# Parametric 3D simulations of the propagation of a solar jet toward the inner heliosphere

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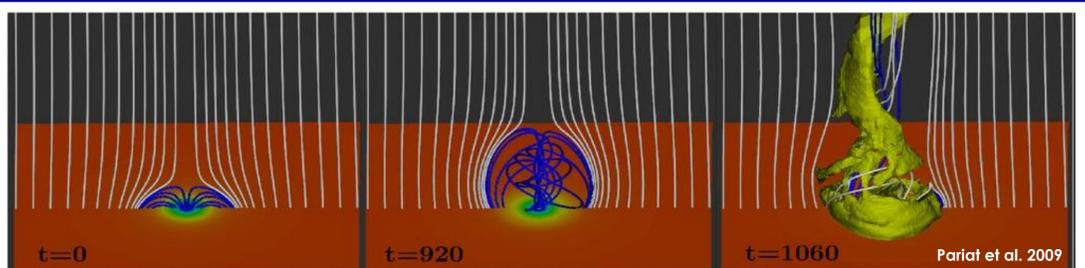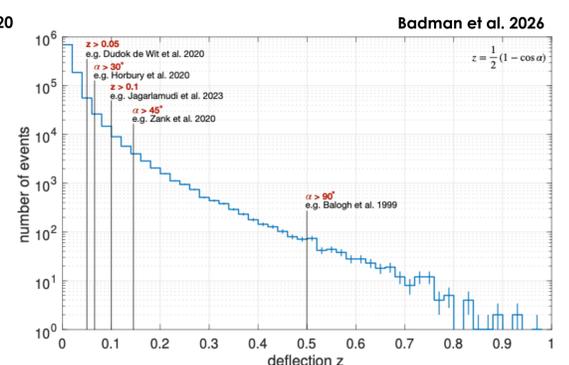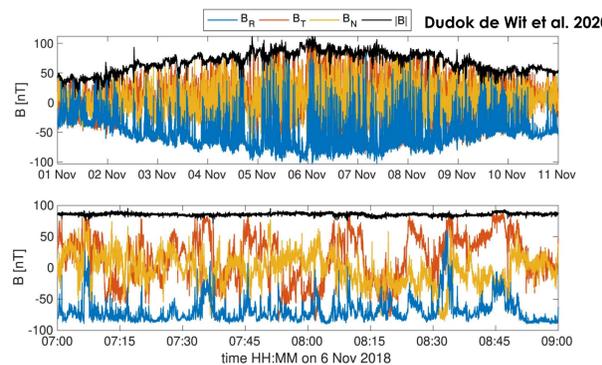
Solar Jets

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
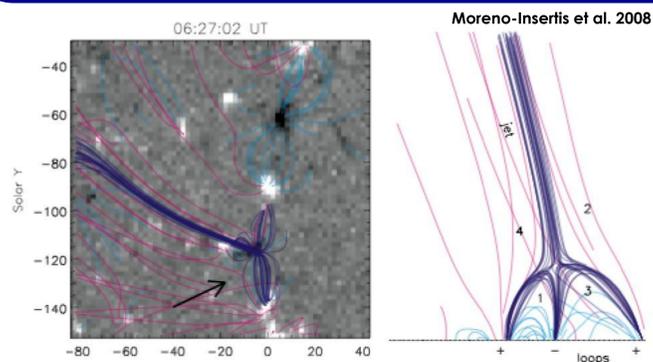
Switchbacks (SBs)

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

**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

Can solar jets explain the origin of switchbacks?

What are the physical mechanisms involved in the jet propagation and SB formation?

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)
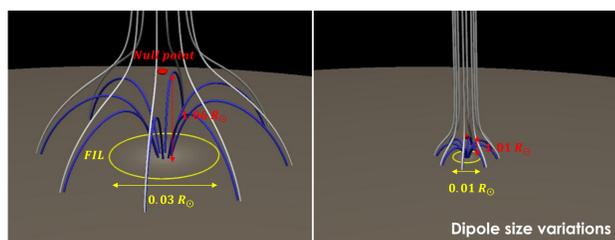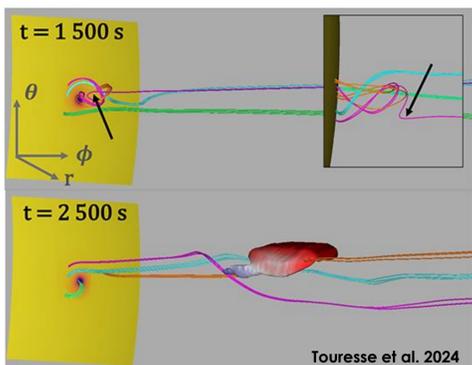
Touresse et al. 2024

Model

We use the **A**daptive **R**efined **M**HD **S**olver (**ARMS**) code [5] to conduct 3D MHD simulations within a spherical wedge, in the framework of the simulations of Touresse et al. 2024 [6].

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

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

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

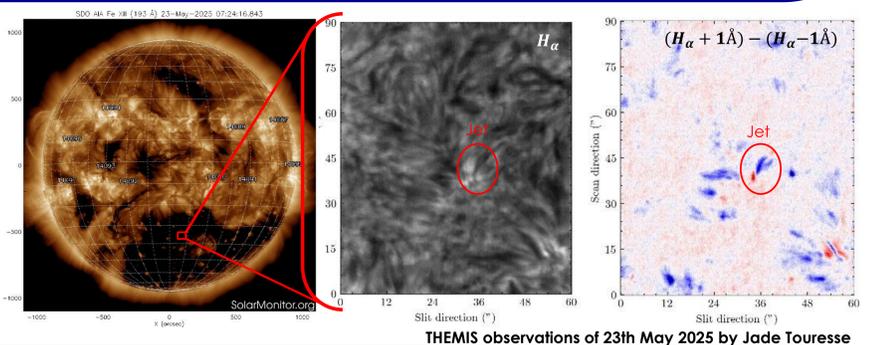$$\frac{\partial \vec{B}}{\partial t} - \nabla \times (\vec{v} \times \vec{B}) = 0 \quad (4)$$

Setup:

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

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

- **Ideal MHD: Plasma follows ideal gaz law**
$$P = 2nk_bT$$

- **Spherical stratified atmosphere with an isothermal Parker solar wind** [7]:
$$\frac{v_r^2}{c_s^2} \exp\left(1 - \frac{v_r^2}{c_s^2}\right) = \frac{r_s^4}{r^4} \exp\left(4 - 4\frac{r_s}{r}\right)$$

Dipole size variations

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