Waves Produced by Merging Magnetic Solar Flux Ropes

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Introduction

What is a Solar Flare?

Solar flares can be defined as the sudden and intense emission of electromagnetic radiation emitted from the solar atmosphere. This process is characterised by the conversion of stored magnetic energy in complex magnetic structures to kinetic and thermal energy through a process known as magnetic reconnection [1].

Research Motivation:

Short-lived temporary periodic oscillations, known as quasi-periodic pulsations (QPPs) are frequently observed in solar flare emissions [2]. An example of a QPP observed in 2014 by Lyra is shown in Figure 1.

Understanding the origin of QPPs and their relation to magnetic reconnection can help develop diagnostic tools that can be used to investigate the conditions inside the solar flare.

Modelling Magnetic Reconnection:

Some solar flares occur when plasma loops in the solar corona interact and undergo magnetic reconnection. QPPs are believed to be generated during this process [2]. This scenario can be modelled as the merging of two twisted magnetic flux ropes.

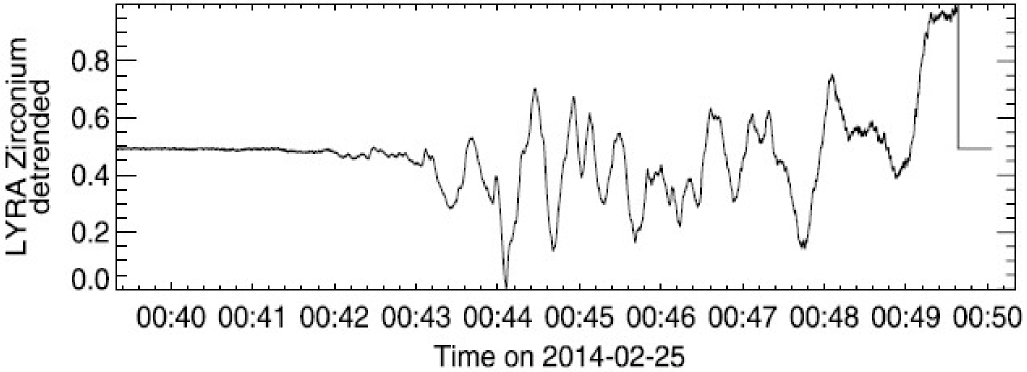

Figure 1: *Detrended flare time series for a QPP, observed in X-Ray radiation, detected by Lyra on 25 February 2014, over a period of 50s. Image taken from [2].*

What This Poster Presents:

This poster discusses simulations performed on two magnetic flux ropes merging and undergoing magnetic reconnection. The aim of these simulations were to study the resulting oscillatory behaviour.

During the merging process, waves were emitted away from the reconnection site. The behaviour of these waves are discussed in this poster.

Two Flux Ropes Merging

Two-dimensional resistive magnetohydrodynamic simulations were performed on two cylindrical magnetic flux ropes, with constant out-of-plane magnetic field, undergoing magnetic reconnection. The model used for the flux ropes was based on similar work by Stanier et al [3]. Simulations were performed using LARE2D code [4].

Two flux ropes start in a position of near equilibrium, distance ± h away from the origin along the y-axis. The Lorentz force attracts the two flux ropes together. The flux ropes merge via the process of magnetic reconnection forming a single flux rope. This process is shown in Figure 2.

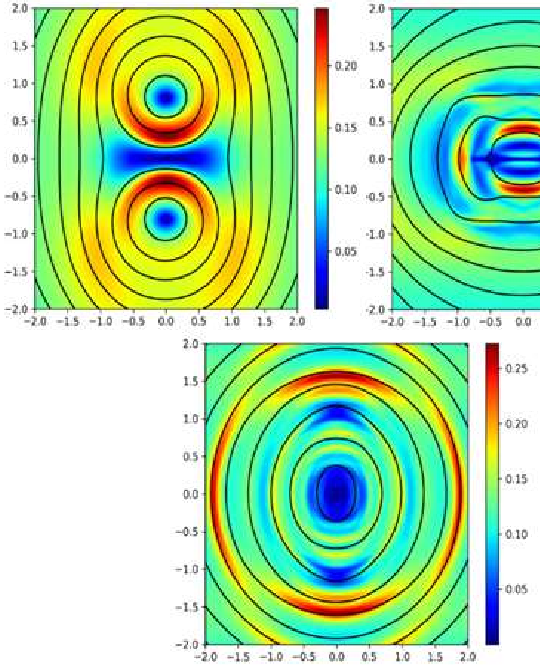

Figure 2: *Contour maps of the in-plane magnetic field taken at simulation time t = 8 (left), t = 18 (middle), t = 100 (right).*

Oscillatory Reconnection

The two cylindrical flux ropes merge together into a single flux rope.

During this process, the magnetic field oscillates. The field cycles between reconnecting along the horizontal and vertical axis. The magnitude of these oscillations decreases over time. One full oscillation cycle is shown in Figure 3.

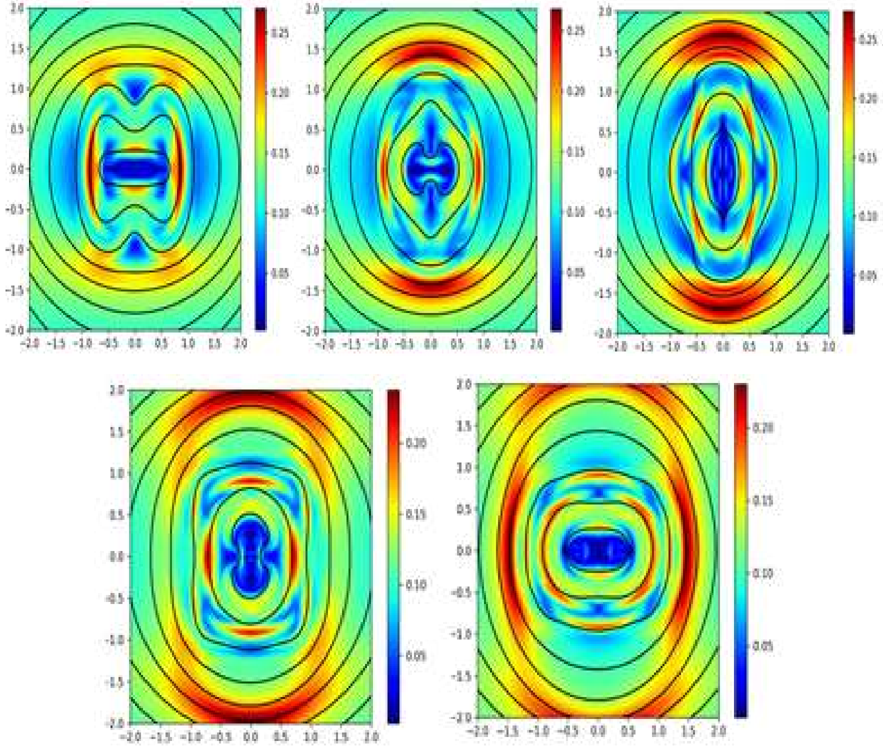

Figure 3: *Contour plot of the in-plane magnetic field at t = 28 (top-left), t = 31 (top-middle), t = 35 (top-right), t = 41 (bottom-left), t = 45 (bottom-right).*

Wave Propagation

During oscillatory reconnection, waves emit radially outwards from the reconnection site. The waves have a quadrupolar structure. These waves are shown in Figure 4.

The nature of these waves are currently being investigated.

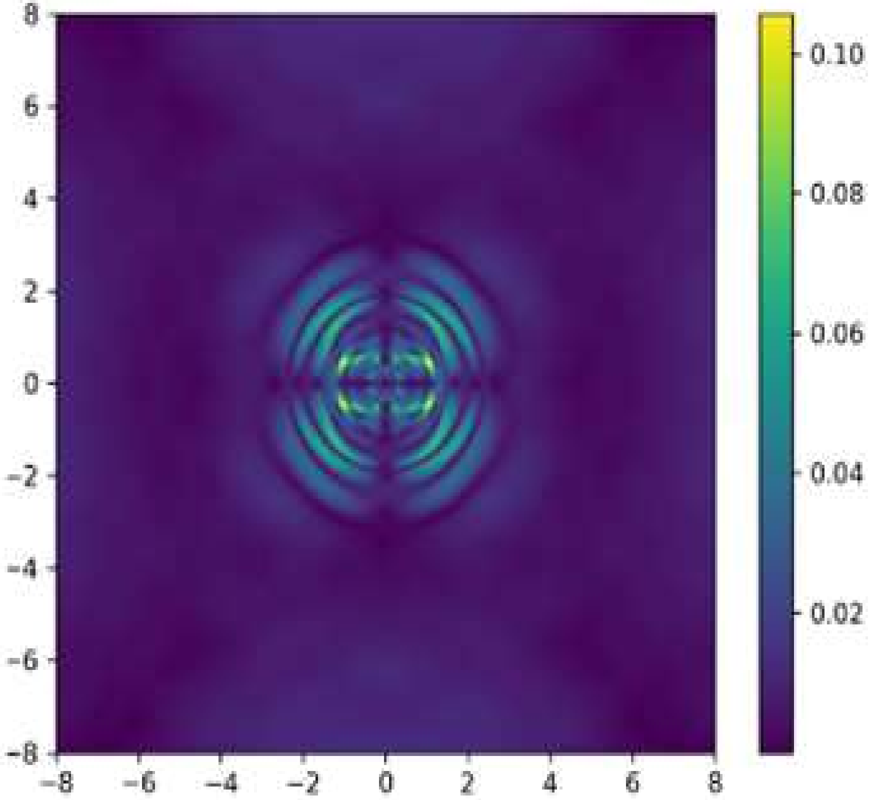

Figure 4: *Contour map of the total velocity, plotted for the whole system at t = 80.*

Propagation Speed

The propagation speed of the waves along the upper-right diagonal of the simulation was calculated. Figure 5, shows a distance-time plot of the propagating waves. The gradient of these waves can be used to calculate the propagation speed.

The propagation speed of the waves was found to be of order $0.1V_A$, (where V_A is the Alfvén speed). This is suggestive of slow waves propagating almost transverse to the magnetic field.

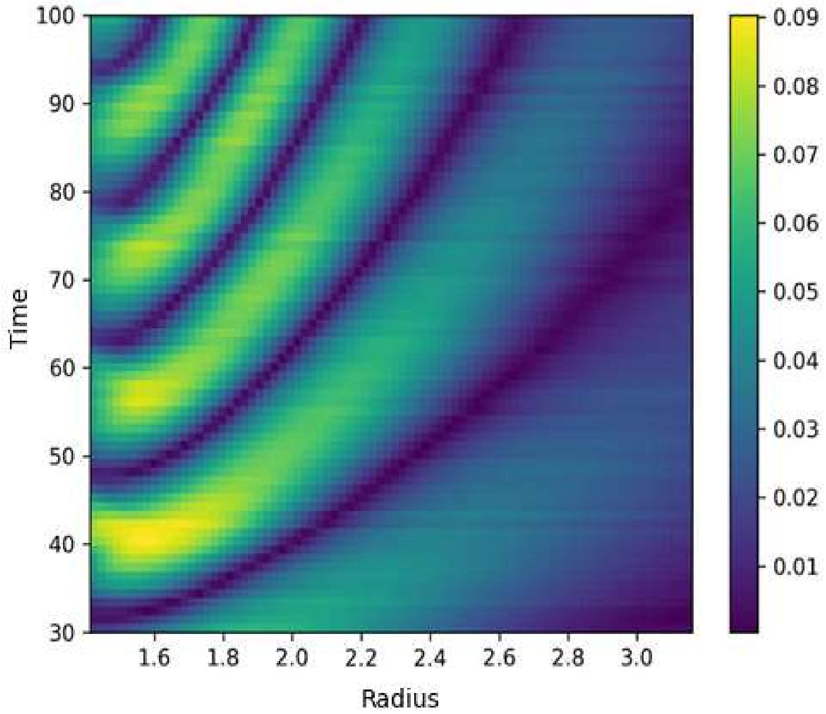

Figure 5: *Magnitude of the velocity of the waves plotted in respect to distance from the origin, and time.*

Parallel and Perpendicular Motion

The velocity parallel and perpendicular to the total magnetic field was calculated. This is shown in Figure 6.

The component parallel to the magnetic field is stronger than the component perpendicular to the magnetic field. This shows that although the waves propagate radially outwards, most of the motion in the waves occurs along the magnetic field lines. This is not behaviour associated with slow waves.

This behaviour indicates that the waves may behave as combination of known wave modes.

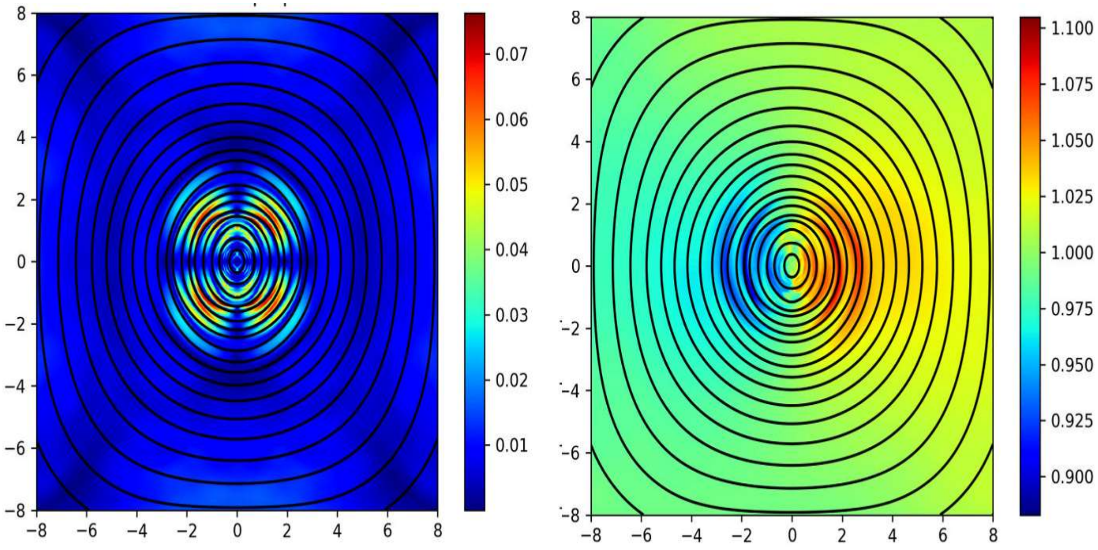

Figure 6: *Contour plot of the total velocity perpendicular (left) and parallel (right) to the total magnetic field, taken at t = 100*

Conclusion

This poster discussed the waves emission from simulations of two cylindrical magnetic flux ropes undergoing magnetic reconnection.

These wave's propagation speed is suggestive of slow waves propagating almost transverse to the magnetic field.

However, most of the motion of waves is parallel to the cylindrical magnetic field, which is not behaviour associated with slow waves. This indicates that the waves may be a combination of currently known wave modes.

References

[1] Priest, E. (2014). “Magnetic Reconnection”. In: *Magnetohydrodynamics of the Sun*. Cambridge University Press. Chap. 2.

[2] McLaughlin, J.A. et al. (2018). “Modelling Quasi-Periodic Pulsations in Solar and Stellar Flares”. In: *Space Science Review* 214.

[3] Stanier, A. et al. (2013). “Two-fluid simulations of driven reconnection in the Mega-Ampere Spherical Tokamak”. In: *Physics of Plasmas* 20.

[4] Arber, T. *LAREXD User Guide*. English. Version 4.0. University of Warwick. 26 pp.