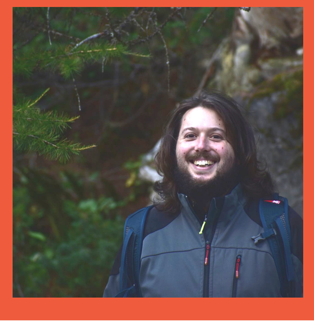

Particle acceleration via magnetic reconnection in large scale jet simulations

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Introduction

Magnetic reconnection is a plasma process that dissipates the energy stored in magnetic field into plasma kinetic energy, through a rearrangement of magnetic field topology, resulting in **particles** heating and **acceleration**. It is thought to play an important role in numerous astrophysical sources like gamma-ray bursts (GRBs) and jets from active galactic nuclei (AGN). MR and shock acceleration are usually invoked among the possible mechanisms to produce particle non-thermal spectra.

MR has been extensively studied with Particles-in-a-cell (PIC) simulations, showing that this mechanism can **generate power-law spectra** for electrons and protons. Details of the final spectra, such as maximum energy, power-law index and acceleration efficiency depend on the plasma quantities that particles experience entering the reconnection region. **Cold magnetization** σ and the **ratio between plasma and magnetic pressure** β result to be the fundamental parameters to determine the resulting post-reconnection particle distribution and the acceleration efficiency [1] [3].

Methods

We developed a novel method to **identify current sheets** (CS) in MHD simulations **and to sample** σ **and** β**, needed to determine the post-MR particles spectrum**. The new method has been implemented in the Lagrangian Particle module in the PLUTO code, a hybrid framework where the non-thermal component is described with Lagrangian macro-particles (MP), representing an ensemble of real particles sufficiently close in physical space and described by their velocity and spectrum. Outside acceleration sites MP spectra evolve accordingly to the relativistic cosmic ray transport equation while MHD equations are solved concurrently. MP position is determined by a simple transport equation using the velocity fluid velocity [2].

Current Sheet Identification and σ, β sampling

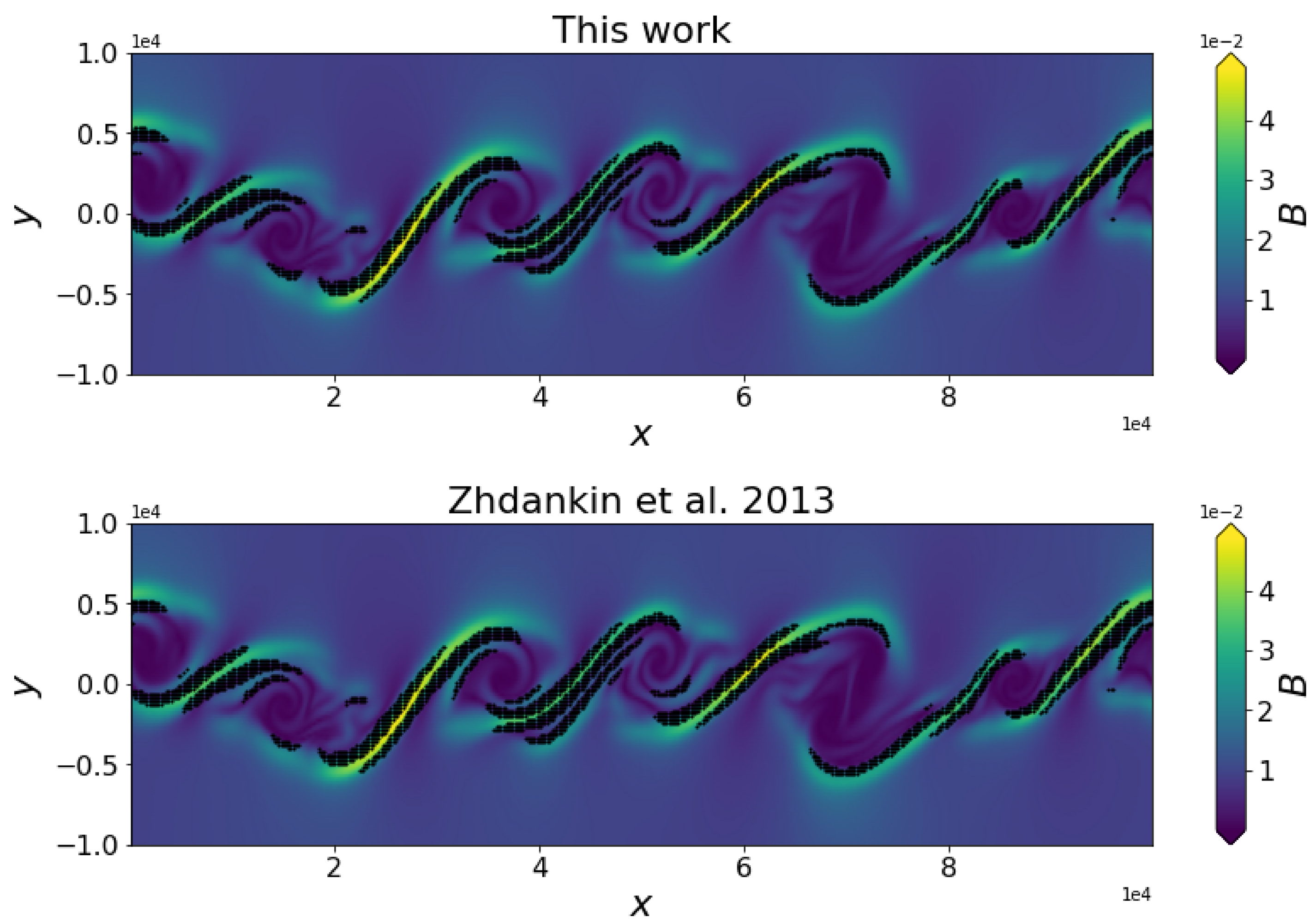

Figure 1. Comparison of the results of the current sheet identification method with the one proposed by Zhdankin et al. [4].

We developed a CS identification algorithm adapt to work in large scale MHD simulations, with complex 2D and 3D CS structures, fast and parallelized and then compared it with other algorithms existing in literature.

The algorithm identifies a current sheet if the quantity in the following equation is larger then a threshold χ_{min} and it can be naturally extended to 3D or other coordinates.

$$\frac{|\Delta_{\rm x} B_{\rm y} - \Delta_{\rm y} B_{\rm x}|}{|\Delta_{\rm x} B_{\rm y}| + |\Delta_{\rm y} B_{\rm x}| + \sqrt{\rho}} > \chi_{\rm min}$$

We use the MP to keep track of $\sigma_{\rm p}$ and $\beta_{\rm p}$, the quantities stored by the MP, while they enter in the reconnection region. Before the MP's spectrum is evolved, σ and β at particle's position are sampled at each step and their value is updated, the stored values are updated with the sampled ones if a new σ peak is detected, otherwise the new sampled value is averaged with the previous saved one.

3D results: Plasma column

Current driven instabilities in a plasma column with initial helicoidal magnetic field structure can lead to formation of powerful reconnection regions. We studied this hypotesis with RMHD simulations, finding in the instability phase values of $\sigma_{\rm p}$ and $\beta_{\rm p}$ that can lead to efficient non-thermal acceleration.

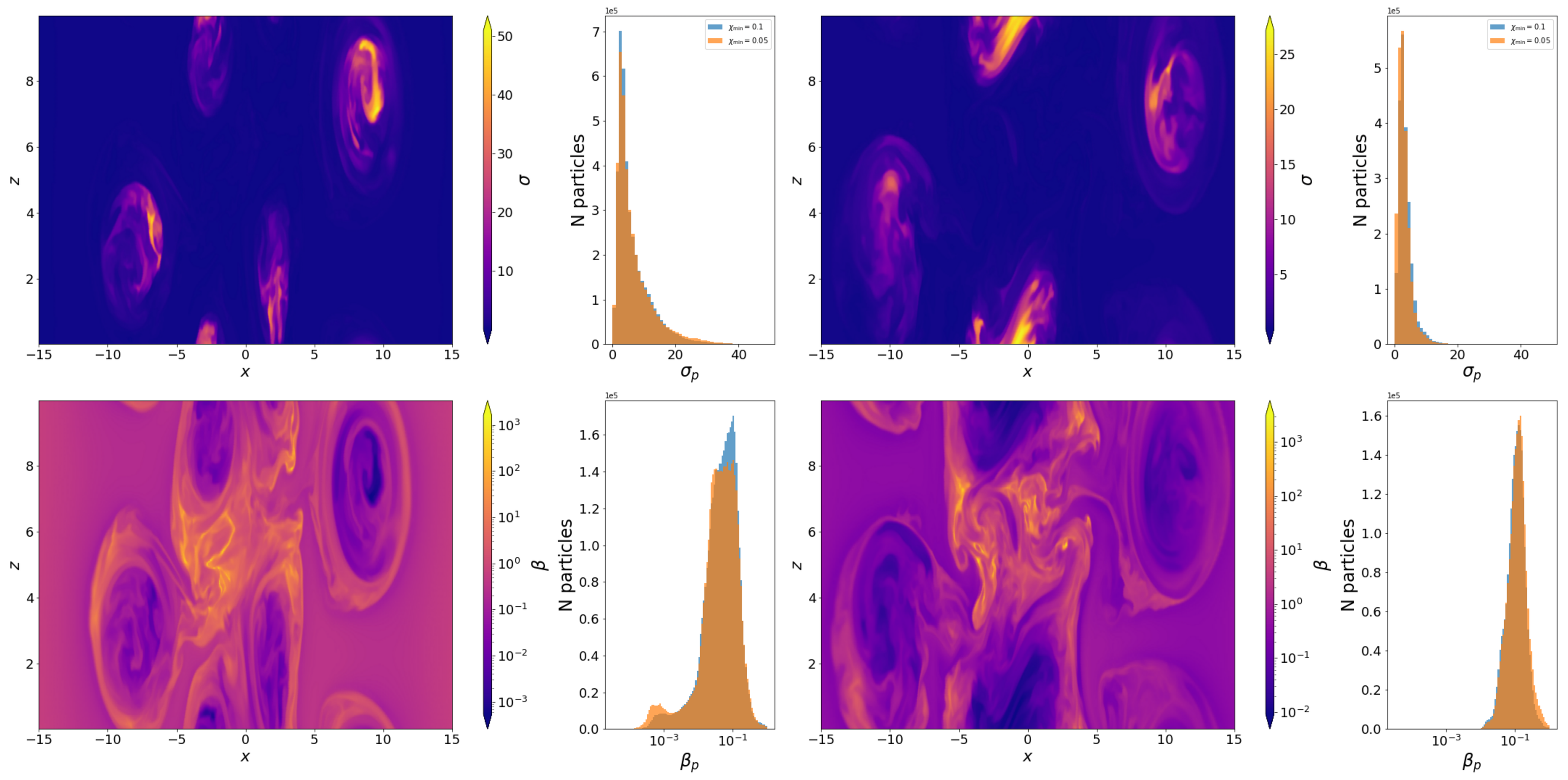

Figure 2. Results for the 3D RMHD jet simulation with initial $\sigma_{\rm h} = 10$ at time $t = 100$ (left) and $t = 140$ (right), with $r_{\rm j} = 10^{16}{\rm cm}$ (where $r_{\rm j}$ is the initial plasma column radius and consequently the unit of time is $r_{\rm j}/c = 3.33 \times 10^5{\rm s}$). Two different values of the threshold $\chi_{\rm min}$ used to determine the reconnection sites are shown.

During the evolution of the instability, shown in Fig. 2 the sampling finds distributions of $\sigma_{\rm p}$ and $\beta_{\rm p}$ values that can give rise to efficient acceleration of a non-thermal particle population, with typical power-law indices in a range of values in broad agreement with observations of blazars.

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