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## How Fast Do Magnetic Islands Interact in a Plasma!

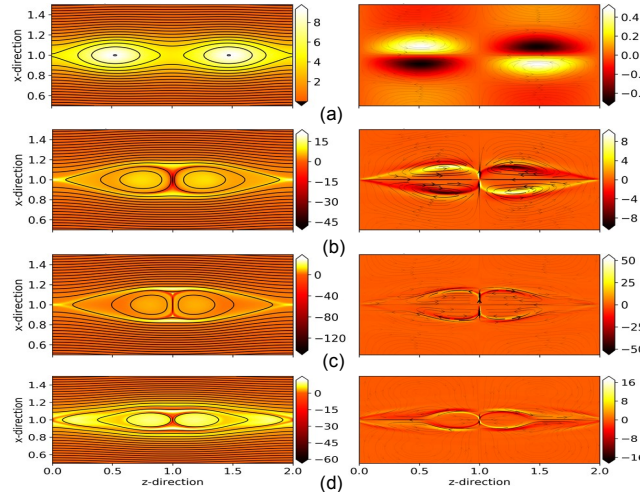
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**M**agnetic reconnection (MR) is a physical process that refers to the breaking and rejoining of oppositely directed magnetic field lines in highly conducting plasmas. The reconnection of the field lines results in the conversion of a large fraction of magnetic energy of the system to kinetic energy, heat energy, and particle acceleration. MR is the driving force behind many naturally observed phenomena such as solar flares, coronal mass ejections from the surface of the Sun, aurora formation in planetary magnetosphere etc. [1]. It is also frequently observed in laboratory plasma (e.g., saw-tooth crash driven by tearing mode instability (TMI) in tokamaks [2]). In ideal condition, plasma stays “frozen-in” to magnetic field lines. This prevents the crossing, breaking, or merging of field lines with each other. However, when two oppositely directed field lines come close to each other, a thin current sheet develops in between them. Non-ideal processes such as plasma resistivity or finite mass of electrons etc. and the sharp gradient in the magnetic field inside the current sheet allows the breakdown of frozen-in condition and field lines start to diffuse. This initiates the MR. How fast MR takes place depends on how less is plasma's electrical resistance ( $\eta$ ), how fast can the plasma respond or move ( $v_A$ ) and how big is the current sheet ( $L$ ). One of the most popular analytical model to establish the relation between reconnection rate and plasma Lundquist number ( $S = Lv_A/\eta$ , where  $L$  is gradient scale length,  $v_A$  is Alfvén velocity and  $\eta$  is the resistivity) is the Sweet-Parker (SP) model [3,4], which uses conservational properties of single fluid magneto-hydrodynamics (MHD) theory. According to the SP model, the reconnection rate scales as  $M \sim S^{-1/2}$ . In the case of space plasma, the value of  $S \sim 10^{12}$ - $10^{14}$ . For this  $S$  value, the predicted reconnection rate by the SP model is very small which is in sharp contrast to the observations. Hence, the SP model is believed to be valid only for smaller values of  $S$ . Also, with an increase in the  $S$  value, the reconnecting current sheet becomes thinner and comparable to kinetic length scales. In that case, MHD theory may fail and one may need two-fluid models or even kinetic models for the investigation.

***“The developed numerical solver will enable us to investigate the effects of plasma parameters on the interaction of magnetic islands using fine grid resolution”***

To start with, we have considered an intermediate value of  $\eta$  ( $= 10^{-4}$  or  $S = 1/\eta = 10^4$ ) such that the length scale or the reconnecting current

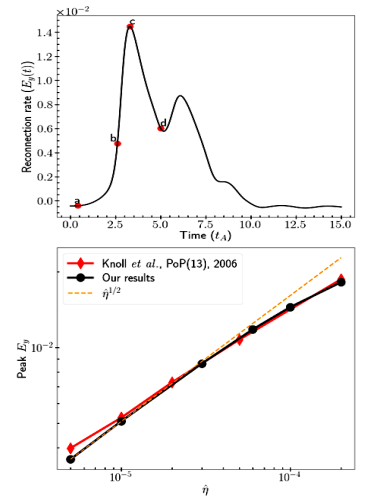


**Figure 1: Magnetic island evolution.** Left panel shows current density (colormap), magnetic flux (contours) and right panel shows vorticity (colormap), velocity (streamlines) at various time points  $t$ : (a)  $0.4t_A$  (b)  $2.6t_A$  (c)  $3.3t_A$  and (d)  $5.0t_A$

sheet thickness is much larger than ion skin depth ( $\delta_i = c/\omega_{pi}$ , where  $c$  is light speed and  $\omega_{pi}$  is the ion plasma frequency). This ensures the validity of the single fluid MHD model and hence SP model is implemented. Here, we solve viscoresistive Reduced-MHD equations [5] (assuming plasma as an incompressible magnetized fluid) in a 2D Cartesian grid  $\{(x,z): 0 \leq x,z \leq 2\}$  using BOUT++ framework [6] which uses a finite difference technique to solve 3D nonlinear partial differential equations. Also, BOUT++ framework has built-in MPI parallelization. We use the Dirichlet boundary at  $x = 0$  and  $2$ , and the periodic boundary along  $z$ -direction (by using FFTW technique). We use a very fine, uniform grid structure ( $dx = 0.001$  and  $dz = 0.0005$  corresponds to  $N_x = 2048$  and  $N_z = 4096$ ) to resolve the thin reconnecting current sheet (see Figure-1(c) left panel).

The equations and all the variables are normalized to Alfvénic units. Let us look at two “magnetic islands” as shown in Figure-1(a) (left panel) [7],

which is an ideal MHD equilibrium, as our initial magnetic flux profile and velocity profile are initialized to zero. The magnetic islands carry current in out-of-plane direction parallel to each other. Hence the Lorentz force between the current filaments provides attractive force between them. This force of attraction leads to a pile-up of magnetic flux on both the sides of X-point. In absence of any dissipation, plasma is unable to cross the X



**Figure 2: (Top)  $E_y$  vs.  $t_A$  for  $\eta = 10^{-4}$ , the labels correspond to Figure 1. (Bottom) Peak  $E_y$  vs.  $\eta$ . Benchmarked with Knoll et al. (2006) [5].**

-point, hence the magnetic pressure caused by flux pile-up prevents the islands to coalesce. However, in presence of finite dissipation, plasma can cross the X-point and the islands start attracting each other, finally merge into a large, single island. The reconnection rate is calculated as reconnecting electric field at the X-point,  $E_y = -\eta J_{y|X\text{-point}}$  ( $J_y$  is the y-directional current density) and is plotted versus time (Alfvénic time  $t_A = L/v_A$ ) in Figure-2 (top). The peak value of  $E_y$  is the maximum reconnection rate. In Figure-2 (bottom), we have plotted peak  $E_y$  for different  $\eta$  values which agree with SP scaling. A total of 6 runs are performed on the ANTYA cluster, each on 256 CPU cores. The right panel figures in Figure-1 shows the characteristic flow pattern of plasma at the reconnection site. Hence, any externally induced flow pattern would affect the MR. Recently, using this efficient numerical solver, the effect of external in-plane shear flow on the coalescence process has been investigated [8].

### References:

1. E. G. Zweibel, and M. Yamada, *Annu. Rev. Astron. Astrophys.* 47, 291 (2009).
2. J. Wesson, *Tokamaks* (Clarendon Press, London, England, 1987).
3. E. Priest and T. Forbes, *Magnetic Reconnection: MHD Theory and Applications* (Cambridge University Press, Cambridge, England, 2000).
4. D. Biskamp, *Nonlinear Magnetohydrodynamics* (Cambridge University Press, Cambridge, England, 1993).
5. D. A. Knoll and L. Chacon, *Phys. Plasmas* 13, 032307 (2006).
6. B. D. Dudson et al., *J. Plasma Phys.* 81, 365810104 (2015).
7. J. M. Finn and P. Kaw, *Phys. Fluids* 20, 72 (1977).
8. J. Mahapatra et al., <https://arxiv.org/abs/2102.01312>.

## Running Jupyter Notebook in the Browser of Your Local Machine from ANTya as a Batch Job

Jupyter Notebook is a useful tool for shortening the feedback loop from coding and seeing the results by performing data analysis, model prototyping, and trials in an interactive way, making it easier to develop scientific code collaboratively. HPC User can launch a "headless" Jupyter Notebook as a batch job in ANTya, but can have the Graphical User Interface (GUI) in the Local user machine's (Desktop/Laptop) web browser. This will allow the User to use the ANTya compute resources and several dependent libraries installed in ANTya without the need of installing any Python packages on the local machine to run the Jupyter Notebook.

Step 1

- From ANTya login1, run Jupyter Notebook with --no-browser on port XXXX

Step 2

- Port forwarding via ssh to local machine port no. YYYY

Step 3

- Open web browser in local machine and type `http://localhost:YYYY`

## Syntax

### 1. Job Script for Launching the Jupyter Notebook

```
[@login1 ~]$ cat jupyter.sh
#!/bin/bash
#PBS -N Notebook_job
#PBS -l select=1:ncpus=2:ngpus=1
#PBS -l walltime=24:00:00
#PBS -q serialq
#PBS -j oe

cd $PBS_O_WORKDIR
NOTEBOOK_LOGFILE=jupyterlog.out
# get tunneling info
node=$(hostname -s)
user=$(whoami)
cluster="AA.BB.CC.D"      # Enter cluster IP address
port=XXXX
export JUPYTER_PORT=XXXX  # Enter a free port number like 9000

# After job submission open the port_forwarding.txt file for port forwarding
echo -e "
Run the following command from your local machine terminal with local port YYYY:
$ ssh -N -f -L YYYY:${node}:${port} ${user}@${cluster}
" > port_forwarding.txt

module load anaconda/3
# launch the Jupyter Notebook run
jupyter notebook --no-browser --ip=${node} --port=${port} > ${NOTEBOOK_LOGFILE} 2>&1
```

"The script and detailed procedure to run Jupyter Notebook can be downloaded from the Github repo"

[click here](#)

### 2. From local machine terminal with port no. YYYY run the following command

```
[@localhost]$ ssh -N -f -L YYYY:cn001:XXXX username@AA.BB.CC.D
```

### 3. Open web browser in local machine and type `http://localhost:YYYY` and copy paste the token number from the `jupyterlog.out` in the token window in browser.

## ANTYA UPDATES AND NEWS

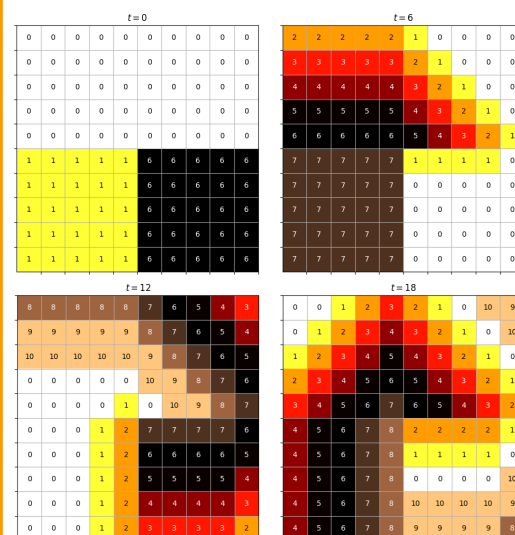
### 1. New Software Installed

⇒ Singularity341 module

⇒ Jupyter Notebook can be opened by loading the module `anaconda/3`

2. DDN Storage Controller issue identified and resolved

## Diffusion in Excitable Media Using Cellular Automata (HPC Picture of the Month)



Pic Credit: **Dr Promit Moitra**

Certain media are characterized as excitable media, such as cardiac tissue, dusty plasma etc. The above image illustrates the evolution of such media, modeled using *Greenberg-Hastings cellular automata*.

The image is generated using in house developed code with Python on ANTya visualization node. Simulating the dynamics with sufficient transients for all possible configurations of increasing sizes, requires extensive use of the ANTya cluster.

## Other Recent Work on HPC

Finite Electron Temperature Gradient Effects on Blob Formation in the Scrape-off Layer of a Tokamak Plasma

**Vijay Shankar**

A 3D Magnetohydrodynamic Simulation For the Propagation of Plasma Plume Transverse to Applied Magnetic Field

**Bhavesh G Patel**

## Acknowledgement

The HPC Team, Computer Division IPR, would like to thank all Contributors who helped to make this newsletter available in time.

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