Results from Numerical Simulation of Magnetic Reconnection

Edoardo Striani\textsuperscript{1}, Andrea Mignone\textsuperscript{2}, Bhargav Vaidya\textsuperscript{2}

\textsuperscript{1} - INFN Torino and IAPS/IASF
\textsuperscript{2} – University of Torino
Magnetic Reconnection

• Rapid rearrangement of magnetic field topology

• Violent release of magnetically-stored energy and its conversion into heat and into nonthermal particle energy

• Observed in numerous physical phenomena such as
  – Solar flares and coronal mass ejections
  – Magnetic storms in the Earth’s magnetosphere
  – Sawtooth crashes in tokamaks
Magnetic Reconnection

The classical Sweet-Parker predicts for the reconnection time scale

\[ t_{\text{rec}} \sim t_A S^{1/2} \]

where \( S = L \nu_A / \eta \) is the *Lundquist number*, \( \eta \) the resistivity of the plasma and \( t_A = L / v_A \) is the Alfven transit time.
Problem

• $S \gg 1$ (e.g., $S \approx 10^{12}$ in solar corona)

• The classical Sweet-Parker therefore predicts a very long reconnection time scale

• This is in direct contradiction with the reconnection time observed, that are very short - usually only 10 to 100 times longer than the global Alfven transit time, $t_A$
When $S > 10^5$ (large aspect ratio) the layer becomes unstable to tearing instability: production of plasmoids (e.g., linear resistive MHD theory, Loureiro et al. 2007)
When $S > 10^5$ (large aspect ratio) the layer becomes unstable to tearing instability: **production of plasmoids**

(e.g., linear resistive MHD theory, Loureiro et al. 2007)

**Fast reconnection regime**

1. growth rate of the instability scaling as $\gamma t_A \sim S^{1/4}$
2. Effective reconnection rate **independent of $S$**
3. number of plasmoids $\propto S^{3/8}$
Reconnection Rate

Graph showing the relationship between \( T_{\text{REC}} \) and the Lundquist Number with a dashed line indicating \( S^{1/2} \).
Reconnection Rate

Up to $S = 10^8$
Number of Islands

\[ S^{3/8} \]
3D simulations of Cartesian Setup
3D simulations of Cartesian Setup
3D simulations of Cartesian Setup

DB: data.0010.vtk

user: plutouser
Thu Mar  5 11:53:50 2015
3D simulations of Cartesian Setup

DB: data.0012.vtk
3D simulations of Cartesian Setup

DB: data.0014.vtk
3D simulations of Cartesian Setup
Bz = 0.25
Bz = 0.5
Open questions and work in progress for 3D simulations

• Scalings (reconnection rate and plasmoid formation) in *fast reconnection* regime.

• Effect of the guide field $B_z$ in the time evolution of the current sheet.

• Morphology of plasmoids in 3D.
Magnetic reconnection and Astrophysics

- Particle acceleration (e.g., Uzdensky et al. 2011)
- Magnetic dissipation in PWN (see e.g., Petry & Lyubarsky 2007, Porth et al. 2013)
- Flares in AGN (see ‘monster plasmoid’ model of Giannios 2013)
- Crab Nebula gamma-ray flares (see, e.g., Cerutti et al. 2013)
Crab Jet simulations

Mignone, Striani, Tavani, Ferrari 2013
Work in progress:

- Reconnection rate
- Number of plasmoids
- Effect of the plasma beta
- Effect of multiple layers
Conclusions

• MHD reconnection in **large** S systems is fast and dynamic. Sweet-Parker theory inadequate.

• Current sheets predicted by the Sweet-Parker theory are *violently unstable* to the formation of *plasmoid chains*.

• Numerical confirmation of linear theory in the *fast reconnection* regime.

• Formation of ‘*monster plasmoids*’.

• Work in progress: scaling laws (reconnection rate, number of plasmoids) for 2D and 3D polar configurations.

• Future: 3D simulation of magnetic reconnection in astrophysical jets.
Thank you