A 3D MHD simulation of flare supra-arcade multiple descending outflows in the solar corona

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Abstract

Observed dark plasma flows descending through the solar corona originated above flare arcades, also referred as supra-arcade downflows (SADs), have been detected in soft X-ray and extreme-ultraviolet observations. Our group proposed a theoretical scenario to explain the nature of SADs, which mainly states that magnetic reconnection burst can generate descending plasma voids sustained by the bouncing and interfering of shock waves. We present our first 3D MHD simulation results in the framework of our model.

1 - Summary

SADs have their origins in ~[40–60]Mm above flare arcades, decelerating speeds in the range ~[50–500] km s^{-1} and exist for times of the order of tens of minutes. They have been reported using space based instruments such as SXT aboard Yohkoh, *TRACE* aboard *SOHO*, and AIA aboard *SDO*. The lack of X-ray and extreme-ultraviolet signatures in images and spectra has lead to a consensus that SADs are likely voided flows generated by magnetic reconnection processes in a current sheet above flare arcades. Fig. 1 shows a X-ray image of a flare taken at a time when dark voids can be seen descending toward the arcade from its top.

The main questions that still remain to be answer are: How SADs are form? And, how can these subdense structures live for relatively long times? Several scenarios have been proposed to explain SADs, for some reference the reader should see for example the jobs presented by Savage et al. 2012 (ApJ, 759, L40), Cassak et al. 2013 (ApJ, 775, L14) and Scott et al. 2013 (ApJ, 776, 54).

In Costa et al. (2009, MNRAS, 400, L85) and Cécere et al. (2012, ApJ, 759, 79; 2014, in revision) we showed by means of 1D and 2D MHD simulations that SADs are consistent with plasma voids generated by the bouncing and interfering of no-linear waves produced by magnetic reconnection bursts. Reconnection burst can be emulated by instantaneous pressure pulses keeping the density constant. With the aim of testing the scope of our model, we extended our previous study of SADs by mean of 3D MHD simulations.

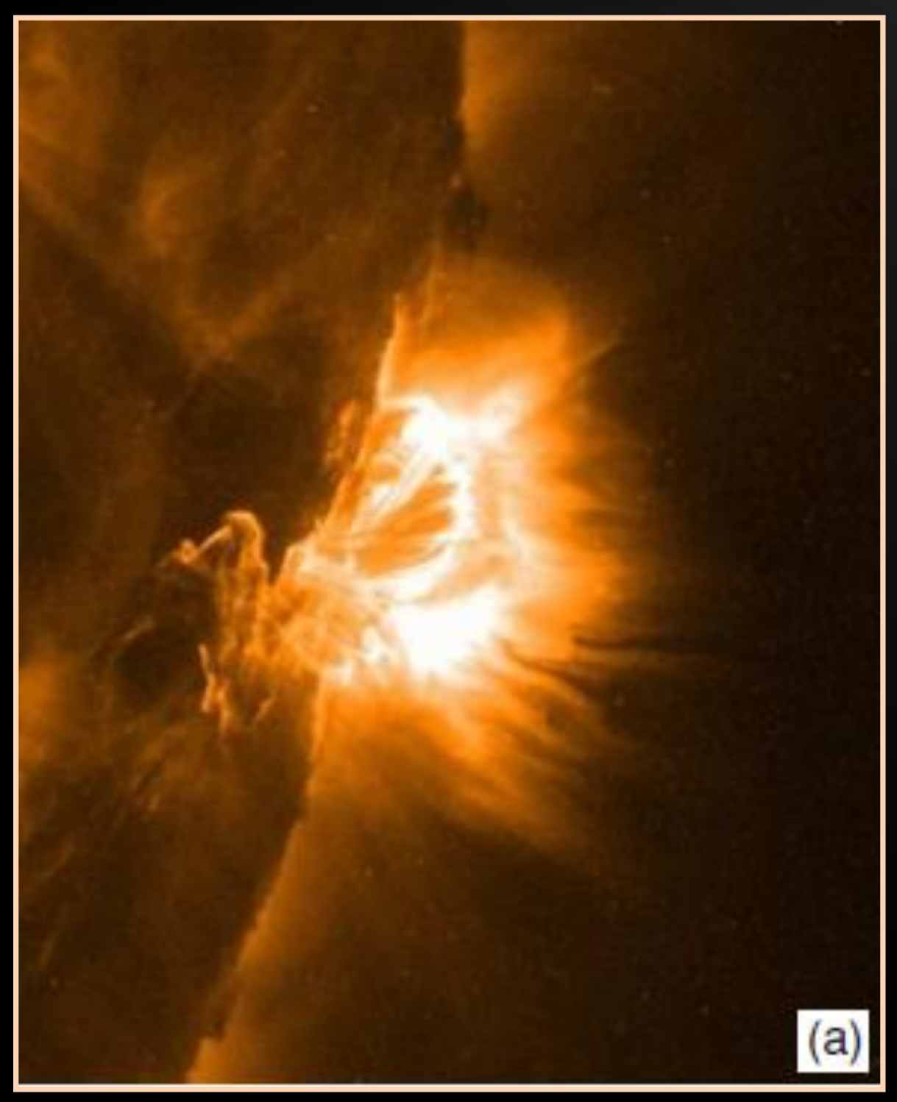

Figure 1: SADs X-ray detection by TRACE during the famous flare of 2002 April 21. (Image taken from the job of McKenzie & Savage 2009 [ApJ, 697, 1569]).

2 - Methodology

We carried out a 3D MHD simulation with the FLASH code (*developed by the Flash Center of Computational Science*). The calculation was performed in a uniform grid of $(x, y, z) = (170,340,85)$ cells and a physical size of $(10,20,5)\,Mm$. The coordinate y represent the radial sunward direction. We employed outflow boundary conditions, except for a reflective upper radial direction to emulate the action of higher reconnection site.

The initial condition intends to emulate an non-homogeneous media previously distorted by the passage of earlier SADs. Therefore, we chose a radial magnetic field, a density profile of the form $\rho = \rho_0 \sin(ax)\sin(bz) + \rho_1$ and a uniform temperature of $T = 5 \times 10^6\ K$. Also, we assumed a steady state (P_{total}=P_{gas}+ $P_{magnetic}$=cte) then perturbed, at the beginning and a later time, by pressure pulses of ΔP/P ~ 40 and radii of ~ 0.6 Mm.

3 - Results & discussion

Fig. 2-A shows a density slice of the $z = 0$ plane at a time of $t = 150\,seg.$ for a configuration with three initial pressure pulses. Furthermore, to analyze if the subdense features seen in Fig. 2-A are compatible with a SAD description we integrated along the line of sight direction (x), considering a plasma width of $3\,Mm$, to evaluate the emission measure (EM) as:

$$EM = \int n^2 dx \ \ ;\ being\ n\ the\ numerical\ density.$$

Fig. 2-B shows the EM view. Comparing with observations Fig. 2-A, reasonably reproduces the falling time, the slow down speeds and the estimated densities, although it suffers the lack of enough wavy appearance. In Fig. 2-B we show the obtained EM where a contrast factor of ~ 4, between the subdense cavities and the background medium, makes the simulated features compatible with SAD observations.

In Fig. 2-C we show the obtained almost homogeneous total pressure between SADs and their surroundings. Thus these subdense cavities have larger temperatures avoiding to be immediately filled-in by the surrounding plasma for times comparable with observations.

We have reproduced the background distortion in terms of propagation of shock and expansion waves driven by reconnection processes.

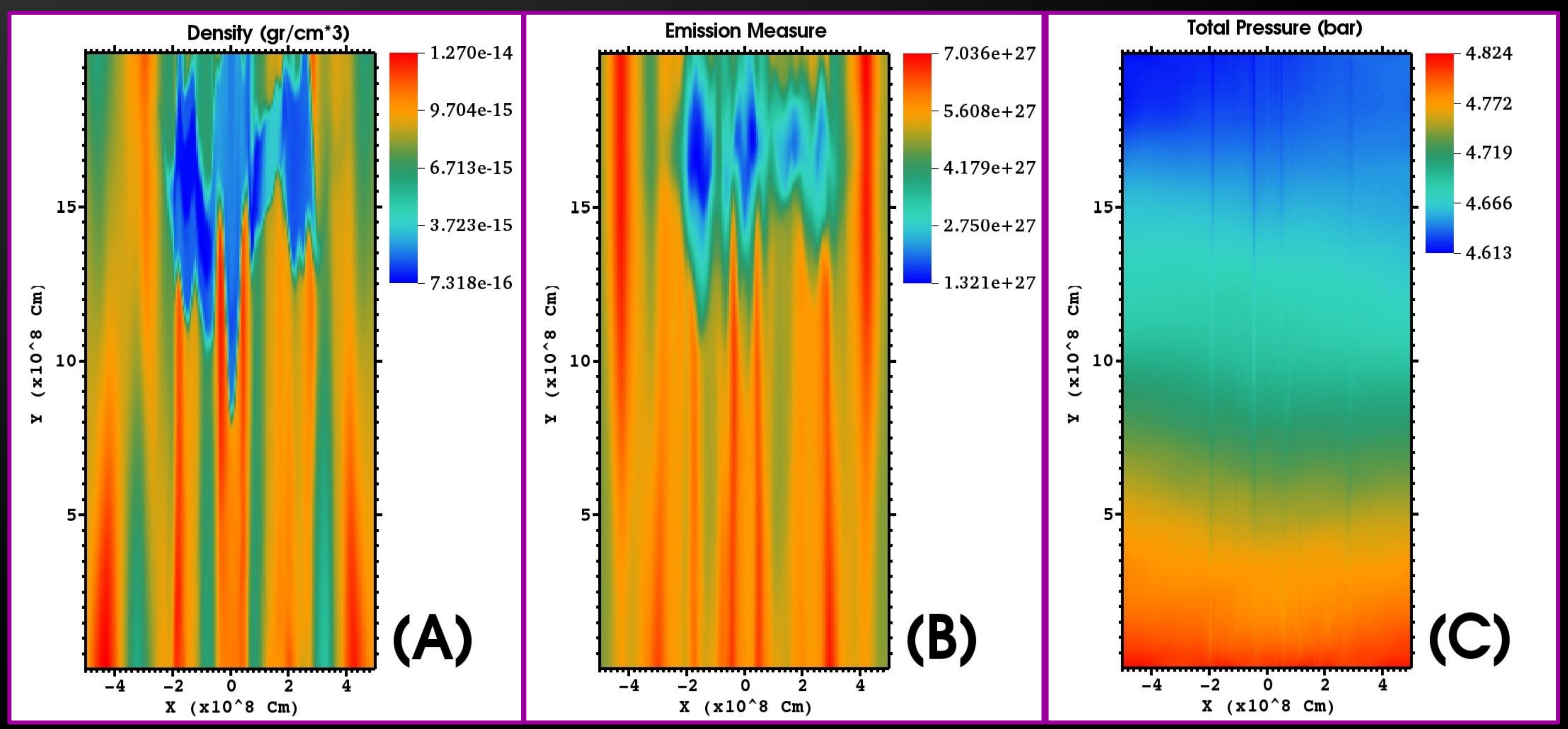

Figure 2: (A) Density voids and shock waves pattern for a slice at $z = 0$; (B) EM pattern showing a nice contrast between the subdense cavities and the background medium; (C) Total pressure slice at $z = 0$, note is almost homogeneous.