Oscillatory Reconnection of a 2D magnetic X-point in hot coronal plasma

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Abstract

Oscillatory Reconnection is a fundamental relaxation mechanism, characterised by changes in magnetic connectivity, the oscillatory nature of which requires no external periodic driving force to be sustained. This process has been one of the proposed mechanisms behind phenomena, such as quasi-periodic pulsations (QPPs). Its manifestation through the interaction of the ubiquitous waves with null points in the solar atmosphere opens the possibility of utilizing oscillatory reconnection as a tool for coronal seismology. We will be presenting the results from a series of parameter studies of a 2D X-point in coronal conditions, which we have performed with the PLUTO code. We report on the independence of the oscillation period from the type and strength of the wave pulse, initially perturbing the null. We will also discuss the effects that the equilibrium magnetic field profile, density and temperature distribution, and anisotropic thermal conduction have on the resulting periodicity and decay rate of oscillatory reconnection. This will offer a better understanding this energy release process and allows us to formulate an empirical formula connecting the previous quantities, opening the way in using oscillatory reconnection for coronal seismology.

I. Introduction

Oscillatory Reconnection (O.R.):

- Plasma relaxation mechanism.
- Periodic changes in magnetic connectivity of an X-point.
- Possible driver of quasi-periodic pulsations (for a review, Zimovets, McLaughlin et al. 2021) .

Aims of current study:

- We aim to create a plasma diagnostic tool based on Oscillatory Reconnection, that can be used for coronal seismology.

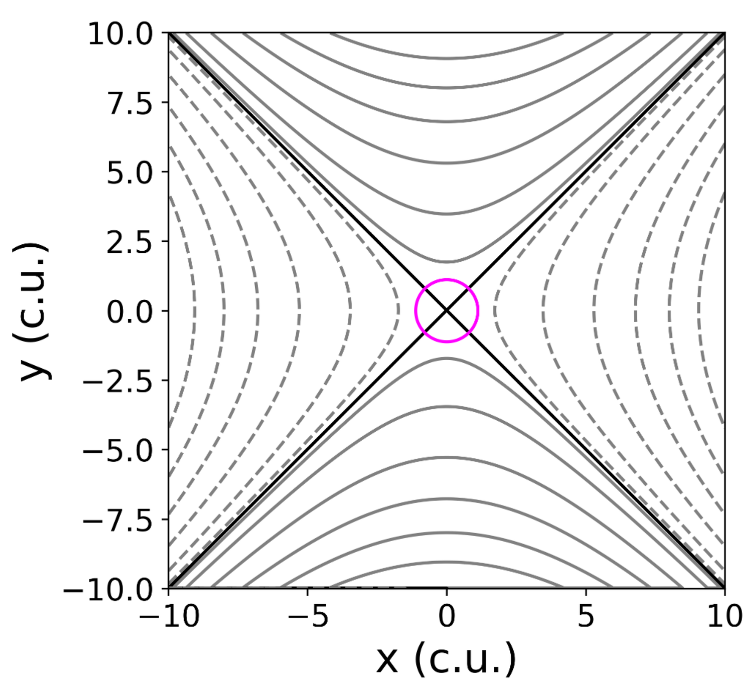

Figure 1. Equilibrium 2D magnetic X-point with the separatrices (black lines) and the equipartition (magenta) for a 1 MK plasma.

II. Numerical model

From Karampelas et al. (2022a,b; 2023):

- 2D compressible and resistive ($R_m = 10^5$) MHD equations solved with the PLUTO code (Mignone et al. 2007).
- Uniform grid with 1801^2 cells and reflective boundaries.
- Magnetic field $\vec{B} = B_0\{y, x, 0\}/L$.
- Initial velocity pulse(s) (a) perpendicular to the magnetic field (*'Ring driver'*) and (b) along the y-axis (*'Pinch driver'*).
- Anisotropic thermal conduction

III. Results

1. Initiating the Oscillatory Reconnection (O.R.):

- We initiate O.R. at the X-point via a velocity pulse (Fig. 2).
- O.R. manifests in hot plasma, in the presence of thermal conduction (Karampelas et al. 2022a).
- As in McLaughlin et al. (2009), horizontal and vertical current sheets are associated with negative and positive values of the j_z current density (Fig. 2 and 3).
- Wavelet analysis reveals the period of the oscillating current density.
- Thermal conduction leads to larger oscillation periods (Karampelas et al. 2022b).
- Parameter studies using the *Ring driver*.

References

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   - 2022b, ApJ, 933, 142, doi: 10.3847/1538-4357/ac746a
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2. McLaughlin, J. A., De Moortel, I., Hood, A. W., & Brady, C. S. 2009, A&A, 493, 227, doi: 10.1051/0004-6361:200810465
3. Mignone, A., Bodo, G., Massaglia, S., et al. 2007, ApJS, 170, 228, doi: 10.1086/513316
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III. Results

2. Empirical formulas – Plasma diagnostic tool:

- Independence of period from initial velocity pulse (Karampelas et al. 2022b, Fig. 4a).
- Empirical relation between the background magnetic field (B, in G), density (ρ, in $kg\, m^{-3}$), temperature (T, in MK) and the period (P, in s) of O.R. (Karampelas et al. 2023, see also Fig. 4b,c,d):

$$P = \frac{35.39}{B} + 25.74 \cdot 10^6\sqrt{\rho} + \frac{7.94}{\sqrt{T}} - 27.55 \pm 3.38$$

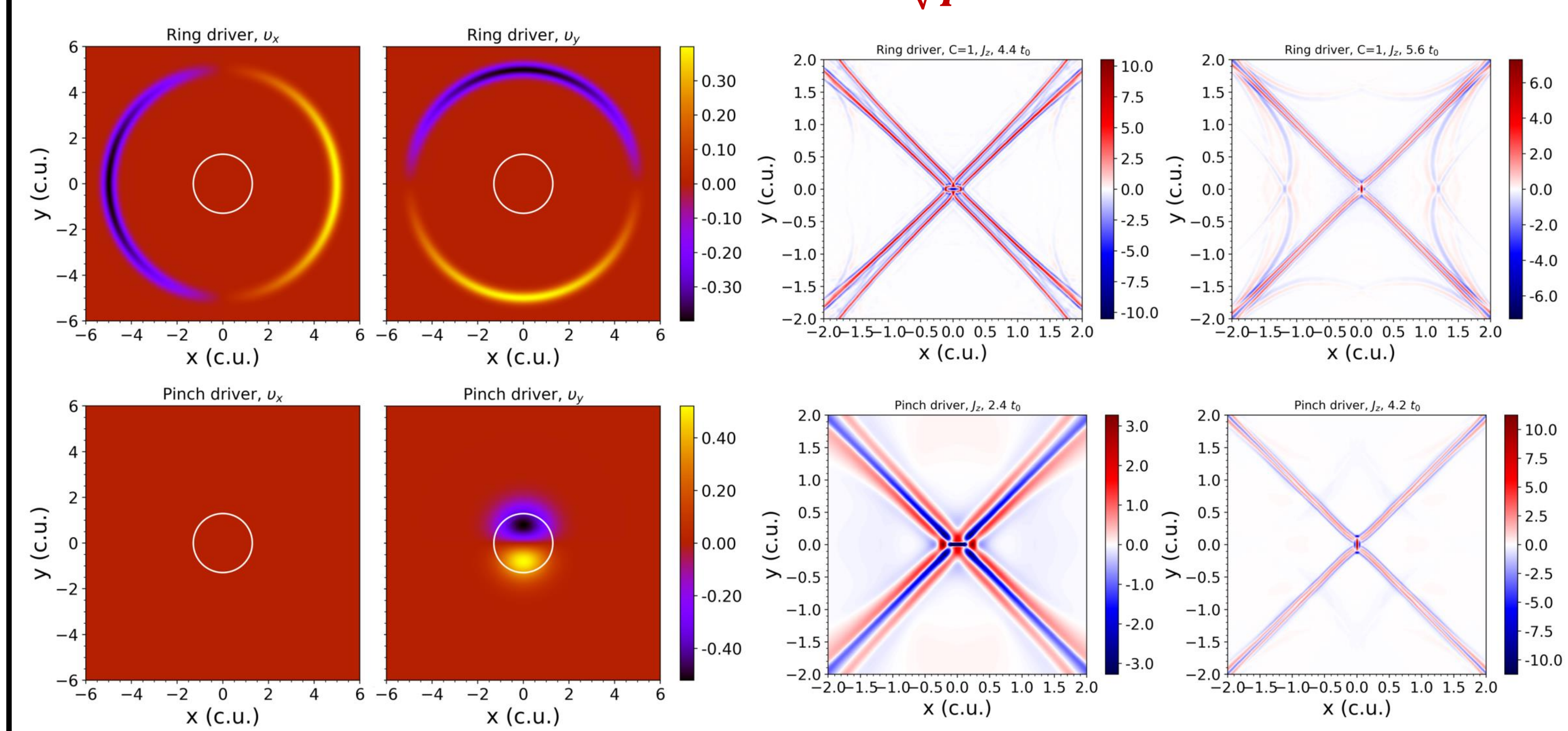

Figure 2. Left panels: velocity components of the initial pulses. Right panels: current density (J_z) near the at the null point, for the two different cases.

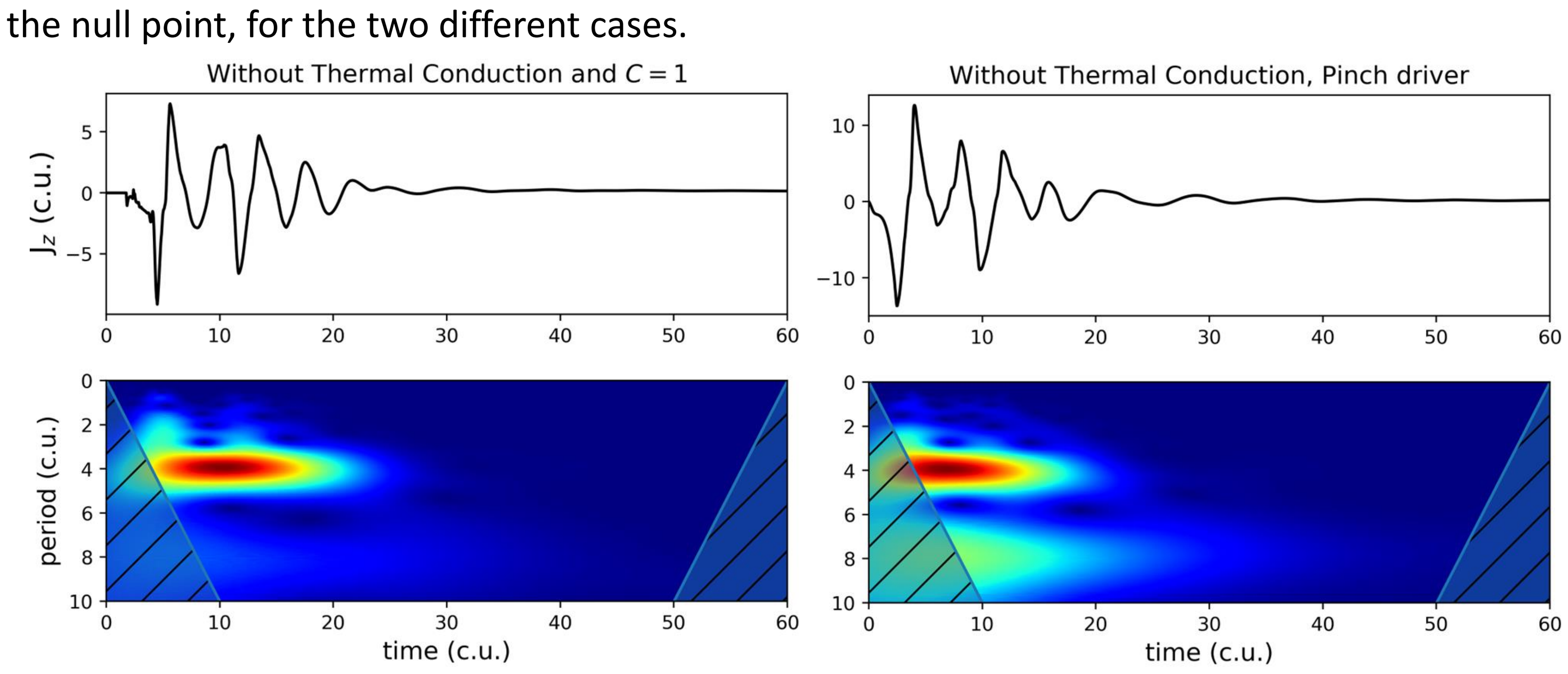

Figure 3. Top panels: current density (J_z) oscillation signal at the null point, for cases with two different drivers. Bottom panels: wavelet spectra of the J_z signal.

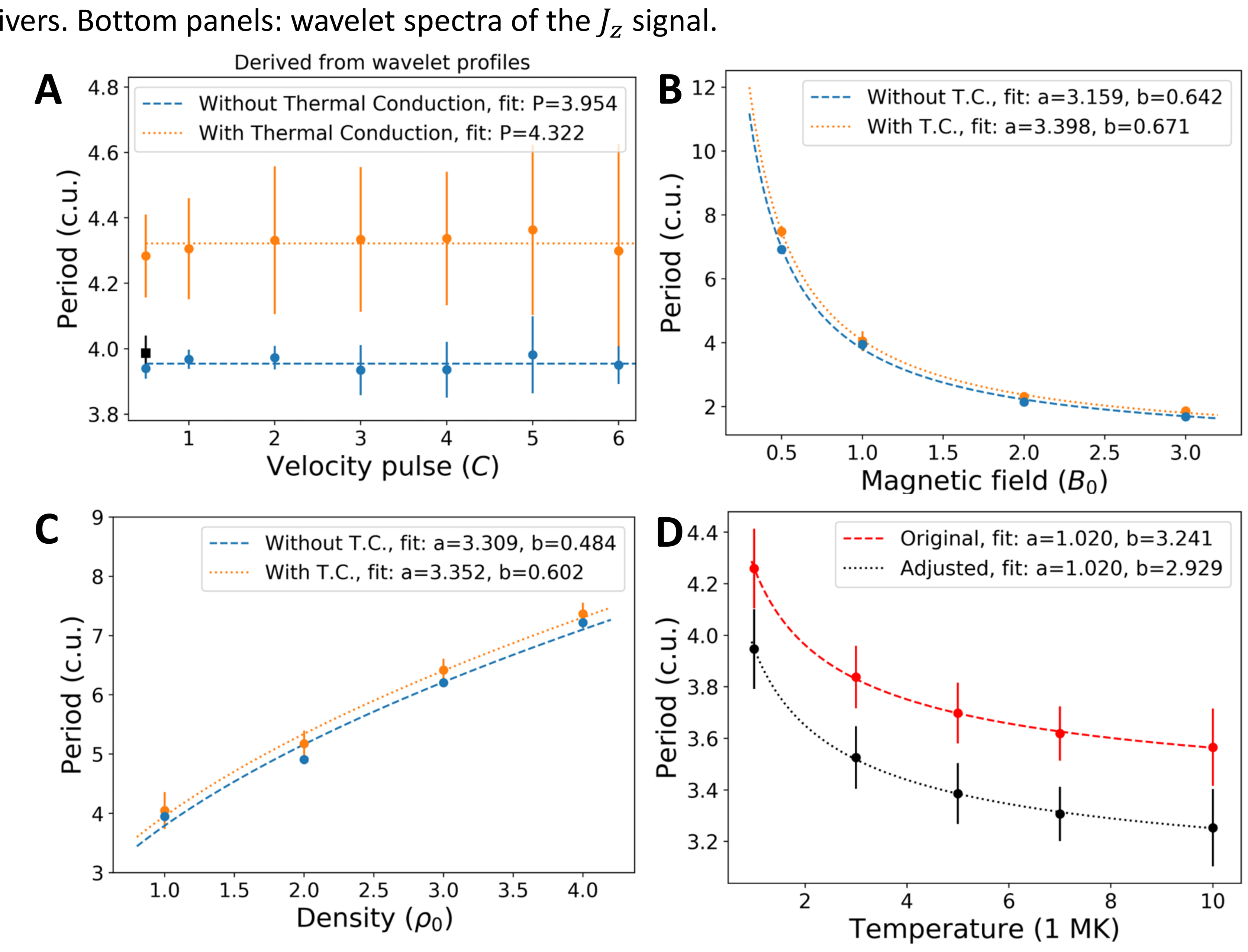

Figure 4. Plots of the period vs the initial velocity pulse strength (panel a), magnetic field (panel b), density (panel c) and temperature (panel d). All plots are shown in code units.