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Observing three-dimensional magnetic reconnection in solar flares

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Solar flares and magnetic reconnection

- Flares: sudden releases of magnetic energy in the atmosphere of the Sun
- Confined and eruptive flares
- Magnetic reconnection: change of connectivity to reach a lower-energetic state
- Standard flare model in 3D: build-up and eruption of a magnetic flux rope Aulanier et al. 2012, 2013, Janvier et al. 2013



2012 April 16 eruption observed in channels of SDO/AIA. © Miloslav Druckmüller.



Magnetic reconnection geometries in 3D

- Aulanier & Dudík 2019: three reconnection geometries in the simulated eruption
- Newly-reported 'ar-rf' geometry:



A sequence of the magnetic ar-rf reconnection. From Aulanier & Dudík 2019.

- Occurs at J-shaped extremities (hooks) of solar flare ribbons
- Causes drifting of flux rope's footpoints across the solar surface

Filament strands reconnecting to flare loops

Lörinčík et al. 2019: SDO analysis of the 2012 August 31 filament eruption

- 1. Eruption begins, flare ribbon hook forms and starts to drift
- 2. Hook sweeps footpoints **O** of filament strands visible in SDO/AIA 171 Å, strands disappear



 Flare loops visible in SDO/AIA 94 Å start to form. Their footpoints O correspond to those of the swept filament strands



Expansion of a core dimming region

Lörinčík et al. 2021a: ar-rf reconnection during the 2015 April 28 filament eruption

1. Eruption starts, CME footpoints **O** drift along ribbon hook encircling core dimming region



2. Footpoints of quiet-Sun canopies 🛇 become a part of the expanding dimming region





3. Formation of flare loops with footpoints O corresponding to those of the CME

Saddle-shaped flare loop arcades



Saddle-shaped arcades of flare loops formed during selected well-known flares. From Lörinčík et al. 2021b.

- Lörinčík et al. 2021b: some arcades of flare loops show saddle-like morphology
- Related to longer and higher flare loops
 termed 'cantles' at edges of arcades
- Cantles rooted in ribbon hooks
- Formation of cantles can be addressed by the ar-rf reconnection geometry

Morphology of flare loop arcades provides information about the reconnection causing

their formation

Summary

- Standard flare model in 3D: a source of information about magnetic reconnection in 3D
- Newly-reported ar-rf reconnection between the erupting structure and overlying arcades
- Its manifestations in our EUV observations of flares and corona:
 - 1. Lörinčík et al. 2019: Conversion of filament strands to flare loops
 - 2. Lörinčík et al. 2021a: Spatial expansion of core dimming region
 - 3. Lörinčík et al. 2021b: Formation of saddle-shaped arcades of flare loops

3D reconnection is responsible for many observed phenomena

See also

- 1. Zemanová et al. 2019: Thorough observational analysis of drifting CME footpoints
- 2. Dudík et al. 2019: Complete evidence for the constituents of the ar-rf and rr-rf reconnection geometries

References

Aulanier et al. 2012, A&A, 543, A110, DOI: 10.1051/0004-6361/201219311 Aulanier et al. 2013, A&A, 549, A66, DOI: 10.1051/0004-6361/201220406. Aulanier & Dudík 2019, A&A, 621, A72, DOI: 10.1051/0004-6361/201834221 Dudík et al. 2019, ApJ, 887, 71, DOI: 10.3847/1538-4357/ab4f86 Janvier et al. 2013, A&A, 555, A77, DOI: 10.1051/0004-6361/201321164 Lörinčík et al. 2019, ApJ, 885, 83, DOI: 10.3847/1538-4357/ab4519 Lörinčík et al. 2021a, ApJ, 906, 62, DOI: 10.3847/1538-4357/abc8f6 Lörinčík et al. 2021b, ApJL, 909, L4, DOI: 10.3847/2041-8213/abe7f7 Zemanová et al. 2019, ApJ, 883, 96, DOI: 10.3847/1538-4357/ab3926