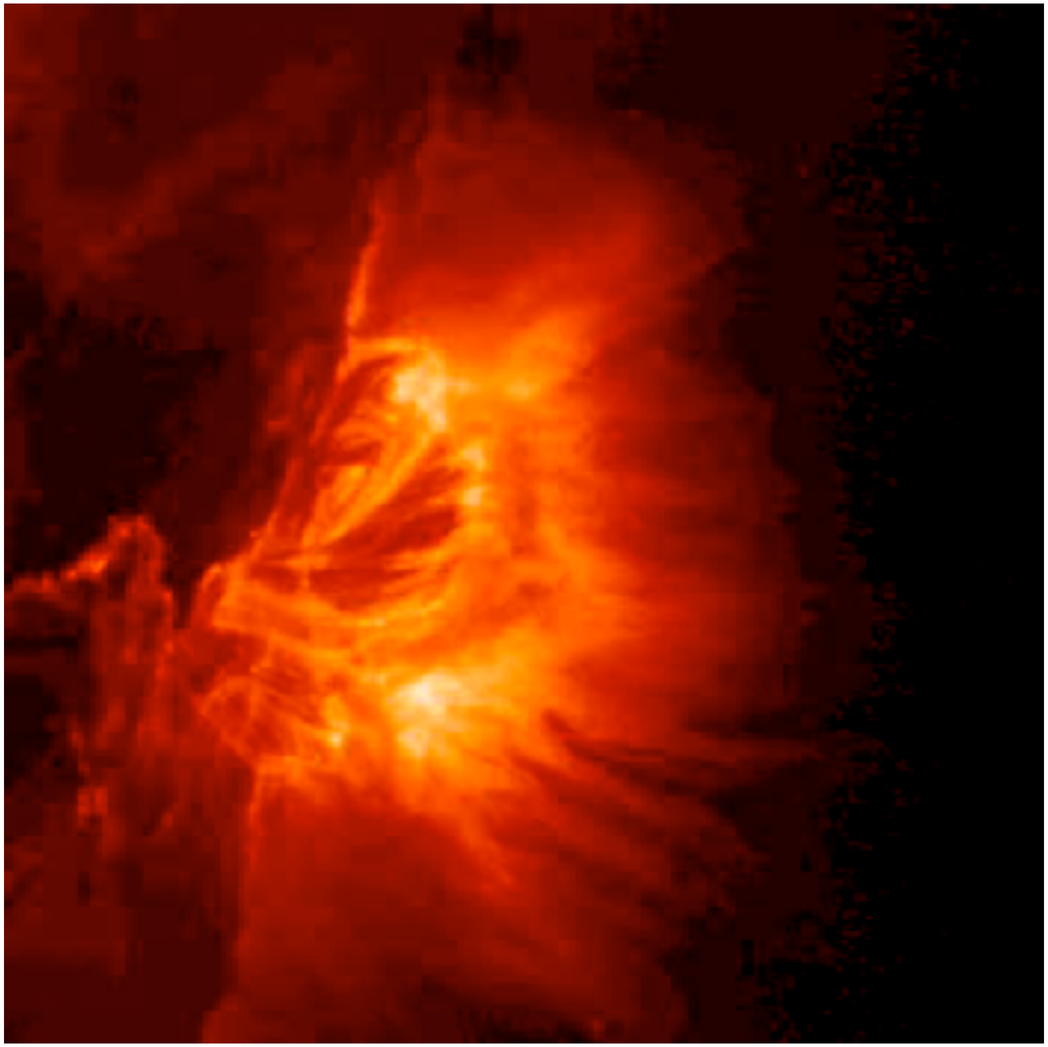
- Dissipation enables magnetic fields to change topology
  - Takes place in narrow boundary layers because dissipation is typically weak
- Newly reconnected field lines expand to release their tension driving Alfvenic outflows
- Resultant pressure drop near the x-line pulls in oppositely directed magnetic fields from upstream which then reconnect
  - Magnetic reconnection is self-driven

Magnetic Reconnection Simulation



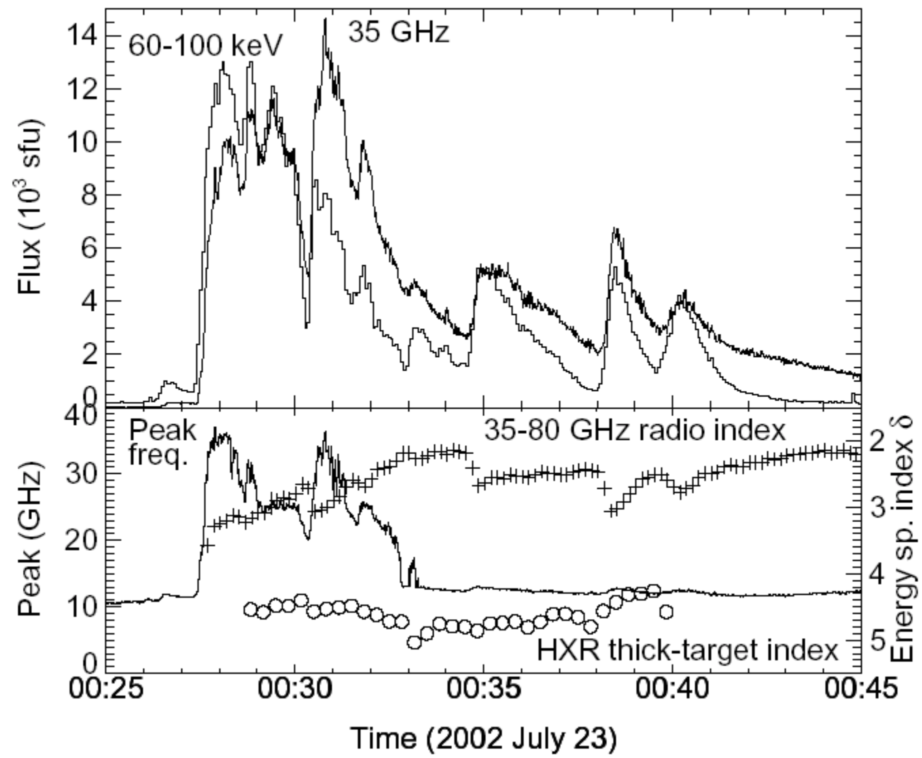
Solar flares: reconnection of coronal magnetic fields

- Trace data from the April 21, 2002, X flare
- Interpreted as patchy reconnection from overlying reconnection site



Impulsive flare timescales

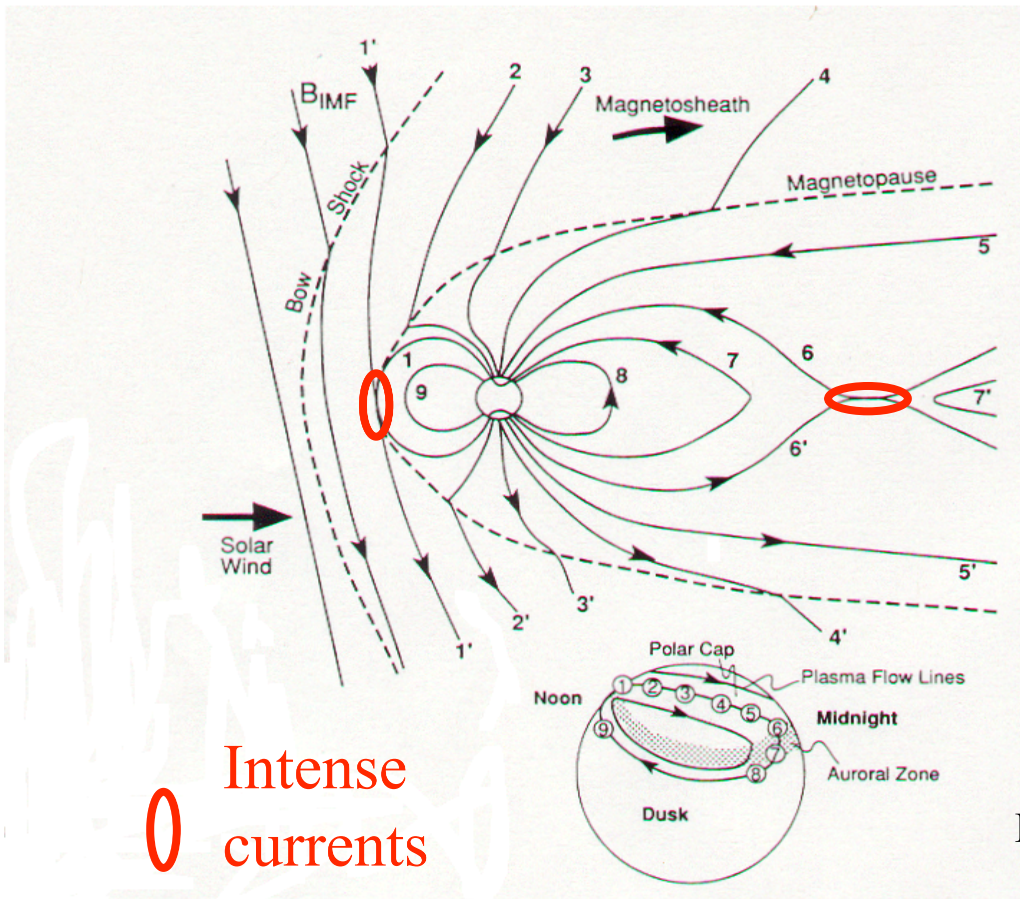
- Hard x-ray and radio fluxes
  - 2002 July 23 X-class flare
  - Onset of 10's of seconds
  - Duration of 100's of seconds.



RHESSI and NoRH Data

(White et al., 2003)

Reconnection in the Earth's magnetosphere

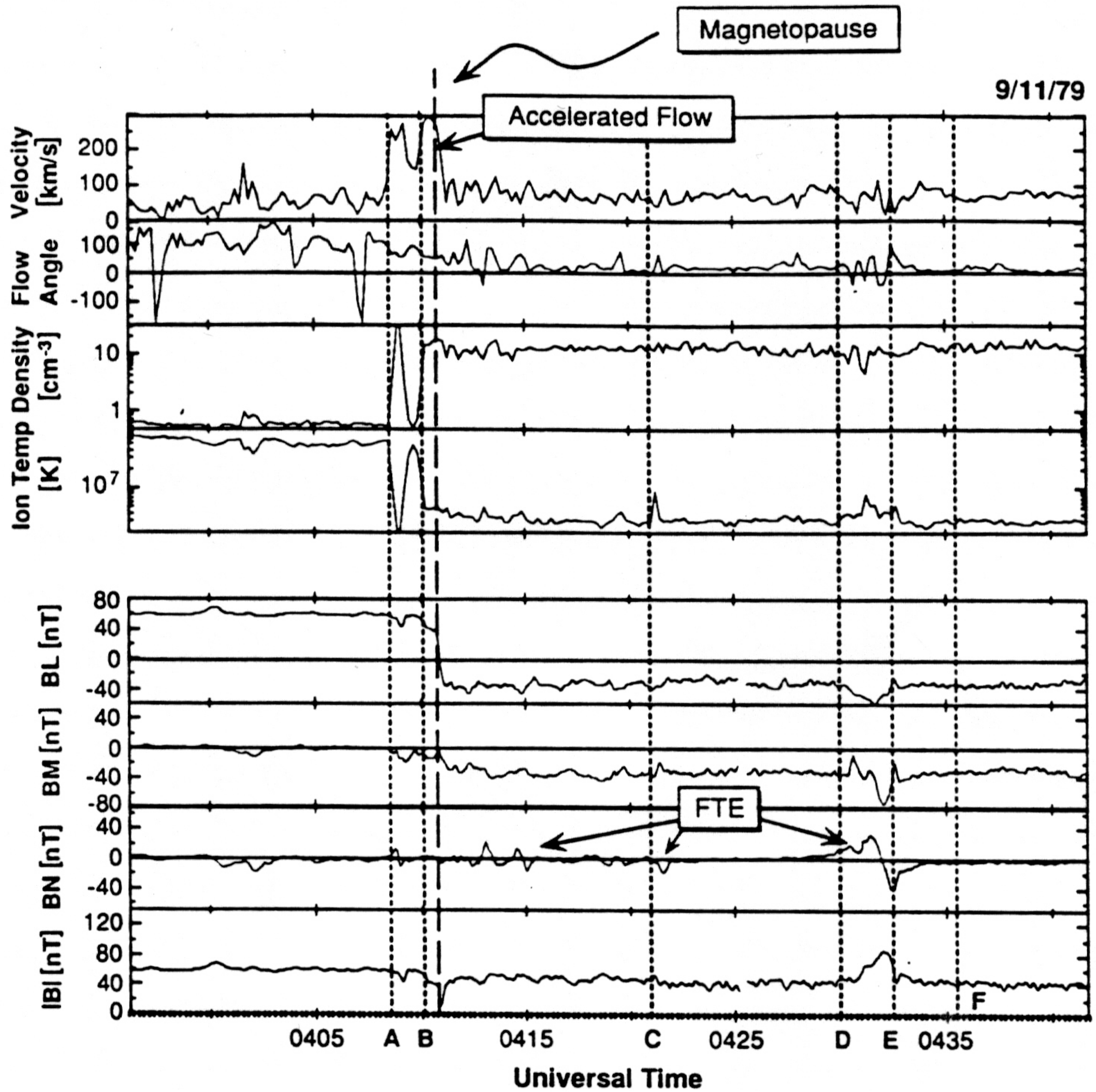


Kivelson et al., 1995

- In-situ satellite measurements provide a wealth of reconnection data

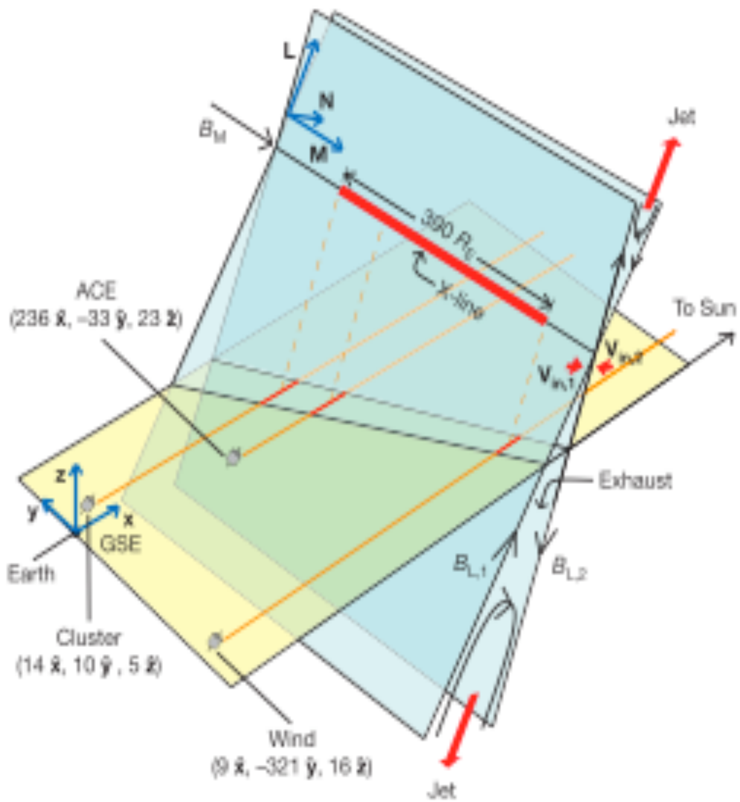
Fast Flows at the Magnetopause

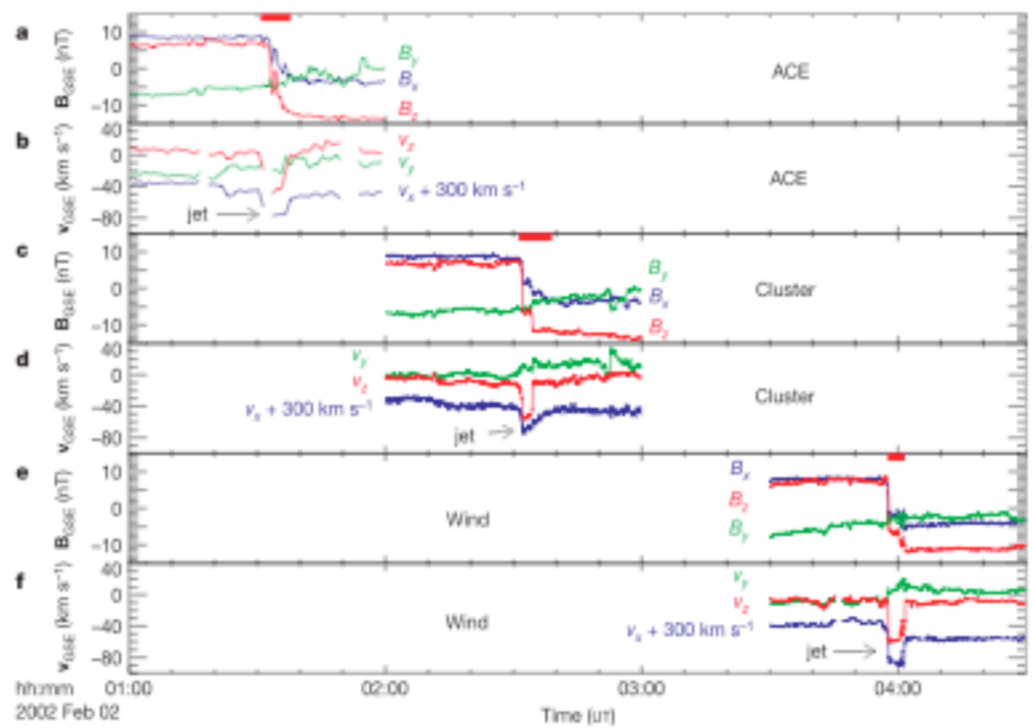
Scurry et al. '94



Huge solar wind reconnection events

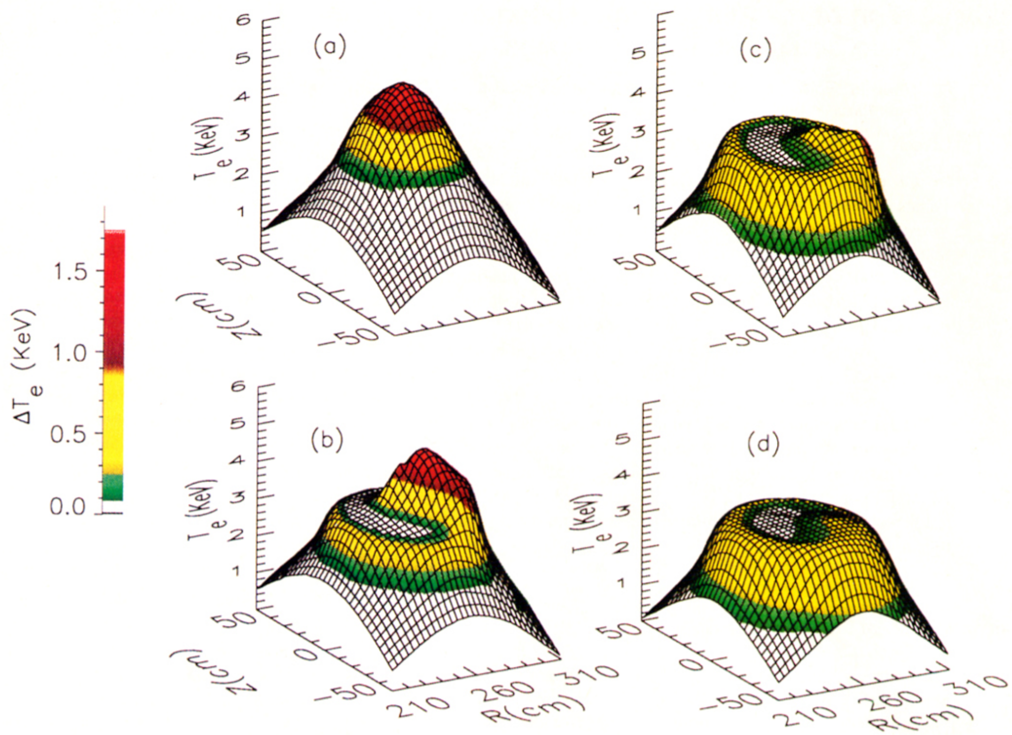
- Solar wind reconnection events are providing an important in-situ source of data for understanding reconnection
  - 390 R_E reconnectionn encounter (Phan et al 2006)





Expulsion of core temperature in tokamak sawteeth

- Measurements of the core electron temperature in the TFTR tokamak documented the loss of core energy during the “sawtooth crash” (Yamada, et al., 1994)

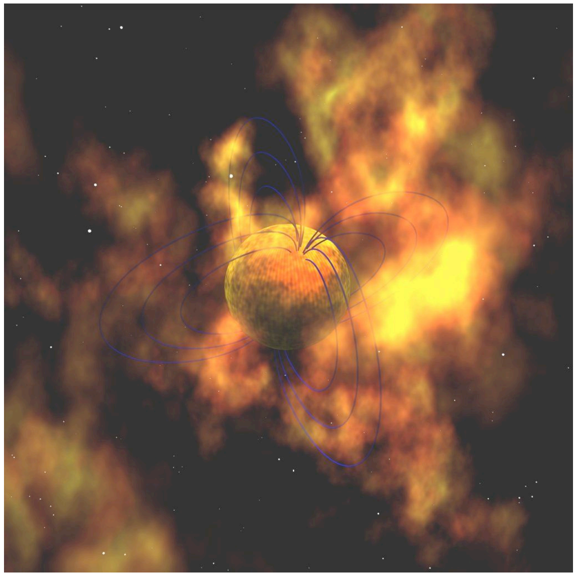


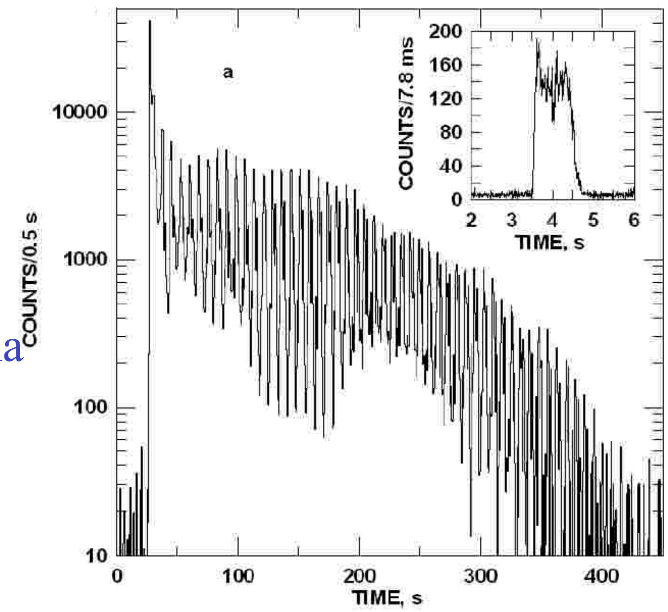
- Reconnection of the magnetic field in the plasma core drives the crash

Flares in high magnetic field neutron stars

- Magnetars: Isolated neutron stars with:
  - B ~ 10^{15} Gauss
  - Strongest B-fields in universe.

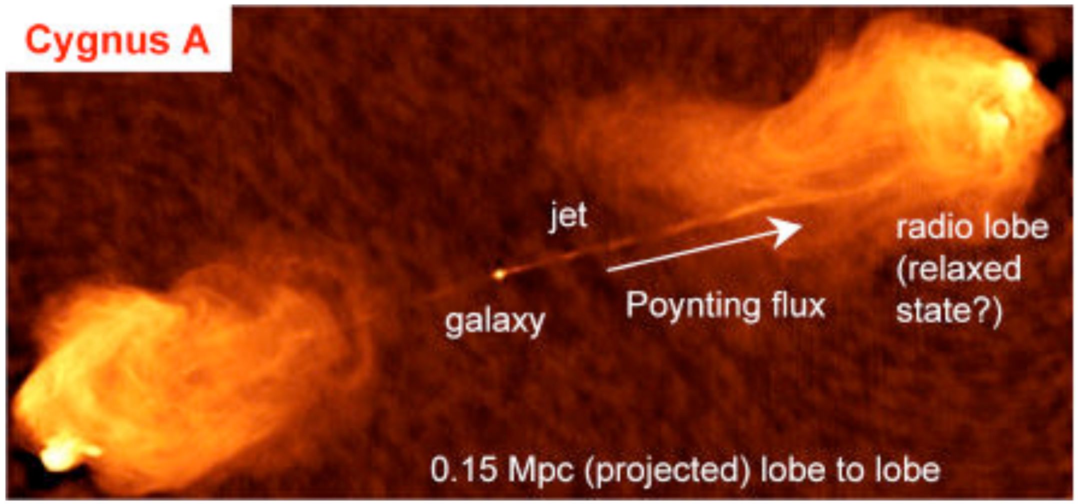
- Giant Flare (SGR 1806-20)
  - Dec. 27, 2004, in our galaxy!
  - Peak Luminosity: 10^{47} ergs/sec.
  - Largest supernova: 4 x 10^{43} ergs/sec.
  - Cause: Global crust failure and magnetic reconnection.
  - Could be a source of short duration gamma ray bursts.





Rhessi data: Hurley et al., 2005

Astrophysical jets



- What is the role of reconnection in the controlling the heating and dynamics of the jet?
- Does reconnection power radio emission from the lobe?

Several fundamental issues

- The rate of reconnection
  - Energy release rates are much faster than expected based on the weak dissipation in most astrophysical and laboratory systems.
- The onset problem
  - Why does reconnection occur as an explosion?
  - Reconnection can not always be fast or could not build up magnetic energy.
- Cross-scale coupling in large systems
  - How does the dynamics of the small-scale dissipation region couple to and release the energy in a macro-scale system?
  - In the corona the ratio of scale approaches 10^9
- Heating and particle acceleration
  - In flares nearly half of the energy goes into the energetic component of electrons and ion
  - Remarkable conversion efficiency of magnetic energy to energetic particles
- Reconnection in extreme environments
  - The astrophysical environment takes on extremes from ultra relativistic systems with pair production to systems with intense radiation