A simulation of a coupled pseudostreamer/helmet streamer eruption

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Abstract

An important aspect in the early evolution of a coronal mass ejection (CME) is its interaction with the magnetic field in the low corona on its way to the heliosphere. This interaction can influence the trajectory and morphology of the eruption, so a better understanding of this field/eruption coupling could lead to better constraints on the inputs into Space Weather forecasting models. Here we report on a simulation of a CME with a complex evolution in the low corona. The CME originates from the eruption of a filament channel formed beneath a pseudostreamer. The eruption interacts with both the pseudostreamer and an adjacent helmet streamer producing a coupled eruption involving both structures. As a result, the CME produced is strongly deflected and contains a mixture of open and closed magnetic flux. Our simulation covers the full length of the eruption process, from formation of the filament channel to propagation of the CME out to 30 solar radii, allowing an in-depth look at the how the CME forms and evolves. This work demonstrates the importance of the global coronal magnetic field in the formation process of some CMEs.

Observations

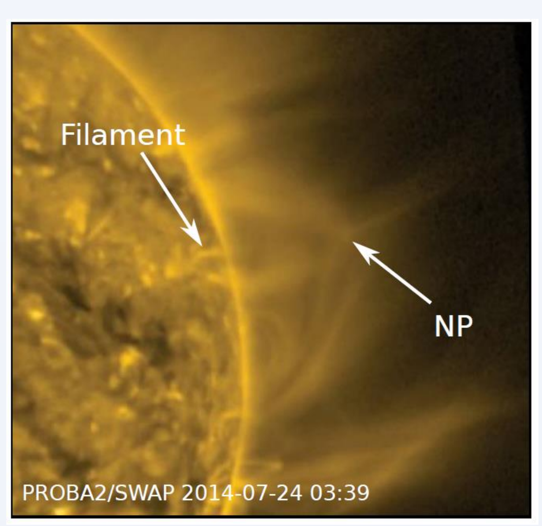


Figure 1: A typical example of a pseudostreamer observed on the limb, showing the classic double arcade structure and apparent null point between two coronal holes. In this example the northern arcade also harbours a filament channel.

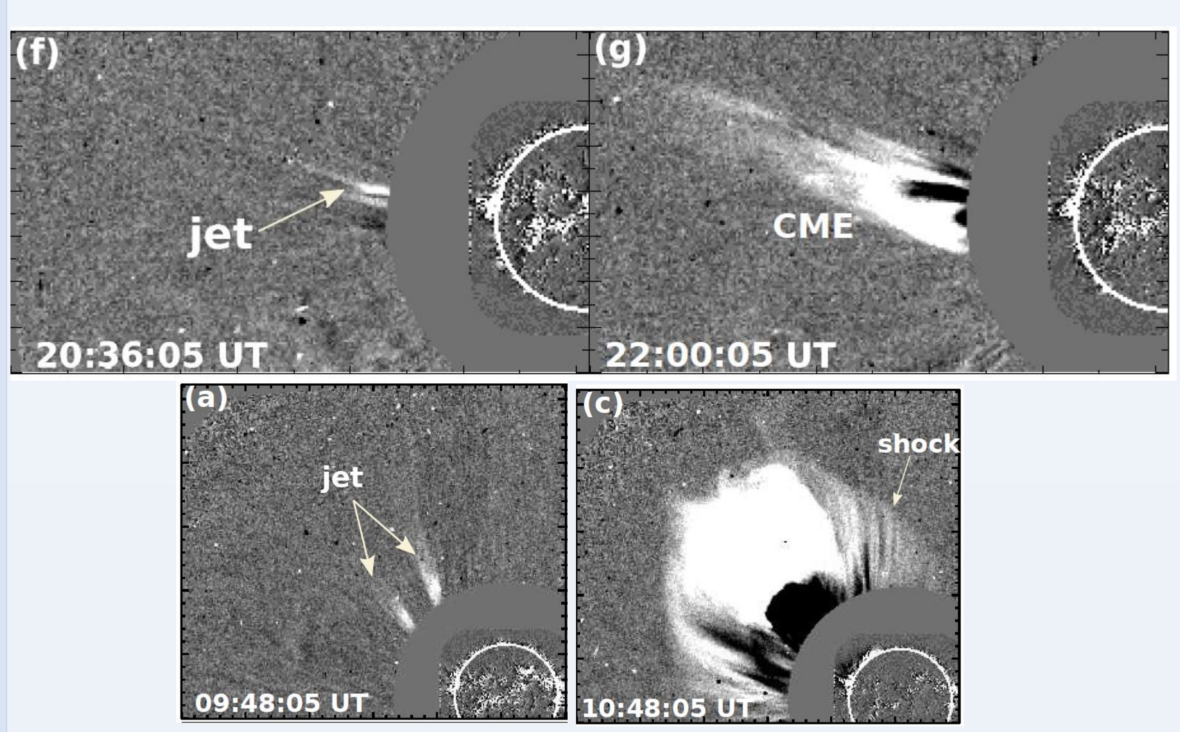


Figure 2: Examples of CMEs resulting from pseudostreamer filament channel eruptions. Both are preceded by a narrow jet (left panels). However, one forms a narrow jet-like CME (top), whilst the other takes on a more typical bubble-like shape and has a clear shock front (bottom). This is a general feature of these events: some have narrow jet-like CMEs and others bubble-like CMEs. From Kumar et al. 2021.

Simulation: Initial Condition

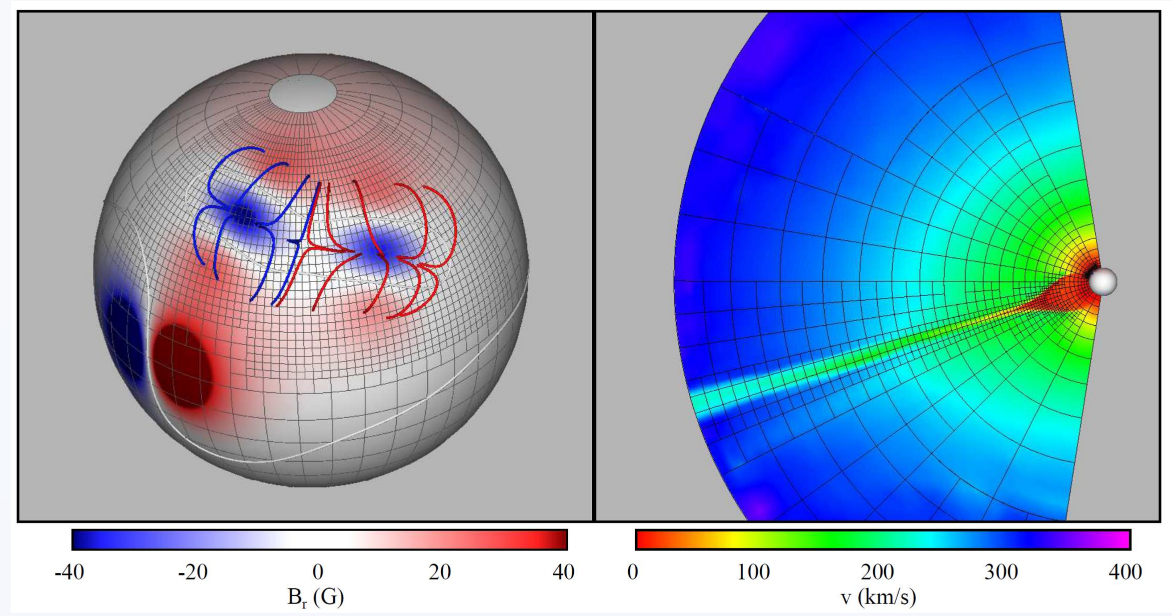


Figure 3: To study the nature of pseudostreamer eruptions we consider an idealized 3D simulation. The simulation is initialised with a PFSS solution constructed from sub-surface magnetic dipoles to which a 1D Parker wind solution is superimposed. The system is then relaxed to an approximate force balance. Left: field lines outlining the pseudostreamer. Right: side view of the helmet streamer and the adaptive grid blocks in the relaxed state.

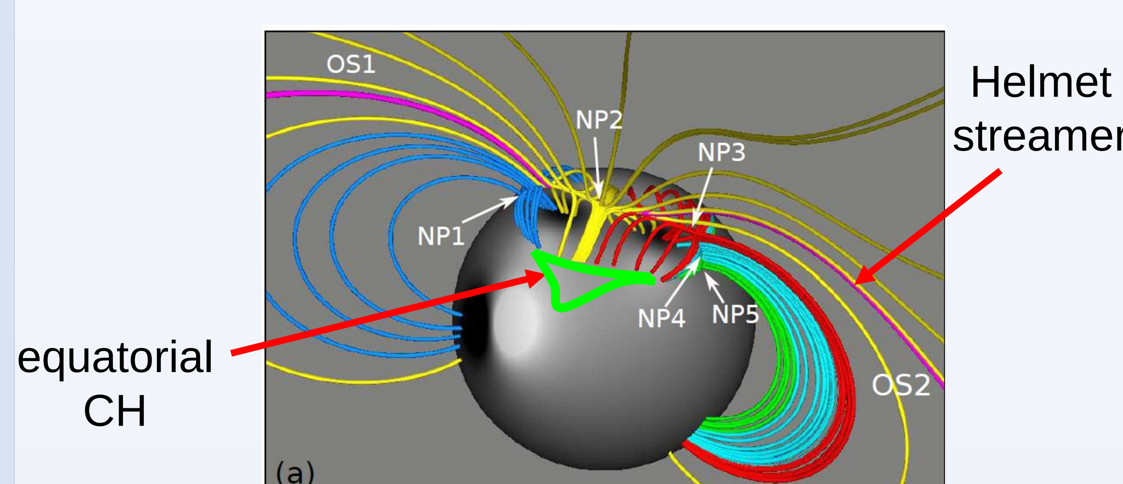
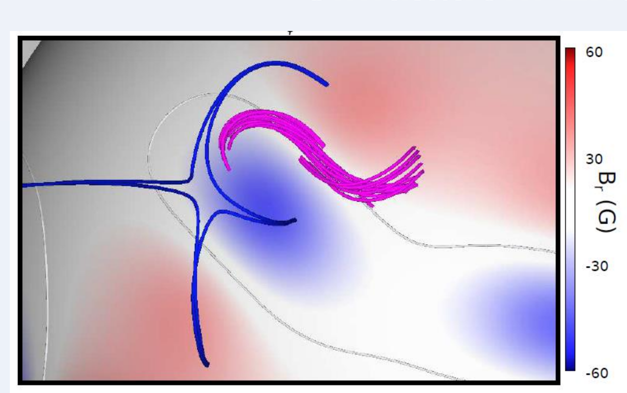


Figure 4: The magnetic topology of the pseudostreamer in the relaxed state is relatively complex; consisting of multiple null points, separators and connections to adjacent helmet streamers. Such complex source topologies are often observed, particularly when the pseudostreamer is formed by a decaying active region (e.g. Titov et al. 2012).

Simulation: Energisation



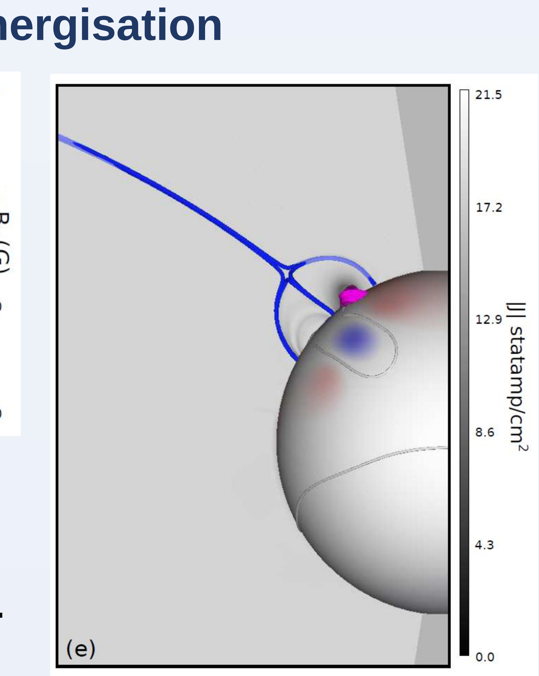
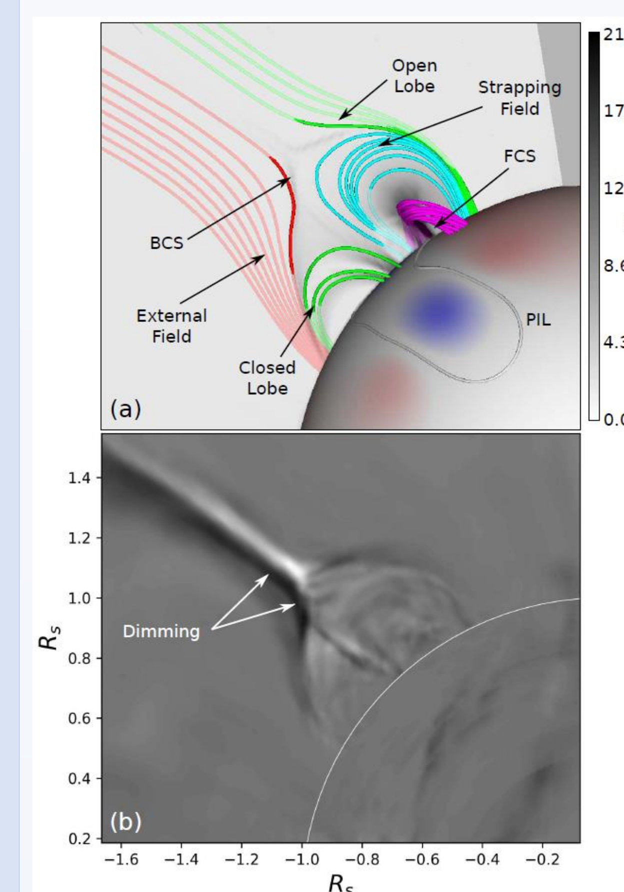
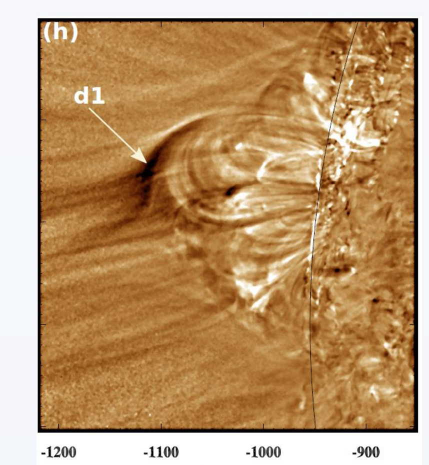


Figure 5: Slow surface motions were used to form a filament channel over ~30hrs. The magnetic field evolves quasi-statically and so has time to react to the applied stress. The filament channel is therefore not over energised and erupts self consistently; at the point at which the system can no longer support it.

Low Coronal Evolution

Figure 6: The eruption is triggered when runaway breakout reconnection begins at the breakout current sheet (BCS) formed at null NP1. This creates a dimming region in synthetic EUV images (bottom left) in agreement with the pre-eruption dimming regions noted in observations by Kumar et al. 2021 (right).





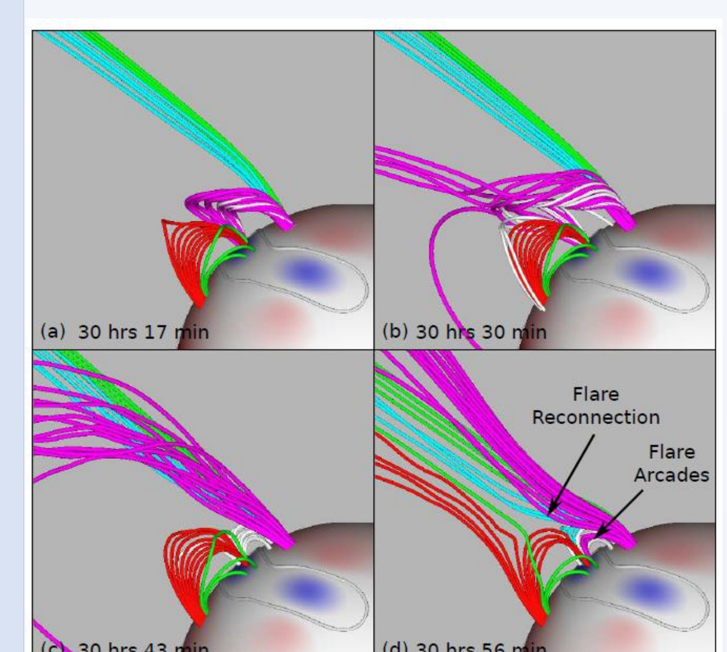


Figure 7: Continued breakout reconnection leads to the eventual reconnection of the erupting flux rope (pink), opening it at one end, exactly analogous to mini-filament eruptions in coronal jets (Wyper et al. 2017, 2018).

Coupling to the Helmet streamer

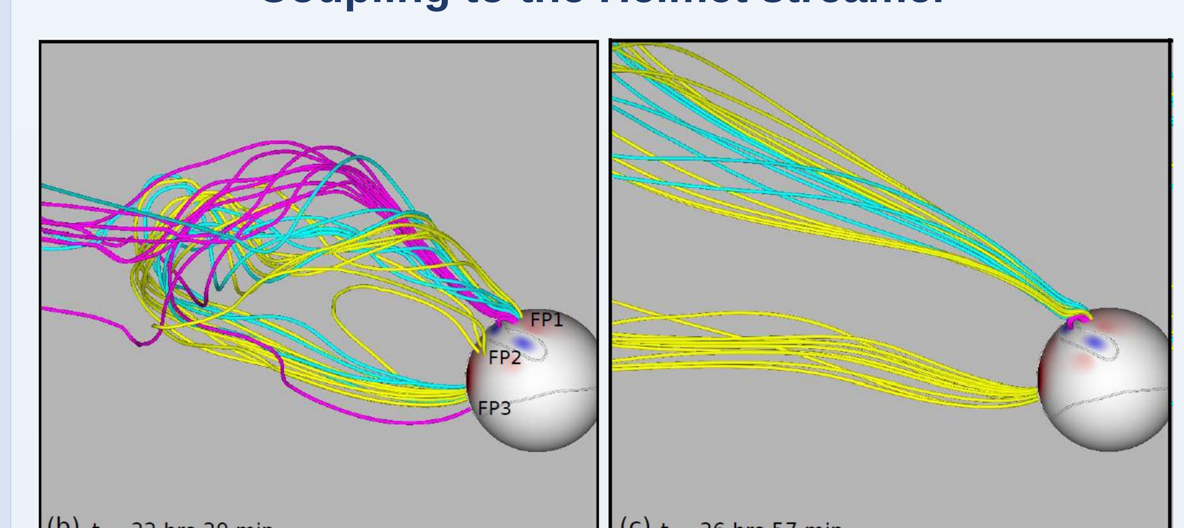


Figure 8: The breakout reconnection that launches the jet sucks in nearby helmet streamer flux. As a result, the jet is launched partially along open field lines and partially along closed helmet streamer field lines (left panel). This coupling blows out the top of the helmet streamer which takes off as part of the CME (right panel). The helmet streamer reforms in the wake of the CME in a similar manner to blowout/stealth CMEs (e.g. Lynch et al. 2016).

CME

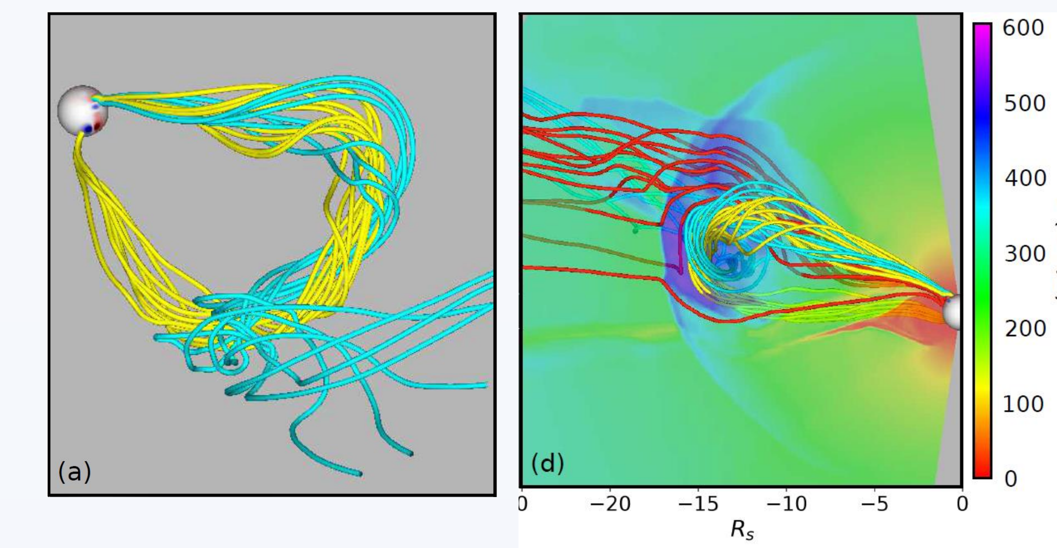


Figure 9: The resulting CME is a mixture of open & closed field lines and is broadly bubble-shaped despite its jet-like form in the low corona.

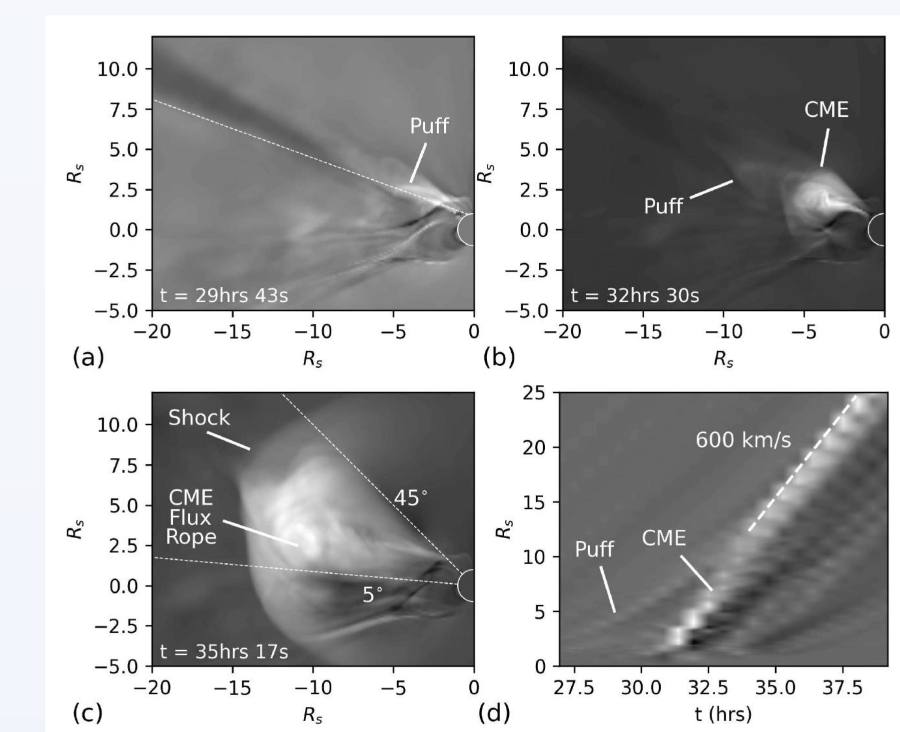


Figure 10: Synthetic white light images show the CME is preceded by a puff/jet caused by the pre-eruption breakout reconnection (as in Fig. 2), the CME is strongly deflected (by around 40 degrees) from its initial trajectory (since the initial jet follows field lines in the low corona), and that it has a broad bubble-like shape. The J-map shows this CME reaches a moderate speed of 600 km/s.

Conclusions

- For the first time we have modelled the formation and eruption of a pseudostreamer filament channel in a realistically complex and 3D magnetic environment.
- Breakout reconnection is strongly involved in these events as suggested by observational signatures of dimming and pre-CME white light puffs/jets which we also find in our model.
- Our model also shows that coupling with the helmet streamer strongly deflects these CMEs and changes their internal structure and morphology.
- Understanding this coupling with the global field is therefore a key aspect of predicting the direction and morphology of the CMEs produced by these events.

References

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- Titov et al. 2012, ApJ, 759, 70
- Wyper et al. 2017, Nature, 544, 452
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