Some concluding remarks

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2nd European Conference on Magnetic Reconnection in Plasmas

Torino 17/06/2025 - 19/06/2025

First day tutorial

Tuesday combined tutorial

MR in fusion/solar physics (Ph. Browning, F. Waelbroeck)

The aim of this two-speaker tutorial was to establish a common language between the fusion (F.W.) and the solar (Ph.B) communities, answering few general questions that had been agreed before.

The presentations covered a set of important points but the time available was probably too short.

I think that this combined tutorial was a useful novelty given the specialisation of the different subfields of plasma physics.

Possibly the choice of the questions could have been more focused on the subjects of the following presentations: some, my fault as the moderator, where too general or too vague.

In my opinion such an experiment should be improved and continued.

Points that were discussed

Following the tutorial, what are the main problems involving MR that fusion/astrophysics are addressing?

Particle energisation and energy transport.
These topics were addressed in detail by the Plasma Observatory team (C. Norgren). This mission aims at multiscale measurements (at fluid and ion scales) in the Earth magnetospheric system.

Multiscale Physics in the context of turbulence and physical dimensions.
Multiscale physics and the role of turbulence were discussed in depth both theoretically and observationally, together with extensive comparisons between two dimensional and three dimensional descriptions of magnetic reconnection.

Self-organization.
The formation of quasi-helical symmetrical magnetic configurations in field reversed magnetic configurations was presented. (M.Veranda)

Points that were discussed

Applications of MR.

It was remarked that *MR is non longer only a theoretical and experimental problem during a presentation (F. Ebrahimi) of MR in plasma thrusters. This is a very interesting application of MR particle acceleration revisited in different physics terms on Wednesday (G.Beccati).*

Dark Matter?

Possible plasma effects in dark matter were indicated in a talk (N. Shukla) that combined Weibel instability, electron positron plasmas and the main simulation codes in the framework of plasma physics available at Cineca (Bologna, Italy).

Electron heating

The role of the parallel electric fields in MR in the Earth Magnetotail (L. Richard) was discussed in the context of electron heating.

Two partially contrasting tutorials

On Wednesday a tutorial on magnetic reconnection in space plasmas underlined the role of a dynamic environment in the development of fast reconnection. (A.Tenerani)

On Thursday a tutorial recalled important results obtained for MR in fusion configurations, stressing the effort in fusion experiments to work in a quasi steady state. (F. Porcelli).

The difference between these two different points of view started a very interesting discussion that, unfortunately, did not find enough time to develop fully.

This turned out to be an unexpected shortcoming of the program and led to a proposal: think about setting a new GEM-challenge in order to settle this point and in general help the transfer of results in MR between the fusion and the space communities.

Main points discussed

Fusion relevant plasma dynamics.

Fishbones, Machine Learning Disruption prediction and neoclassical tearing modes were discussed in a series of presentations. Special attention was played on *MR and runaway electrons*.
The energy redistribution between thermal and nonthermal distribution fwas discussed in an ion electron multi-species plasma (S. Totorica)

Magnetic reconnection in a alternative fusion configurations

MR in a stellarator configuration (Wendelstein 7-X K. Aleynikova) in the presence of ECCD current drive provided an important experimental result on the problem of plasma disruptions.

Partially ionized plasmas

MR in partially ionized plasmas was presented with reference to particle acceleration in the solar atmosphere and in protoplanetery disks. (F.Pucci)

Main points discussed

Relativistic plasmas.

M.R. in relativistic plasmas was first introduced on Tuesday (V.Berta) and then extended on Wednesday by a comprehensive talk (D.Udzensky) that introduced the audience to plasma physics in high energy astrophysics.

PIC simulations of energetic particle spectra in relativistic reconnection were also discussed (K. Schoeffler).

MR in relativistic plasmas in high energy astrophysical configuration is fast developing as a very interesting and productive field of research. In a future meeting it should be probably represented more extensively.

Poster session

A small but very interesting poster section was available from Wednesday afternoon up to the end of the meeting.

Files of the posters will be available on line to the conference participants.

Some additional comments

A few additional points that might have been addressed:

Magnetic reconnection in advanced fusion experiments

What is the main threat of magnetic reconnection besides degradation of confinement in future tokamaks ?
stability?
Saw-teeth (m= 1 kinks) ?
The generation of runaways? disruptions ?

How to compare these effects in high (e.g. in Sparc) and low (e.g. in ITER) magnetic field experiments?

An additional point on magnetic topology

Topology and energy production

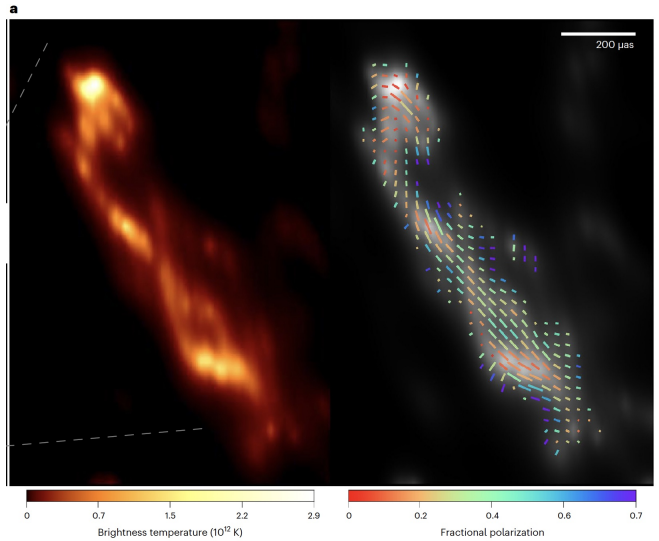
1) Magnetic reconnection involves two features.- a topology change - an energy source

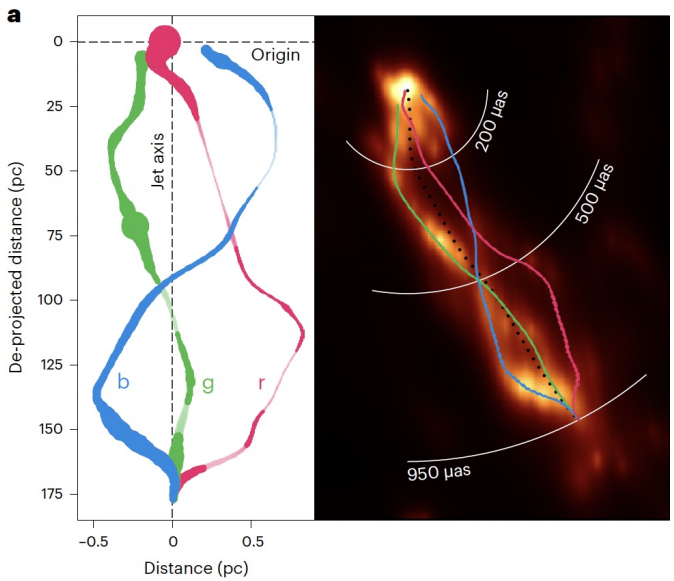
In the “topology change regime” non-magnetic free energy that was already available is released because a topological constraint is broken (see e.g. resistive modes and resistive reconnection in MHD) or weakened. There is also an energy release due to the rearrangement of the magnetic field but it is a minor contribution with respect to the release of the ideally constrained free energy.
In the case of the “energy source” the energy that is transferred to the plasma in the form of heat and/or non thermal particle acceleration is generally attributed to the “burning” of the magnetic energy only. The main focus is not on the change of topology

In fact in most astrophysical configurations the field topology, even if possibly relevant, is either not known of difficult to reconstruct, see e.g. next slide.

Topology in astrophysical context: Blazar 3C279

A. Fuentes et al., *Nat Astron.*, **7**, 1359 (2023).





Some additional comments

In a strongly inhomogeneous plasma low density regions (even vacuum) regions can occur. Beams and magnetic disturbances propagating in such plasma-vacuum regions can produce reconnection type modes that change to e.m. modes when the perturbation of the magnetic field cannot be sustained any more by the perturbed current and the displacement current starts to count.

This “current starvation” process has been reexamined recently and shown to be effective in accelerating electrons[1].

Can one invoke such a mechanism to account for particle acceleration in apparently MHD regimes where however, at least locally, the constraint $|E| < |B|$ *seems to be violated? (Synchrotron radiation above the so called burn off limit*[2]*).*

[1] S.Boldyrev and N. F. Loureiro, 2025 ApJ, 979, 232 and reference therein.

[2] Simulations of Particle Acceleration ..., B. Cerutti et al., ApJ. 770, 147 (2013)

Some additional comments

A new context: “Reconnection” in Laser Plasma interactions

A number of recent experiments, shining ultra-intense laser pulses on solid surfaces or on wires, have produced colliding magnetic fields that produce X-point configurations in the electron “plasmas” that they extract from the solid structures[3]. Such processes have been described as examples of relativistic reconnection and presented as relevant to high energy astrophysical configurations (Laboratory Astrophysics).

Is there a clear distinction between what it would be better called “magnetic field annihilation” and magnetic reconnection?

[3] See e.g. Kuramitsu, Y., et al. Electron scale magnetic reconnections in laser produced plasmas, Rev. Mod. Plasma Phys. 7, 24 (2023).

Magnetic field annihilation

P. M. Nilson et al. *PRL*, **97**, 255001 (2006)

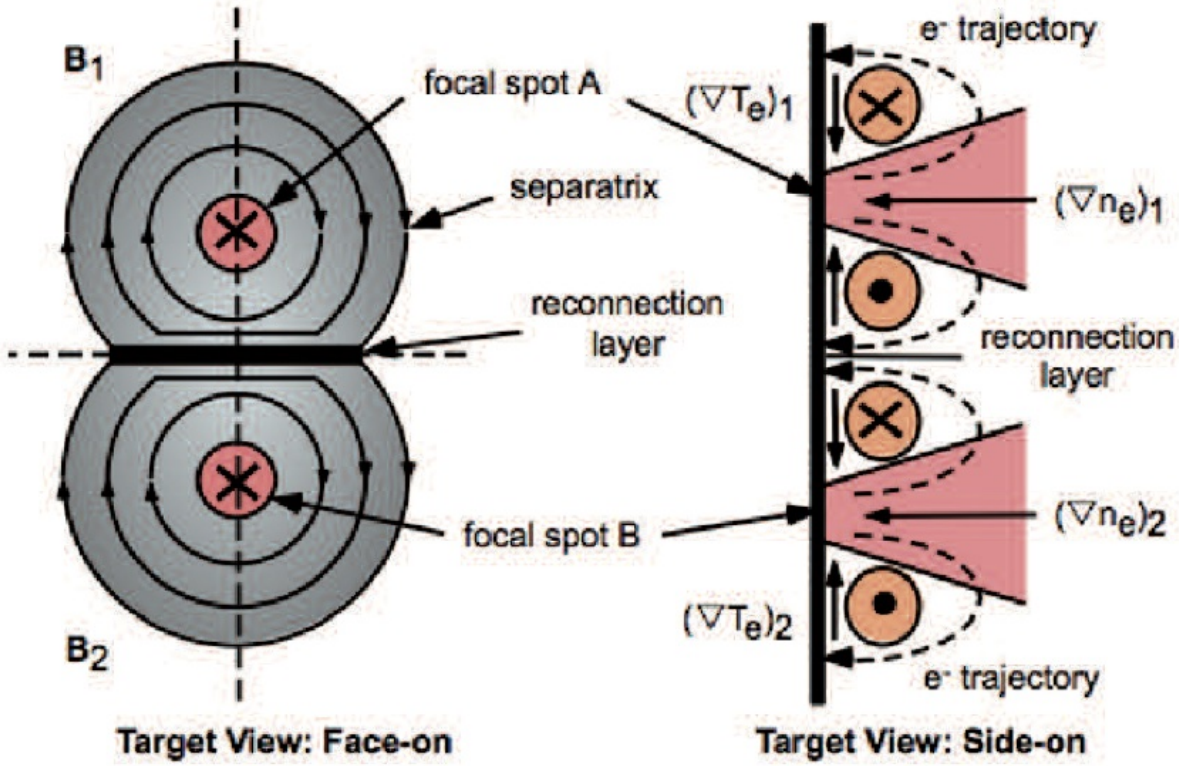


Figure 1. The target and field configuration of a self-generated magnetic reconnection geometry in a laser-produced plasma using two heater beams.

New geometries can be exploited

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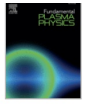

Collisionless relativistic magnetic reconnection driven by electron vortices in laser-plasma interaction

Yan-Jun Gu [a], Kirill V. Lezhnin [b], Sergei V. Bulanov [c d]

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Magnetic reconnection (MR) is a fundamental process in space and laboratory plasmas. The appearance of high power lasers opens a new way to investigate MR under the relativistic condition. In this paper, relativistic collisionless MR driven by two ultra-intense lasers and a pair of asymmetric targets is studied numerically via the kinetic simulations. The static magnetic fields produced by the electron vortex structures with opposite magnetic polarities approach each other driven by the magnetic pressure and the density gradient. The antiparallel magnetic fields annihilate accompanied with the topological variation and the corresponding magnetic field energy is being dissipated to the kinetic energy of the nonthermal charged particles. Besides the outflows along the current sheet, a fast particle bunch is accelerated perpendicularly contributed by the displacement current.