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MHD avalanches and DC heating in solar coronal loops: MHD and forward modelling of nanojets

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Abstract. In the solar corona, heating might stem from numerous, localised and impulsive episodes of magnetic energy release, referred to as **"nanoflares"**. During avalanche-like processes, misaligned magnetic field lines can rupture and reconnect, thus generating a nanoflare storm. Small-angle field line reconnection is known to produce the acceleration of collimated outflow jets, named **"nanojets"** [1]. Detection and analysis of such reconnection nanojets becomes then important, because they are a signature of the reconnection. We performed full 3D magnetohydrodynamic (MHD) simulations of interacting and twisted coronal flux tubes strands [2]. In this work we address the nanojets which form from reconnection episodes, at Parker energies (about 10^{24} erg) and at speeds of few 100 km/s, and we study their detectability, in particular considering EUV observations with the **Atmospheric Image Assembly** (AIA) on-board Solar Dynamics Observatory and the forthcoming **MUltislit Solar Explorer** (MUSE) [3].

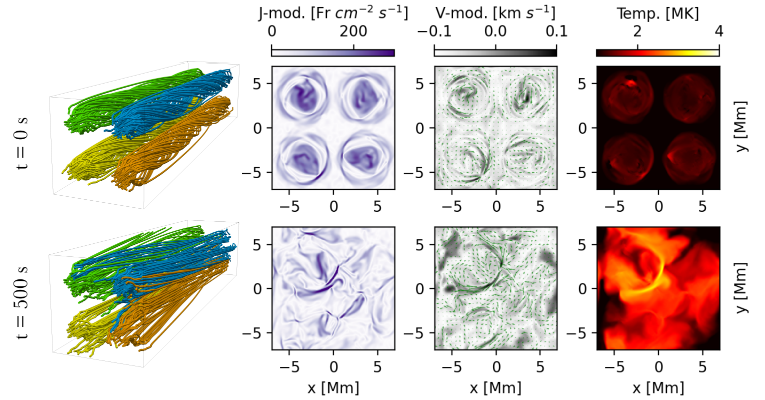
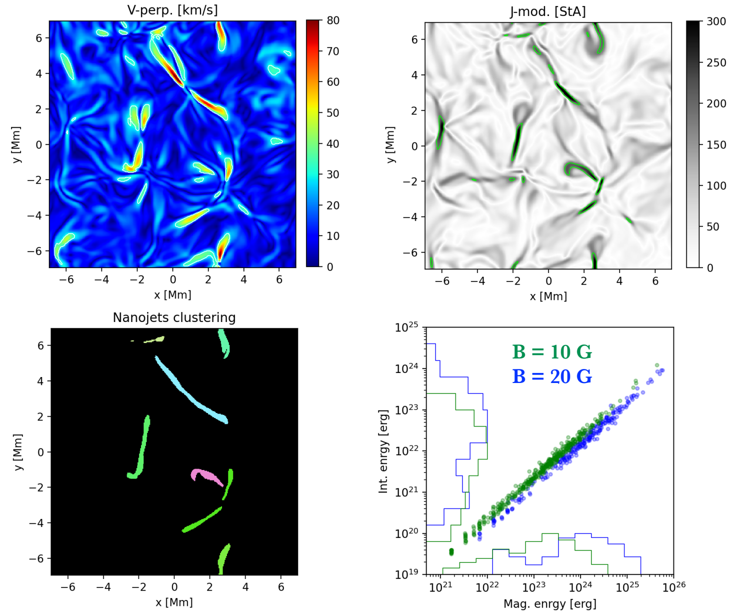


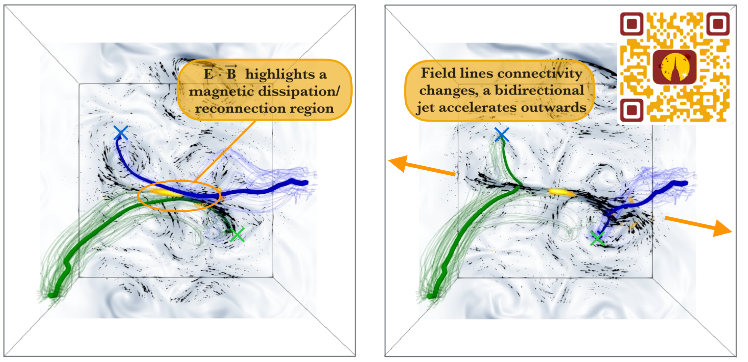
Figure 1. *Left*: 3D rendering of the magnetic field lines before (top, t=0) and after (bottom, t= 500 s) the avalanche. *Right*: current density, velocity, and temperature mid plane cuts.

A nanojet. We identified an outflow event generated by small angle magnetic reconnection (Fig. 2). This event exhibits typical features of nanojets, such as an energy budget of **10^{24}erg** and outflow velocity of few hundreds km/s. In particular, it is up to **8 MK** hot and **$\sim 200\,\mathrm{km\,s^{-1}}$** fast.

Forward modelling. **AIA 94Å** and **MUSE 108Å** channels are sensitive to such 8 MK outflow event, although with small count rates due to low density ($n \lesssim 10^9\,\mathrm{cm^{-3}}$). The Fe XIX 108 Å line profile, when sampled along the nanojet propagation axis, shows a double-peak shape, with peaks shifted to **$v \approx \pm 200\,\mathrm{km\,s^{-1}}$** (Fig. 3, *left*). Fig. 3 also shows MUSE Fe XIX line (*middle*) and AIA 94 Å channel (*right*) images (15 s exposure time) from a point of view which captures the bidirectional outflow structure of the jet. AIA 94 Å channel includes emission from cooler plasma (~1 MK).



Introduction. In our model the magnetised atmosphere is stratified from the high-beta chromosphere to the corona through the narrow transition region. In our simulation with the PLUTO 3D MHD code [4], photospheric rotation stresses the flux tubes until they become kink-unstable and determine an **"MHD avalanche"** [5] of reconnection episodes with the formation, fragmentation, and dissipation of current sheets akin to a nanoflare storm (Fig. 1).



$\vec{E} \cdot \vec{B}$ highlights a magnetic dissipation/ reconnection region

Field lines connectivity changes, a bidirectional jet accelerates outwards

Figure 2. 3D rendering of the reconnecting field lines (**green** and **blue**) and the nanojet flow (**black** arrows) at the current sheet formation (*left*) and during nanojet acceleration (*right*, 30 s after), nanojet direction is marked (**orange** arrows).

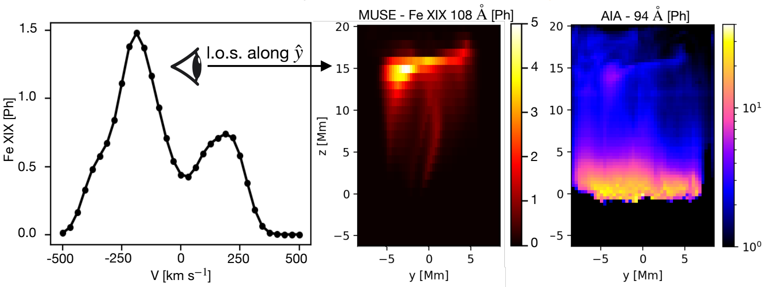


Figure 3. *Left*: Fe XIX line profile along the nanojet propagation axis; *middle*: MUSE Fe XIX emission on the nanojet plane; *right*: AIA 94Å channel emission

Automatic detection. To study nanojets statistically we device a method to pick up them automatically in the simulations. The method is based on the velocity component perpendicular to the magnetic field ($v_{\perp B}$, nanojet wings , Fig. 4, *top-left*), and on the magnetic dissipation region (its core, *top-right*). We applied the detection method to a set of MHD avalanche simulations with different injected Poynting fluxes at the boundaries and made some cluster analysis. On average, nanojets **internal and kinetic energy scale as the Poynting flux**, the higher the background magnetic field, the more energetic will be the detected nanojets (*bottom-right*).

Conclusions. Numerous high temperature $\sim 8\,\mathrm{MK}$ nanojets can develop from MHD avalanches. Our automatic detection method allows us a statistical and cluster analysis. As a first output, we expect an **easier detection for higher background magnetic field** ($> 10\,\mathrm{G}$). MUSE Fe XIX line will detect more likely events higher in the nanoflare energy range ($\lesssim 10^{25}$ erg) (with e.g., for $B = 40\,\mathrm{G}$).

Figure 4. *Top*: mid plane cuts of $v_{\perp B}$; current density. *Bottom:* detected nanojets, each color is a different nanojet; scatter plot of nanojets magnetic energy vs. internal energy.

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