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Parametric 3D MHD numerical simulations of the generation of switchbacks induced by solar coronal jets

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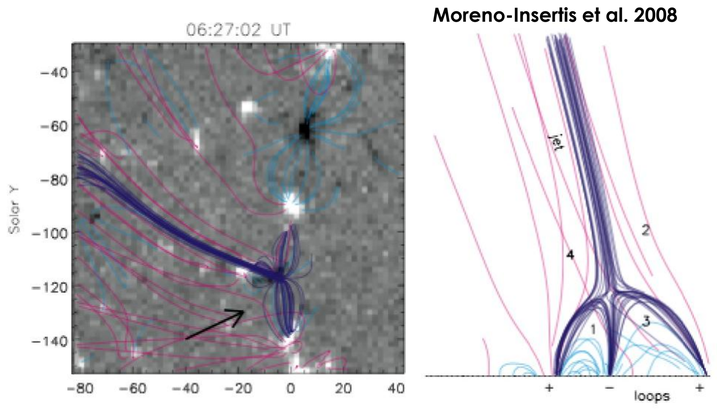
Solar Jets

Solar jets are **sharp-edged**, **collimated**, **axially-extending** and **impulsive** phenomena. These transient features are observed all over the solar atmosphere in a broad range of wavelengths, spatial scales ($L \sim 10 - 10^5 km$) and temporal scales. They often display **helical** or **twisting** structures. Jets are typically associated with an "anemone" magnetic topology at their source. [1]

Moreno-Insertis et al. 2008



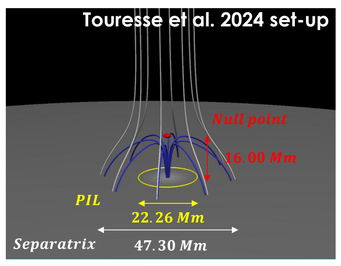
Based solely on solar observations, SB could be induced by solar jet-like events, due to their shared properties [4]:

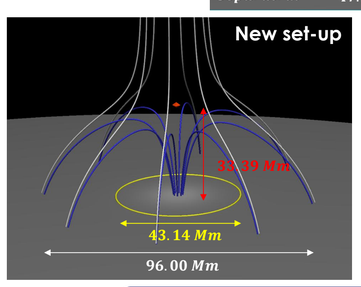
- **Ubiquitousness** and **intermittence**
- **Large scale jets** observed to propagate over **several $R_\odot$**
- **Helical/twisting** structures at all scales
- **Interchange reconnection**: production and propagation of non-linear **Alfvénic waves**

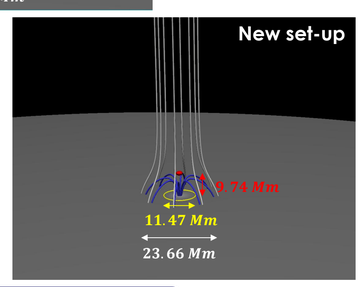
Simulations + observations: U-loops present at the onset of solar jets

Self-consistent jet generation forming a **propagating magnetic deflection** [8]
(no user defined switch-on trigger)

To what extent can the implementation of realistic parameters enhance/affect the formation of SBs through more realistic jet trigger and onset dynamics?





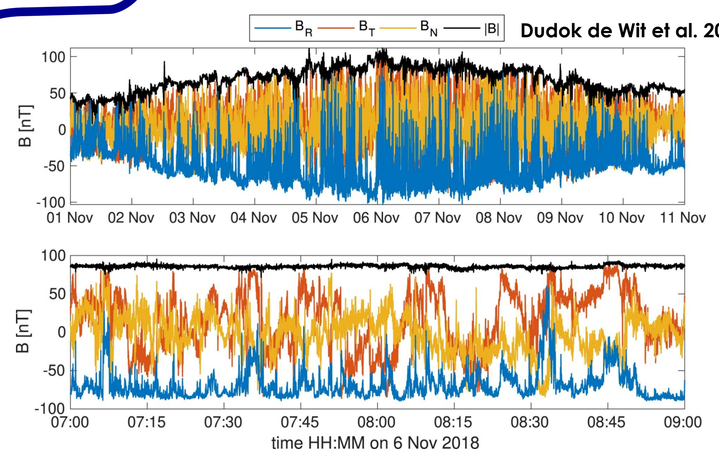


Switchbacks (SBs)

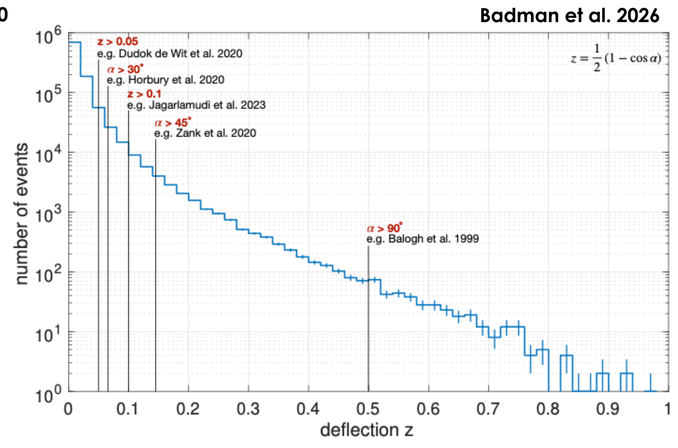
SBs are intermittent Alfvénic magnetic deflections. They are characterized by a variation in the radial magnetic field (B_r) and a proportional increase in radial velocity (v_r). During a switchback, the magnetic field magnitude ($|B|$) remains roughly constant (within ~ 15%).

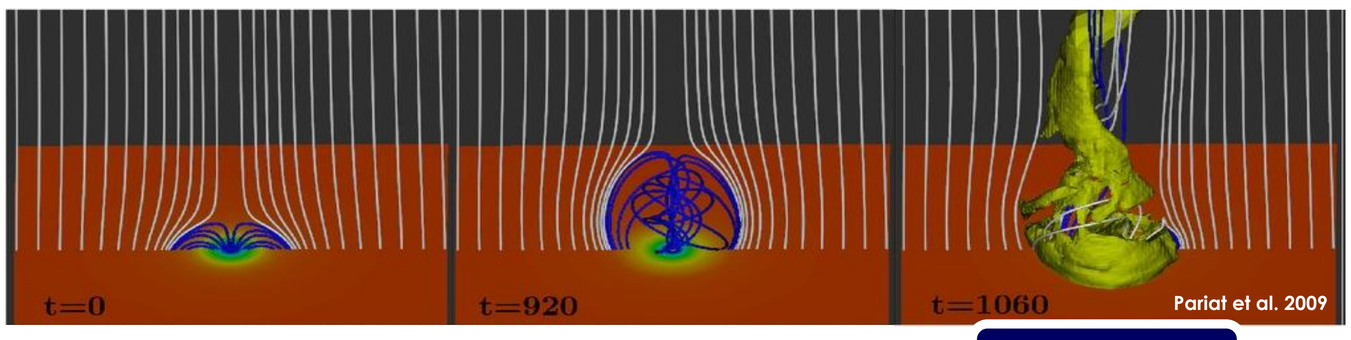
Parker Solar Probe (PSP) has discovered in 2019 that the inner heliosphere is filled with SBs [2][3]

Dudok de Wit et al. 2020



Badman et al. 2026





Pariat et al. 2009

Model

We use the Adaptive Refined MHD Solver (ARMS) code [5] to conduct 3D MHD simulations within a spherical wedge, in the framework of the simulations of Touresse et al. 2024 [6].

$$\frac{\partial \rho}{\partial t} + \nabla \cdot (\rho \vec{v}) = 0 \quad (1)$$

$$\frac{\partial (\rho \vec{v})}{\partial t} + \nabla \cdot (\rho \vec{v} \vec{v}) + \nabla P + \rho \vec{g} + \frac{(\nabla \times \vec{B}) \times \vec{B}}{\mu_0} = 0 \quad (2)$$

$$\frac{\partial U}{\partial t} + \nabla \cdot (U \vec{v}) + P \nabla \cdot \vec{v} = 0 \quad (3)$$

$$\frac{\partial \vec{B}}{\partial t} - \nabla \times (\vec{v} \times \vec{B}) = 0 \quad (4)$$

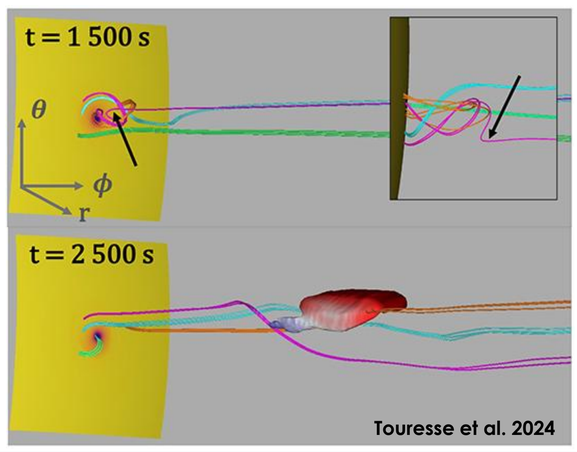
Setup:

- **3D null point topology**
- **Dynamically refined or de-refined grids**
- **Ideal MHD: Numerical resistivity only**

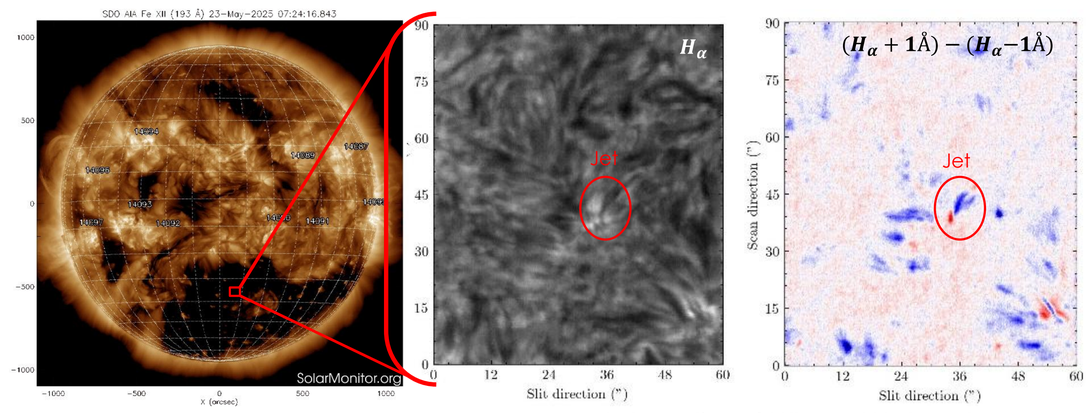
In this model, jets are driven by magnetic untwisting that results from interchange reconnection.

- **Plasma follows ideal gaz law** $P = 2nk_bT$
- **Spherical stratified atmosphere with an isothermal Parker solar wind** [7]:

$$\frac{v_r^2}{c_s^2} \exp\left(1 - \frac{v_r^2}{c_s^2}\right) = \frac{r_s^4}{r^4} \exp\left(4 - 4\frac{r_s}{r}\right)$$



Touresse et al. 2024



THEMIS observations of 23th May 2025 by Jade Touresse

Research Aims

My objective is to use magnetogram-based 3D magnetic field reconstruction as initial conditions for my simulations. Innovative data-initiated simulations shall provide more realistic dynamics of the trigger and onset of jets. They shall lead to a better understanding of the physics of their propagation and therefore to a more accurate modeling of switchbacks.

Preliminary checks:

- **Effect of source size:** New simulations with larger and smaller magnetic dipoles at the solar surface.
- **Observations:** Provide more realistic initial conditions with THEMIS 3D magnetic extrapolations of jet source regions within solar coronal holes.
- **Driving mechanism:** Distinct driving conditions for the self-consistent generation of the jet.
- **Wind model:** Transition from an isothermal Parker wind to a polytropic model, which may provide a more realistic representation of plasma expansion and heating.

References & Acknowledgements

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[8]: E. Pariat et al. 2009, ApJ 691 61