Numerical modeling of Magnetic Switchbacks

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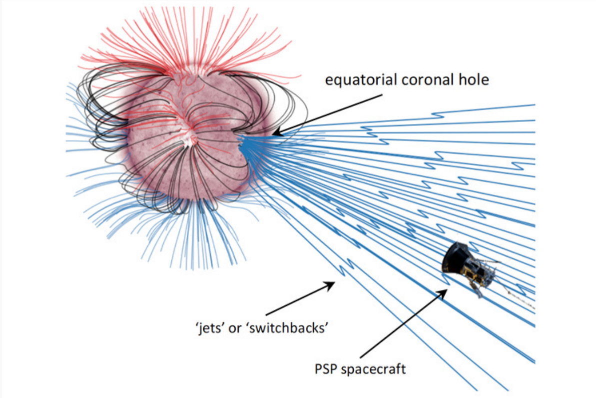
Funded by:
ERC SLOW_SOURCE project (DLV-819189)

Introduction:

During Parker Solar Probe's (PSP) first encounter with the Sun, the analysis of in situ data revealed that the solar wind is continually perturbed by transient Alfvénic structures which display magnetic reversals called switchbacks (SBs) accompanied by plasma jets or velocity spikes. Theory and observations have suggested that they may originate from interchange reconnection that occurs when coronal magnetic loops reconnect with open magnetic field lines. In this presentation we will cover some potential mechanisms that are responsible for the formation of switchbacks. Using 2.5-D magneto-hydrodynamic(MHD) simulations, we study the effects of flux emergence on the possible generation of SBs through interchange reconnection and the evolution of SB-like structures in the expanding solar wind.



During first encounter of PSP with negative equatorial coronal hole (Bale et al 2019)

SBs are characterized by [1,2] :

- *High Alfvénicity*
- *An increase in the wind velocity by approximately 20%*
- *The proton density increases inside these Switchbacks*

Origins of magnetic SBs

Lower corona[3]

- *Plasma jets associated with reconnection events deep inside the corona*

Expanding solar wind

- Velocity shear
- Kelvin-Helmholtz*[4]*
- Turbulence[5]

We focus on the scenario of the low coronal origin and try to assess the conditions necessary to reproduce the observations.

Flux Ropes origins:

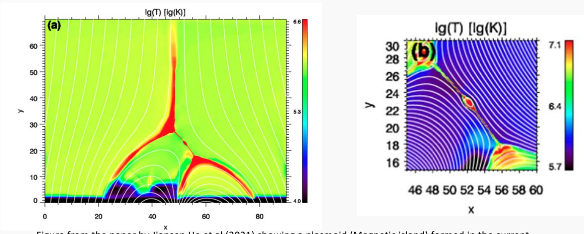


Figure from the paper by Jiansen He et al (2021) showing a plasmoid (Magnetic island) formed in the current sheet at the interface between rising magnetic flux and pre-existing magnetic field in the atmosphere.

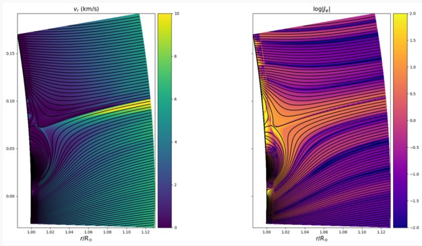
During flux emergence, magnetic reconnection can create magnetic islands (plasmoids) in the current sheet regions.
These structures have been observed with PSP, and it has been suggested that it's a pertinent way to create small scale flux ropes (Fisk & Kasper 2020, Zank et al 2020) .

Drake et al (2021) study the hypothesis that SBs are flux ropes structures that propagate and evolve in the solar wind.
We study this process at larger scales, typical of solar granules, using the setup developed by Réville et al. 2020 [6], which have been shown to create magnetic islands through a tearing instability at the tip of the heliospheric current sheet.

Modeling of Flux emergence

The MHD model has been developed starting from the PLUTO code [7]. The setup is 2.5D in spherical geometry. We initialize the atmosphere with a transient region and a supersonic Parker wind . The corona is heated with an ad-hoc Withbroe function.

Using time dependent boundary conditions, we drive the emergence of a pseudo-streamer in a radially expanding atmosphere. Magnetic island can be triggered by tearing instability in the current sheet. To achieve that the coronal Lundquist number should be substantially greater than $S \sim 10^3$. We chose the minimal resolution to achieve this criterion and set the effective Lundquist number to $S = 1000$. A plasmoid is formed but is quickly dissipated.



Radial component of velocity field and azimuthal current

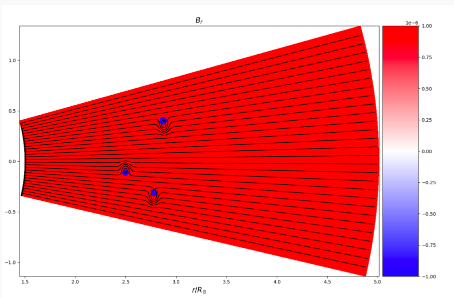
Scan the QR code for movie

Discussions:

We have investigated, via 2.5D resistive MHD simulations, SBs formation and persistence during their propagation.
Our setup is able to create magnetic islands during flux emergence via a tearing instability. We need to investigate further the effect of the Lundquist number on the structure of the magnetic islands and their ability to be ejected in the corona.
Furthermore, we looked at the survival of SB-like propagating structures in the corona and solar wind. We find that they decay in a few solar radii. We need to understand how to lengthen their lifetime. 3D effects could be essential.

Propagation of a pre-exisiting magnetic reversal:

Let's suppose that we have a pre-existing magnetic reversal (from flux emergence or created in the corona), how will it propagate in the corona and solar wind? Starting from profile considered by [8,9], We implemented several configurations in different locations in the lower corona and computed their lifetime in the expanding solar wind. The domain extends up to 20 solar radii.



Radial component of magnetic field

Scan the QR code for movie

In this simulation, we have seen that the lifetime of these structures are related to the strength and shape of the plasmoid. However, they are dissipated quickly while propagating, well under 10 solar radii.

References:

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