Probing Current Sheet Instabilities from Flare Ribbon Dynamics

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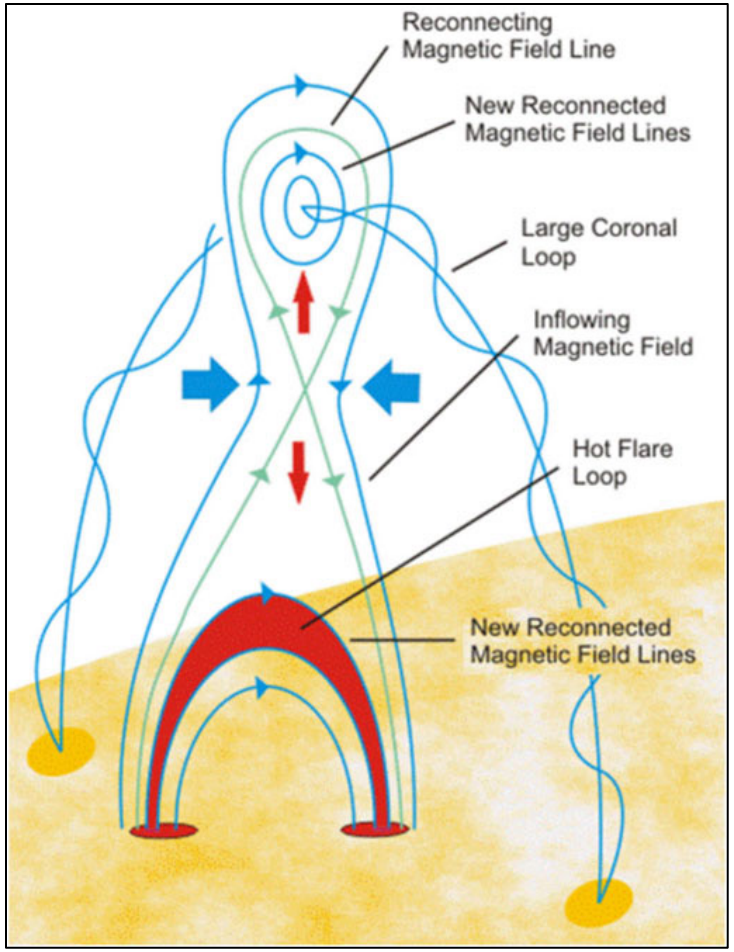
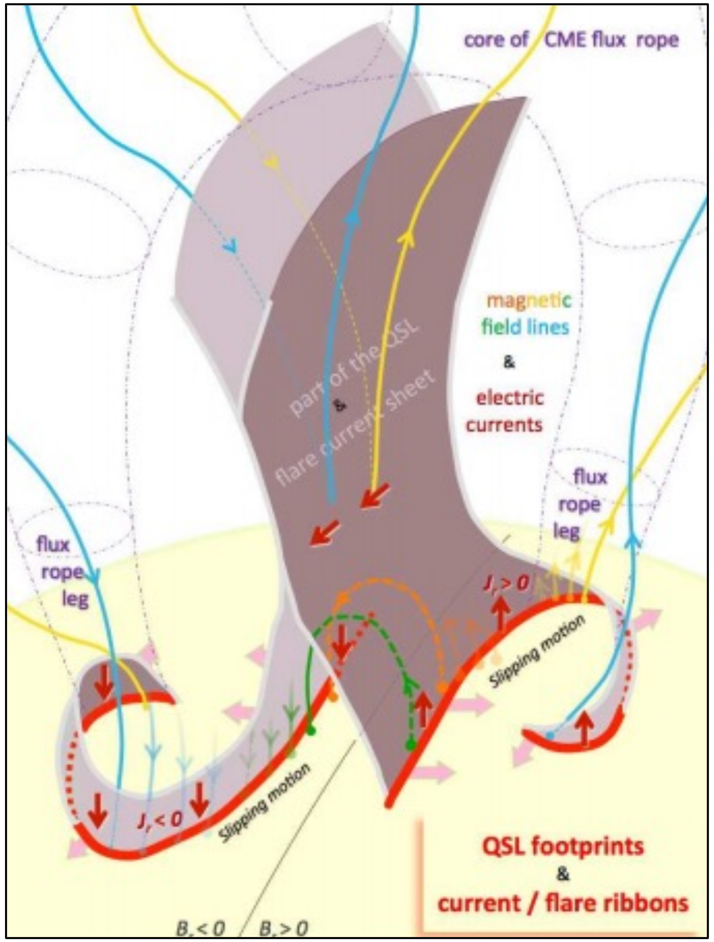
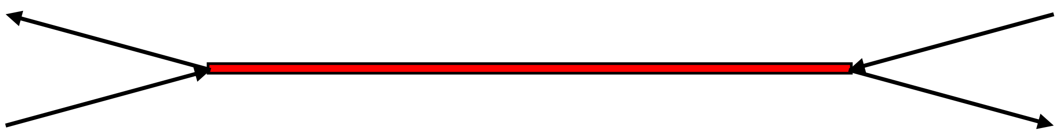
Magnetic Reconnection in Flares





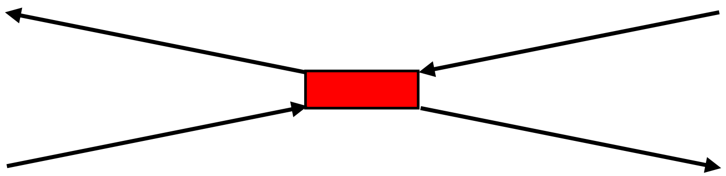
Janvier et al 2014

Key reconnection models



Sweet-Parker reconnection (1957)

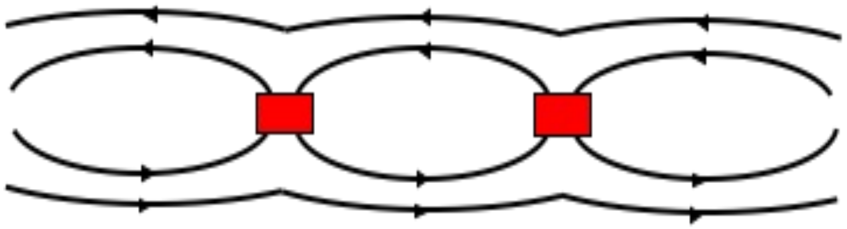
- Magnetic reconnection along an entire current sheet of oppositely orientated field lines.
- Energy release rate is far slower than that observed in flares.



Petschek reconnection (1964)

- Reconnection along a small fraction of the sheet, with a configuration sustained by slow shocks.
- It is unclear whether such a configuration can be sustained during a flare.

Key reconnection models



Tearing mode / plasmoid instability

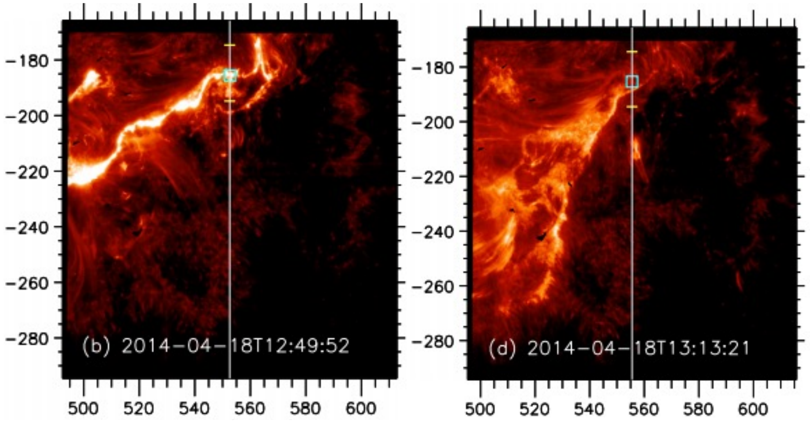
- If the sheet's length greatly exceeds its width, the current sheet collapses/reconnects in certain locations to produce plasmoids or 'magnetic islands'.
- These plasmoids continue to break down to progressively smaller scales in a turbulent cascade.
- Island coalescence can also form larger islands.

How do we search for the role of instabilities in elusive current sheet regions?

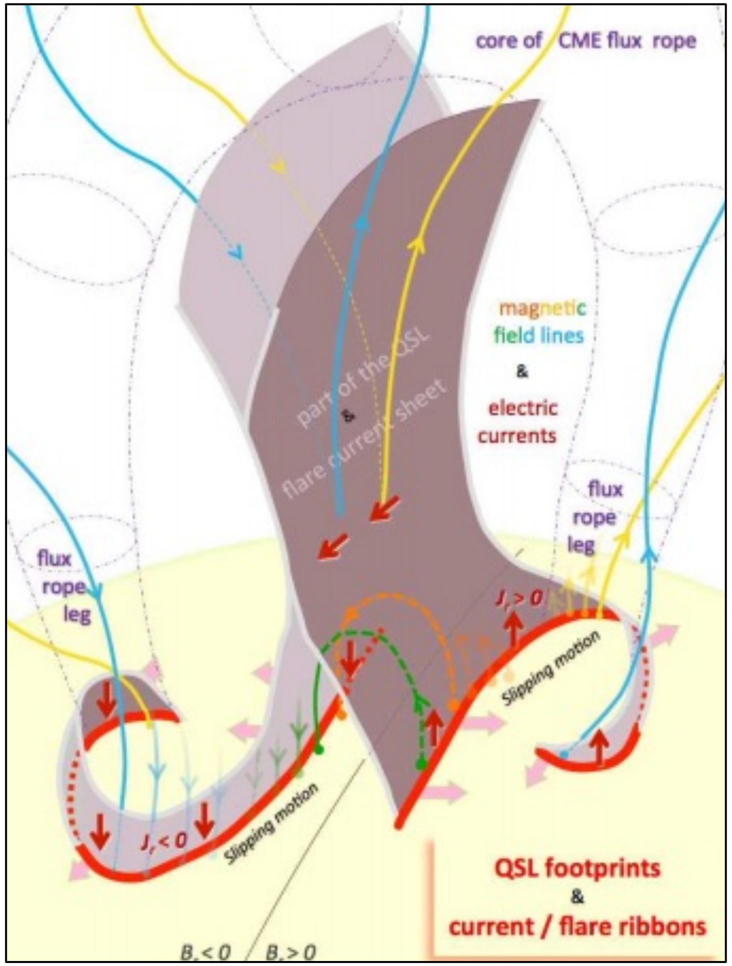
- Current sheet regions have been observed off limb (e.g. PhD work *French et al 2019,2020*), but observations are rare.
- Instead we can utilise the connection between current sheet and flare ribbons on disk.

Ribbon Insights into Flare/Eruption Dynamics

- Due to their magnetic connectivity, behaviour of flare ribbon substructure must reflect processes in the flaring current sheet region (*Forbes & Lin 2000*).
- Spectroscopic signatures suggestive of waves and/or turbulence (*Brosius & Daw 2015*) - consistent with the presence of either the tearing mode or Kelvin-Helmholtz instability in the current sheet (*Brannon et al. 2015*).



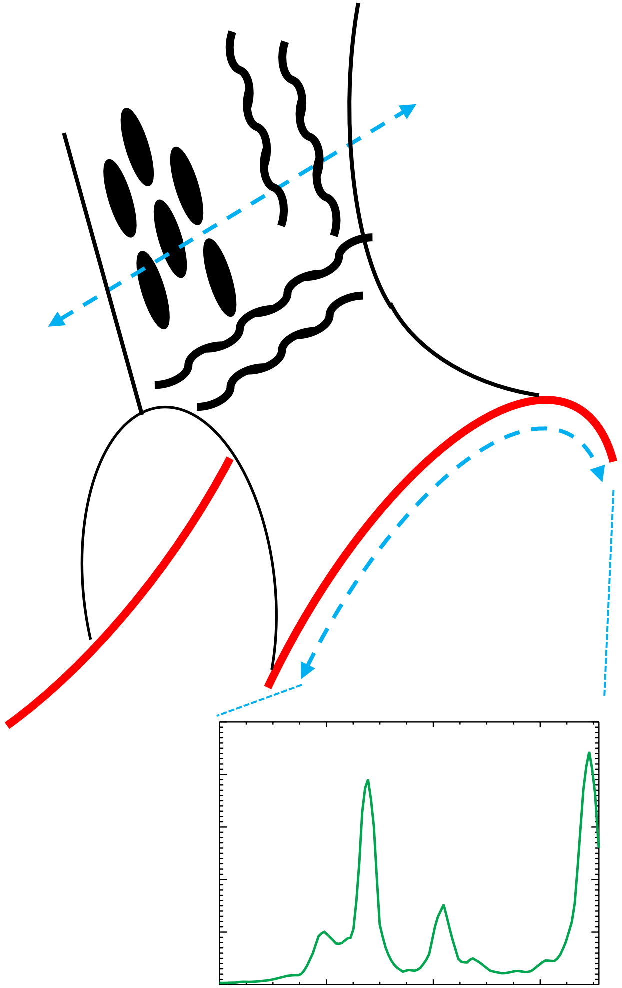
Brosius & Draw 2015

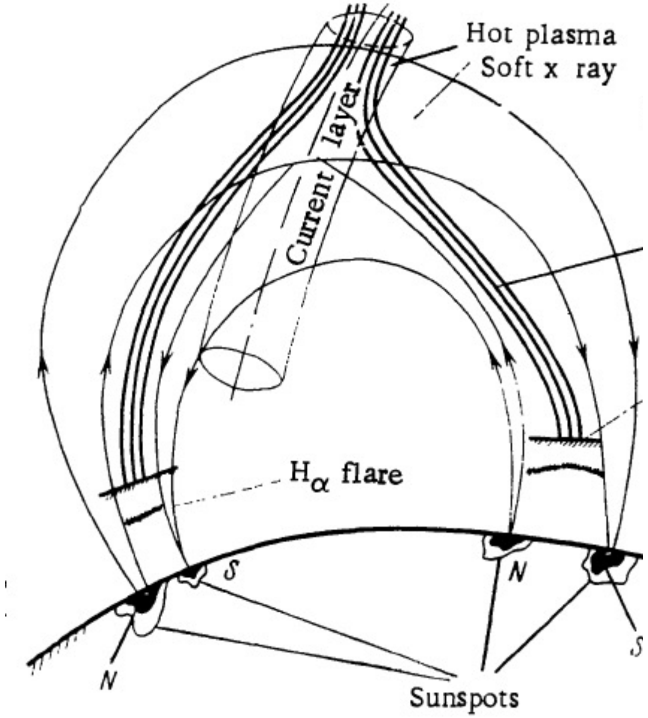


Janvier et al 2014

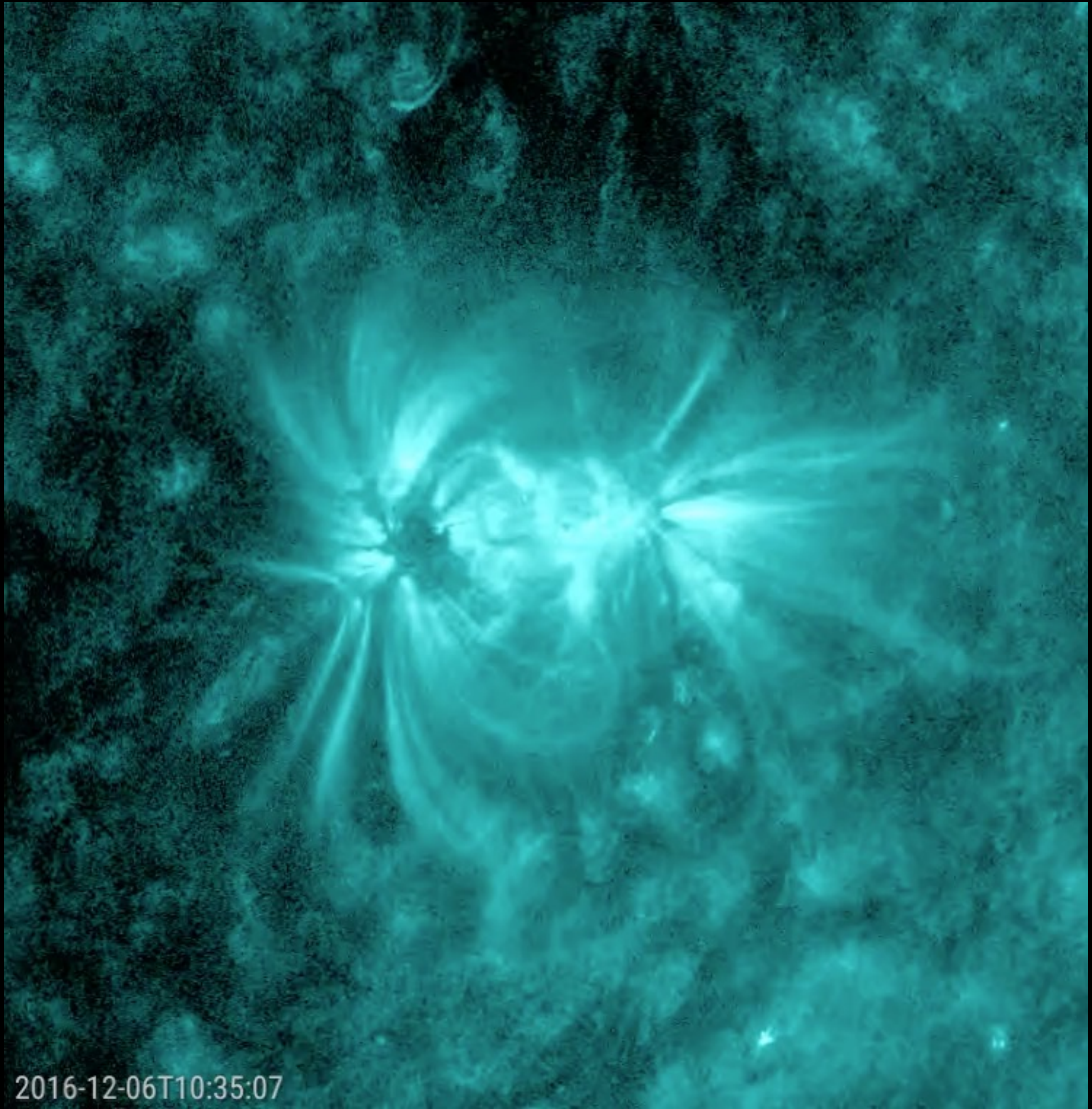
Our Project Aim

- Motivated by the method used in study of the terrestrial aurora, search for growth and timing of key spatial scales along the flare ribbons of a small, *simple* event.
- Compare observed parameters with those predicted by instability theory, and to the timing of plasma turbulence and flare onset.



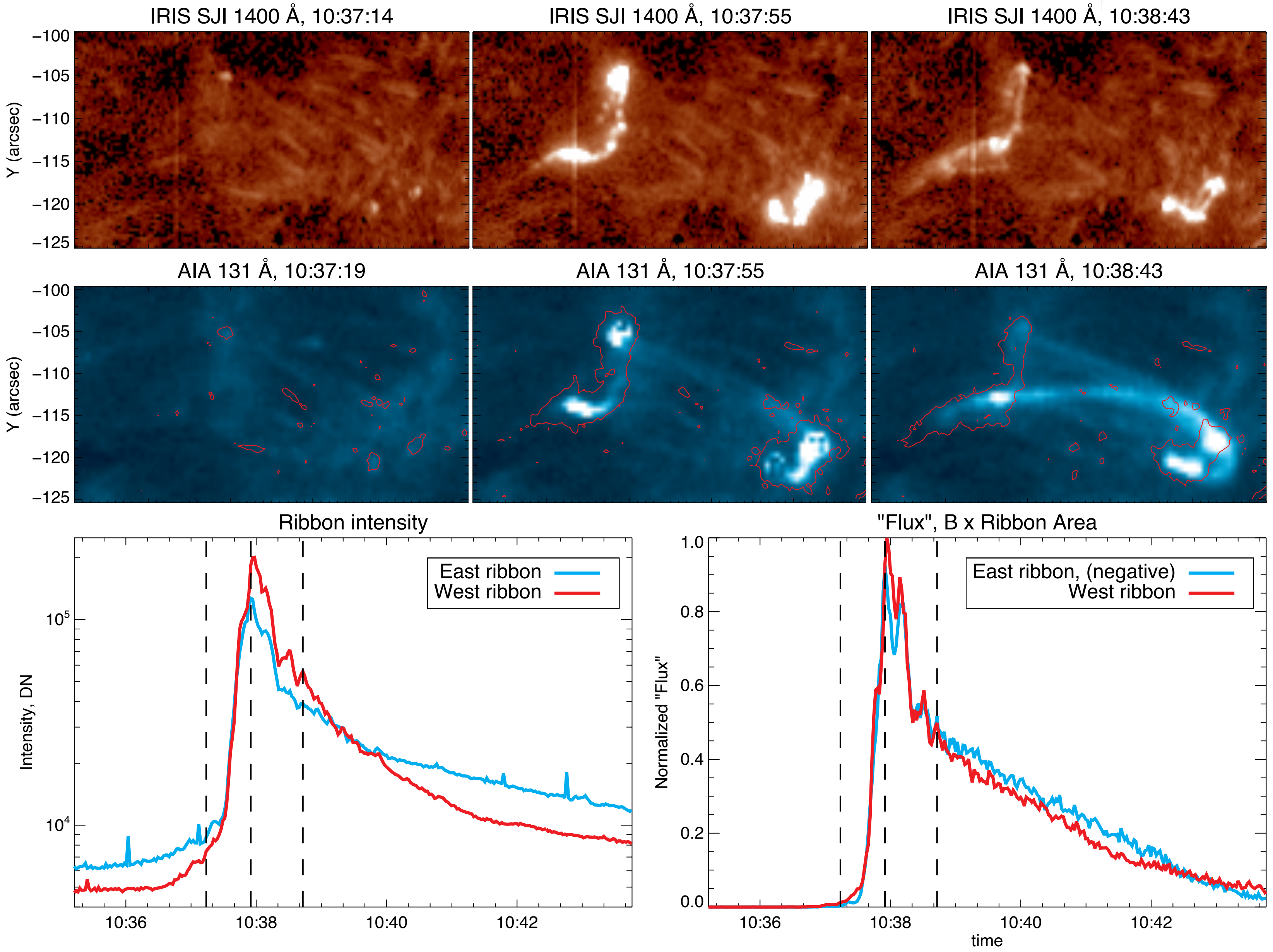


Pikelner et al 1977


2016-12-06T10:35:07

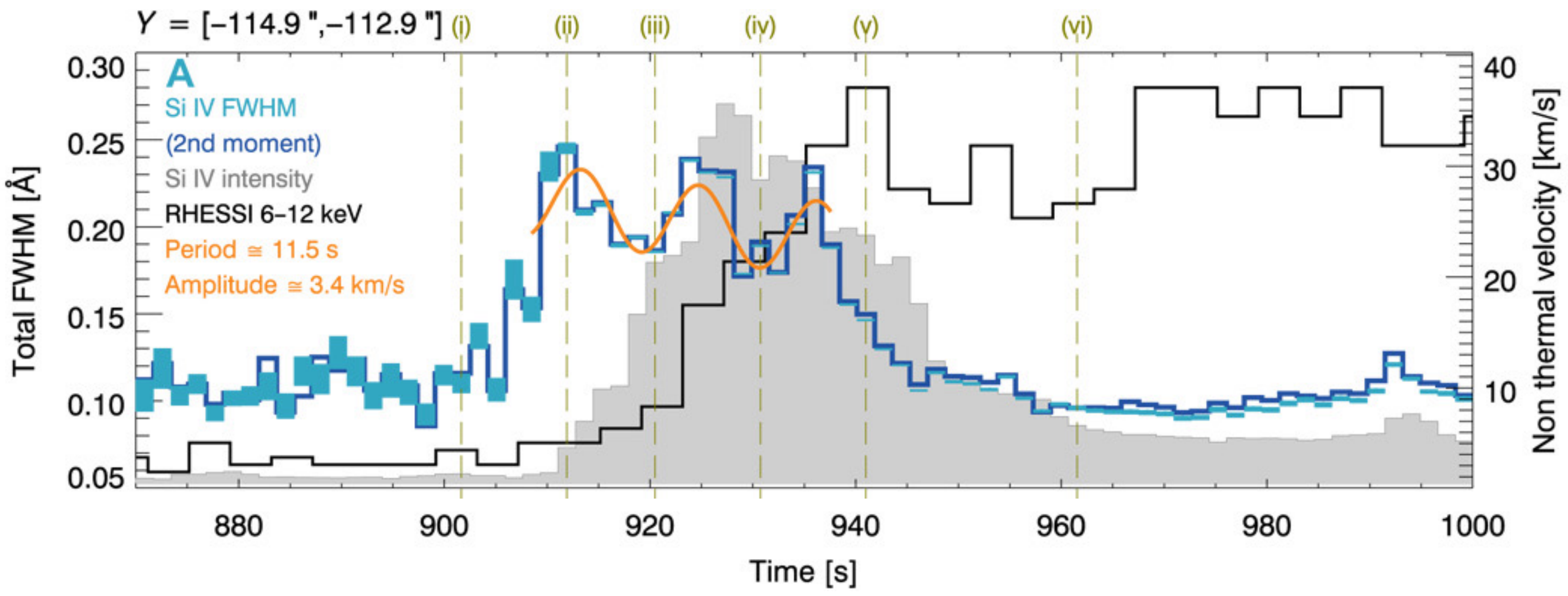
6^{th} Dec 2016 – B-class flare

- IRIS SJI 1400 Å, 1.7 s cadence.
- Ribbons brightening cotemporally, followed by the appearance of loops in AIA 131.
- BxA equal in both ribbon over impulsive phase.



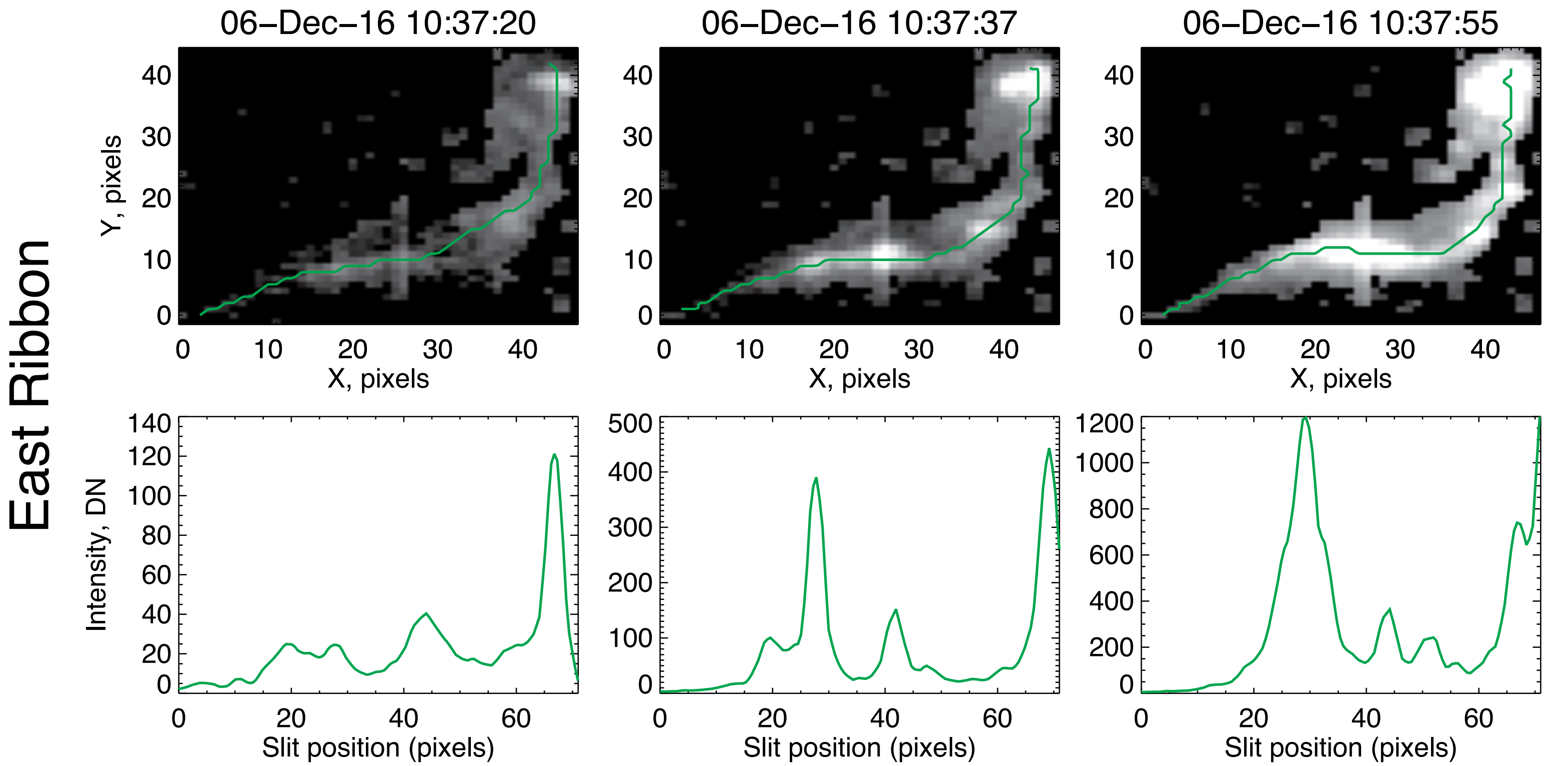
6th Dec 2016 – *Jeffrey et al 2018*

- Non-thermal velocities rise precedes ribbon intensity enhancement.
- Suggests plasma turbulence occurs before plasma heating and flare onset.
- The ongoing presence of turbulent signatures mean the driver of turbulence persists for longer.

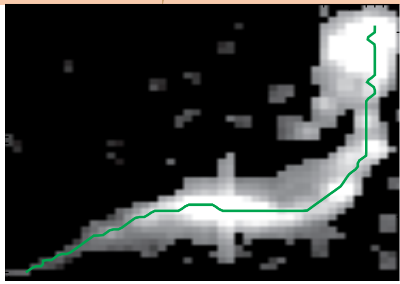


Ribbon Tracking

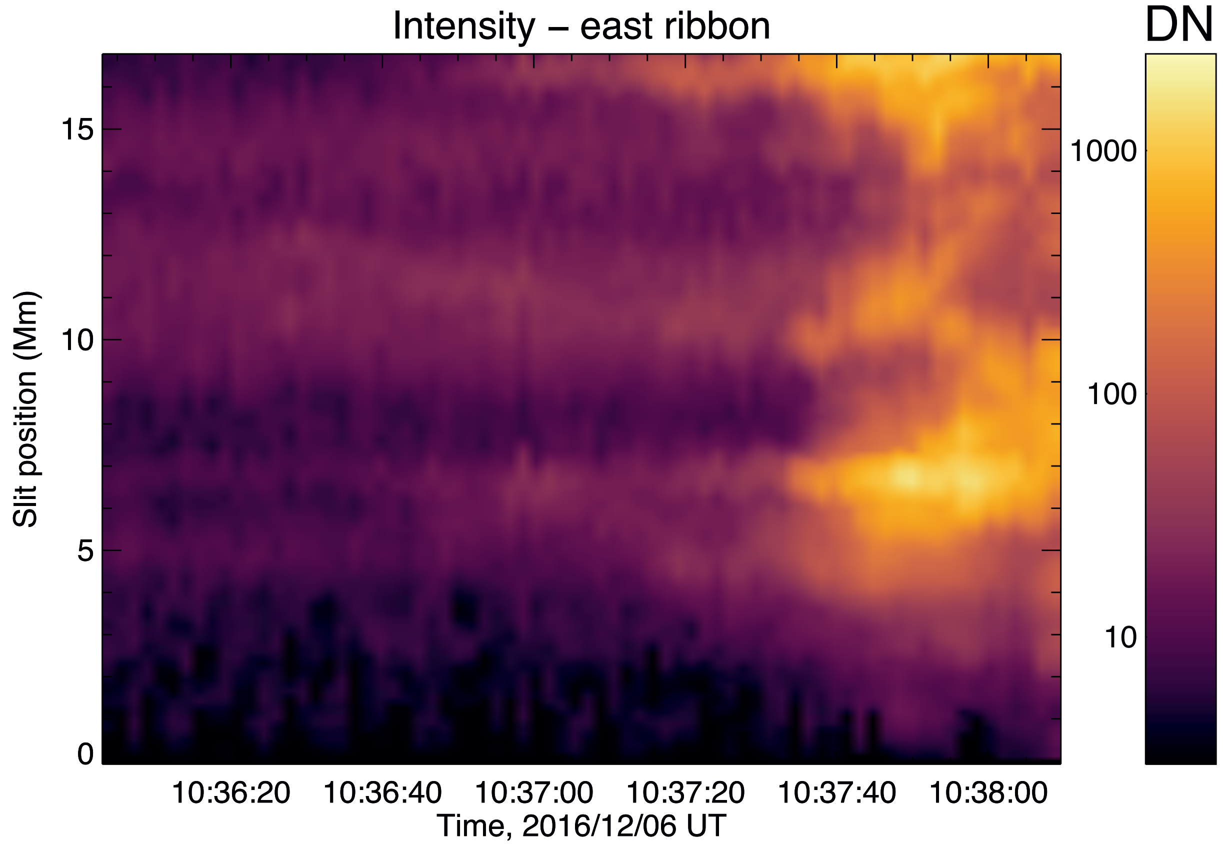
- Track a central slit along the evolving ribbons, plotting the mean intensity around each pixel along the centroid slit.
- Process the signal, and calculate the spatial Fast-Fourier Transform for each time step.

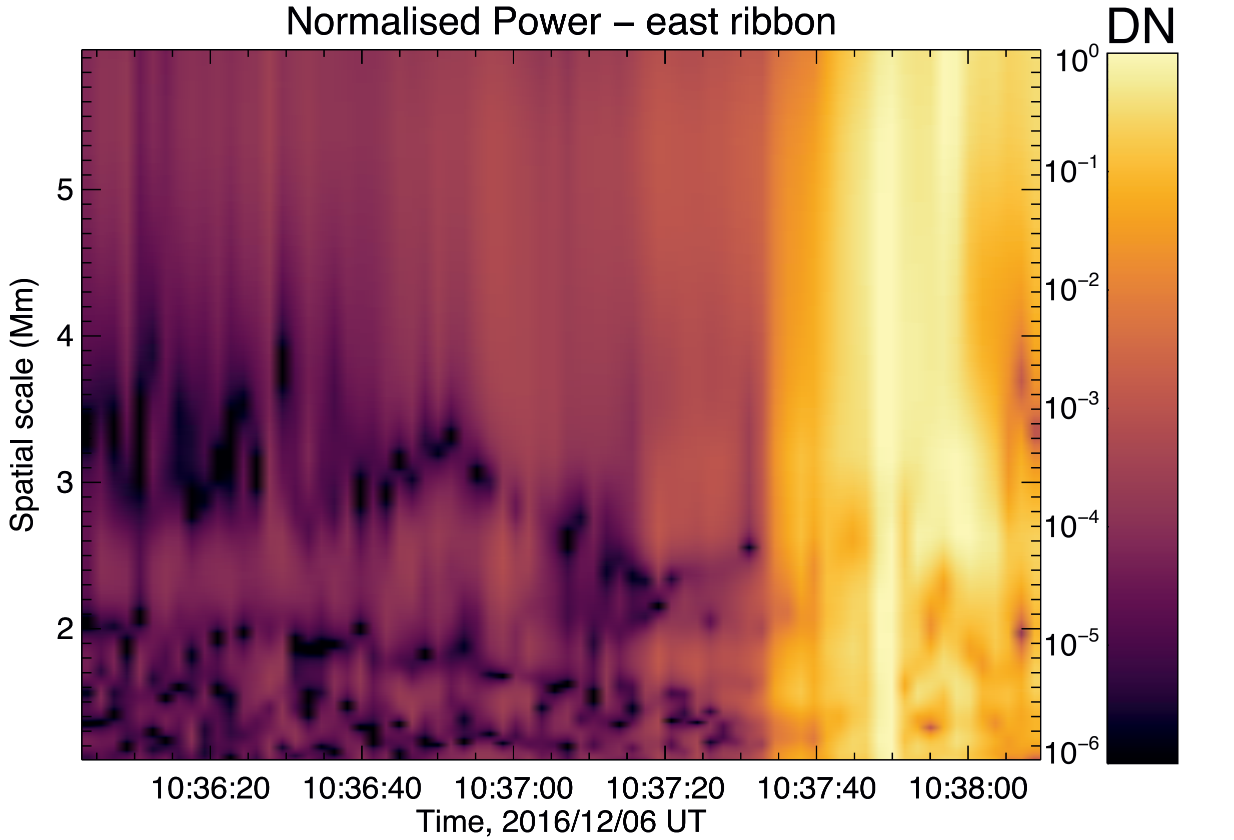


Intensity & Power Evolution



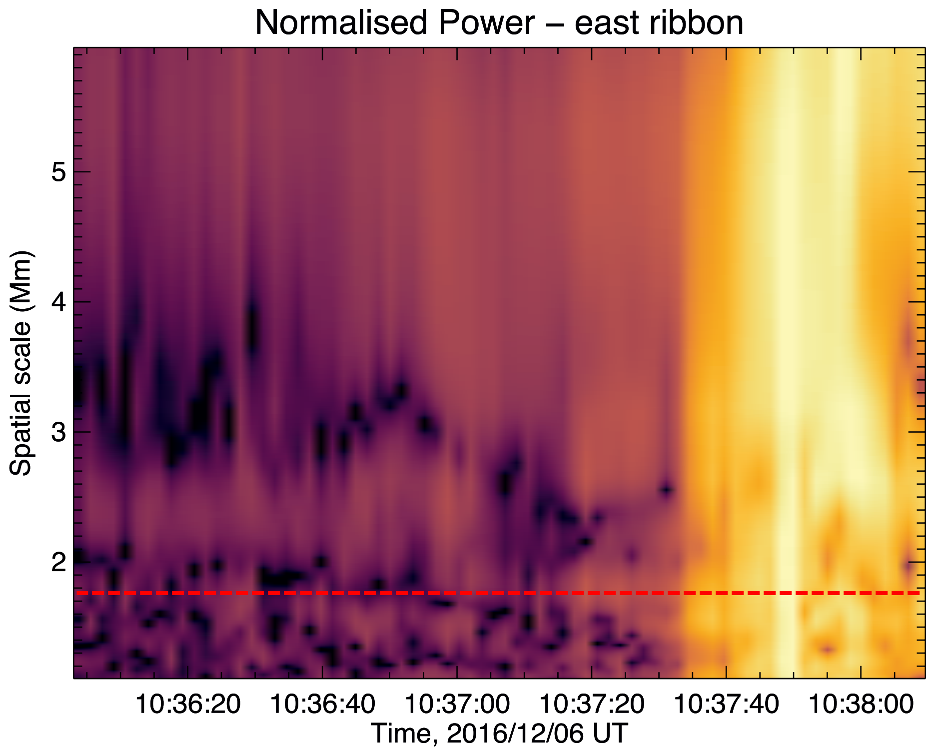
- We produce a stack plot of spatial FFTs at each time step.
- We detect power growth across the spatial scale range, of up to 6 orders of magnitude.
- Growth start-time appears to vary with spatial scale.

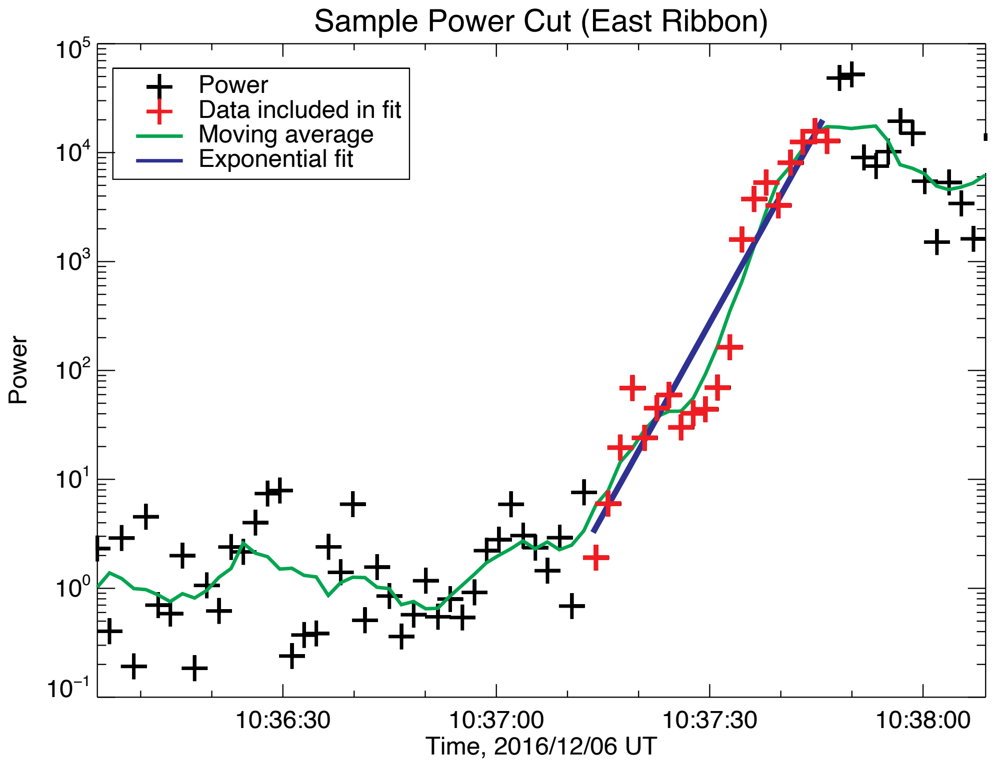




Instability Growth Rate

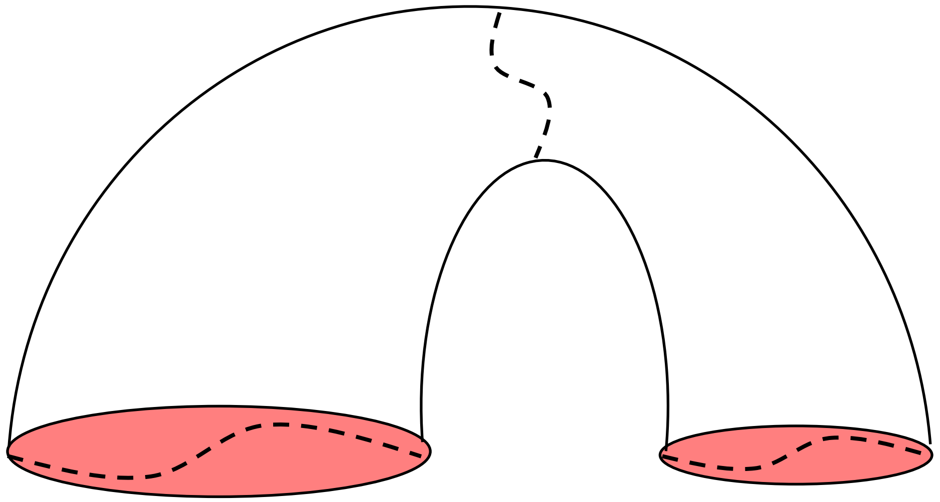
- We take a horizontal cross-section, to sample the time evolving power and determine the rate/duration exponential growth at each specific spatial scale.



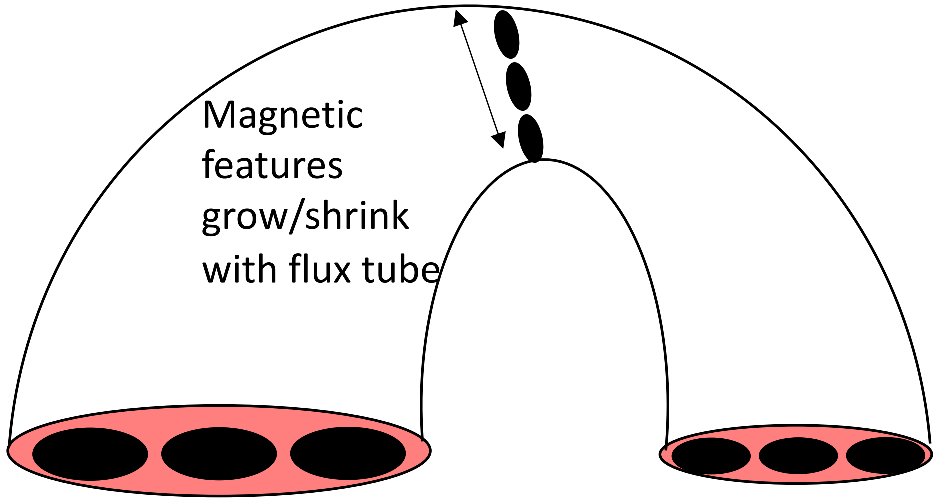


Comparison of Ribbon Scales

- Conservation of flux – spatial processes will scale as flux tube grows between reconnection site and ribbons.
- We can approximate the scale change by the square root of the ribbon areas, allowing us to compare spatial processes in each ribbon.

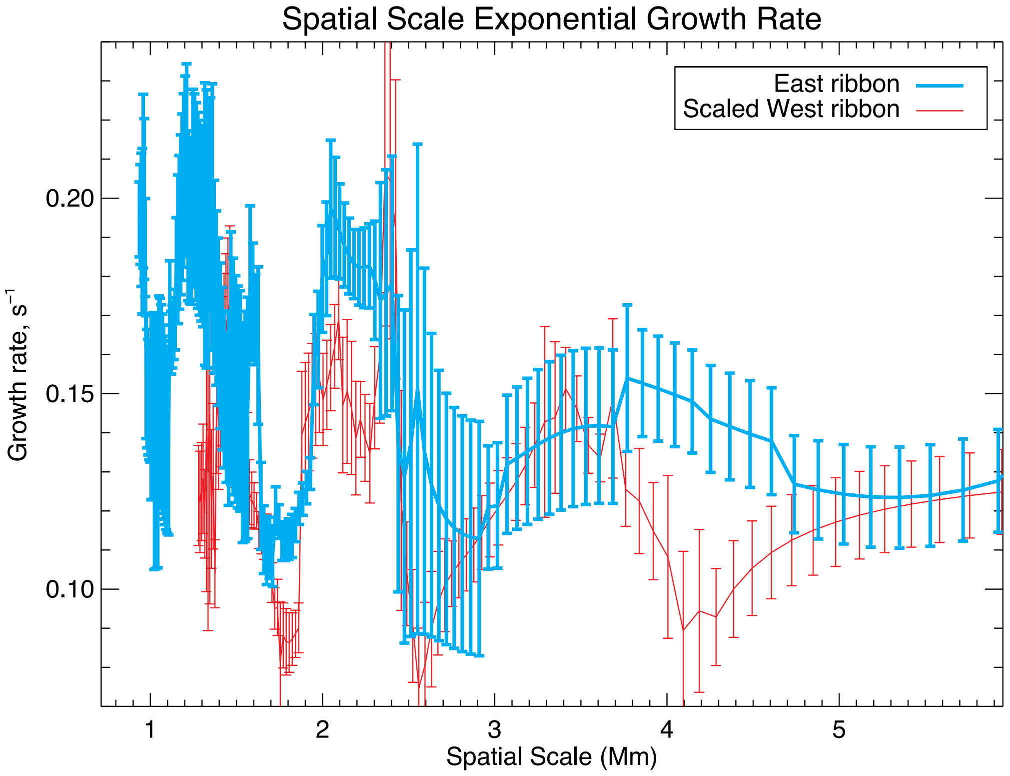


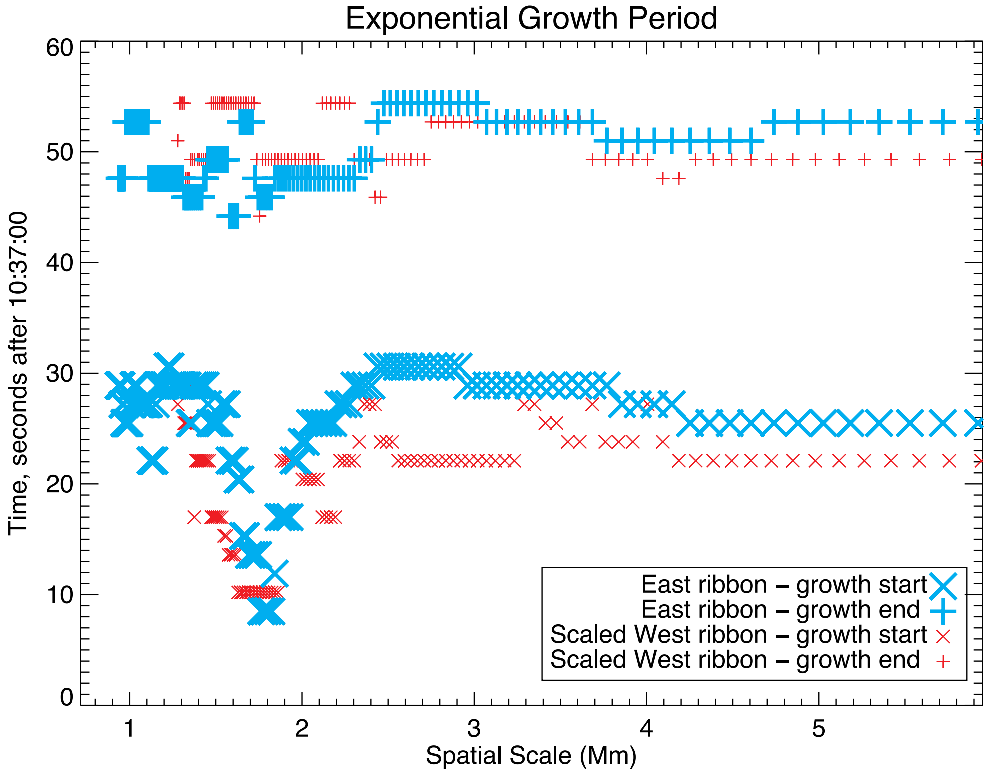
NOT to scale



Exponential Growth Rate / Timings

- Compare rate and timing of exponential growth at each spatial scale.
- We detect evidence of cascade & inverse cascade from key wavelength.
- Matching patterns confirm common connection – the current sheet.





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Observables to Compare with Theory

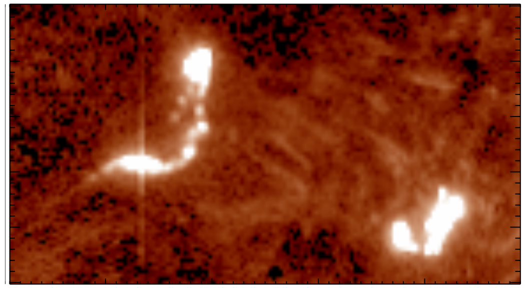
1. Exponential growth across all wavelengths, with a preferred spatial scale.
2. Exponential growth rate of ≈ 0.1–0.2 s^{-1}.
3. Evidence of simultaneous cascade and inverse cascade.

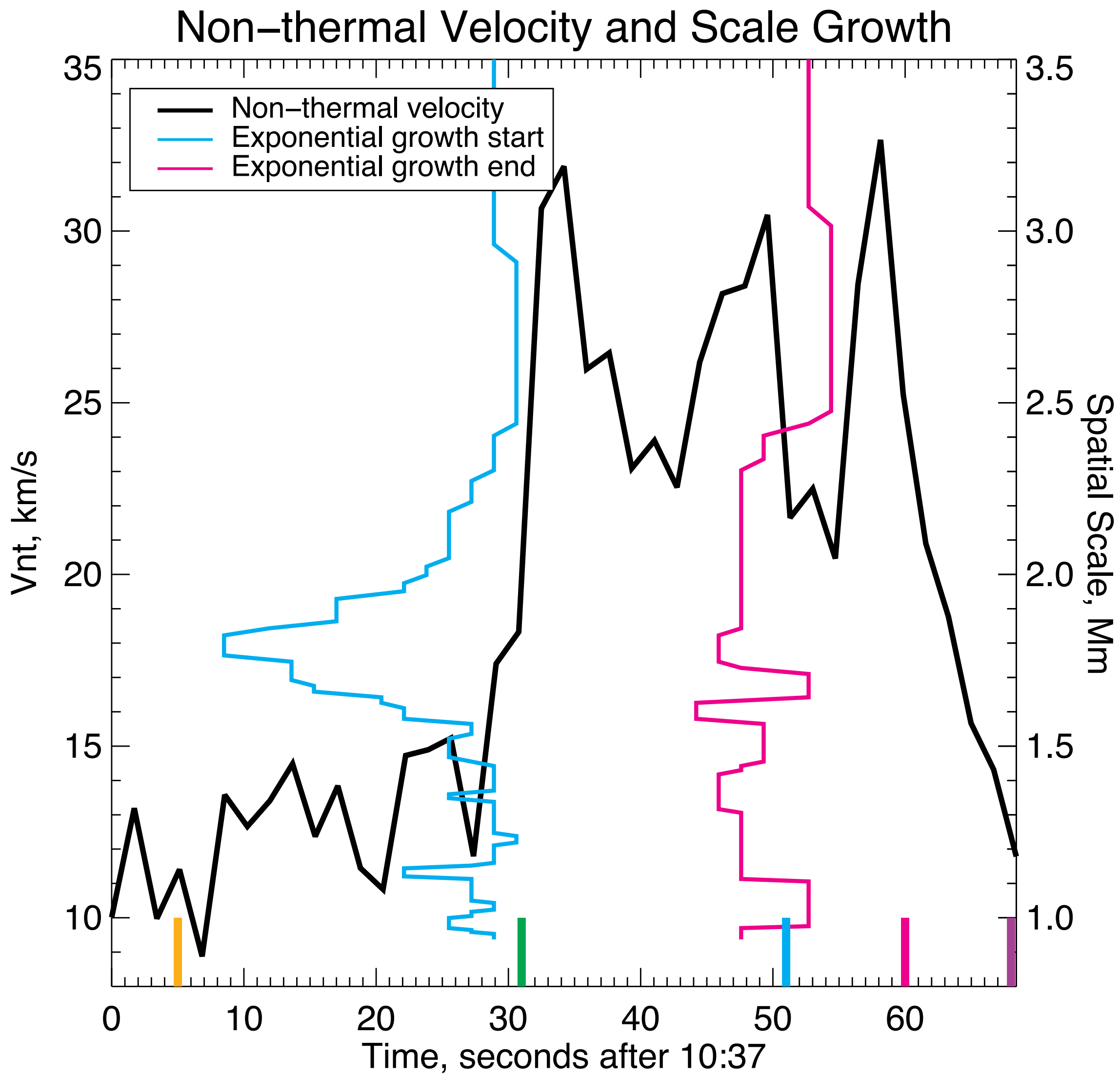
→ **Suggestive of the *tearing mode instability***

Instability Relationship with Turbulence

- Compare with non-thermal velocities at slit location (*Jeffrey et al 2018*).
- Growth precedes non-thermal velocity turbulence signatures by around 15 s.
- Indicates that plasma turbulence is driven by tearing mode instability for this confined event.

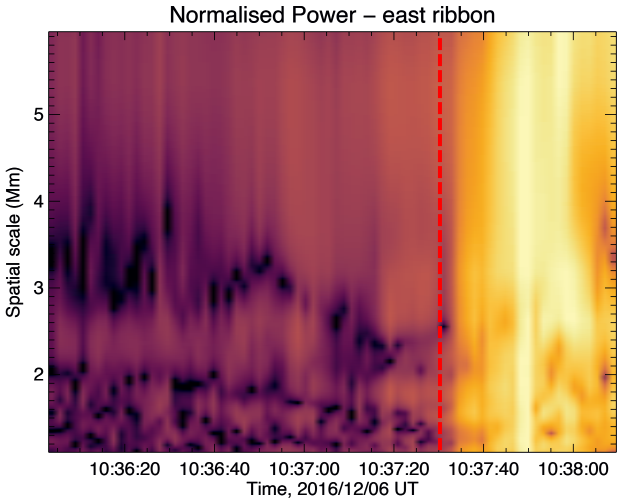
IRIS SJI 1400 Å, 10:37:55

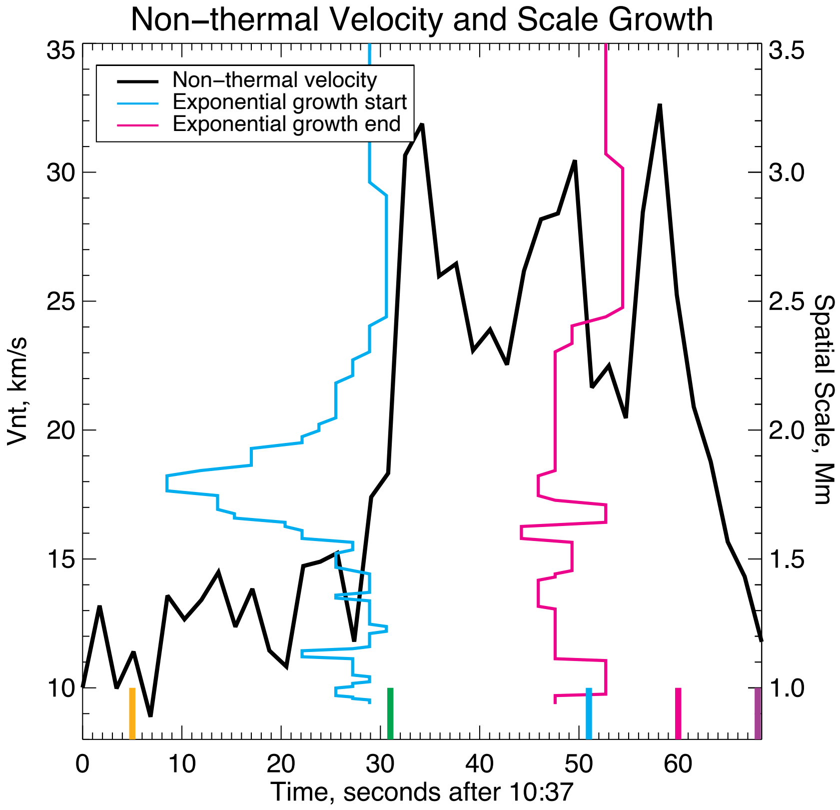


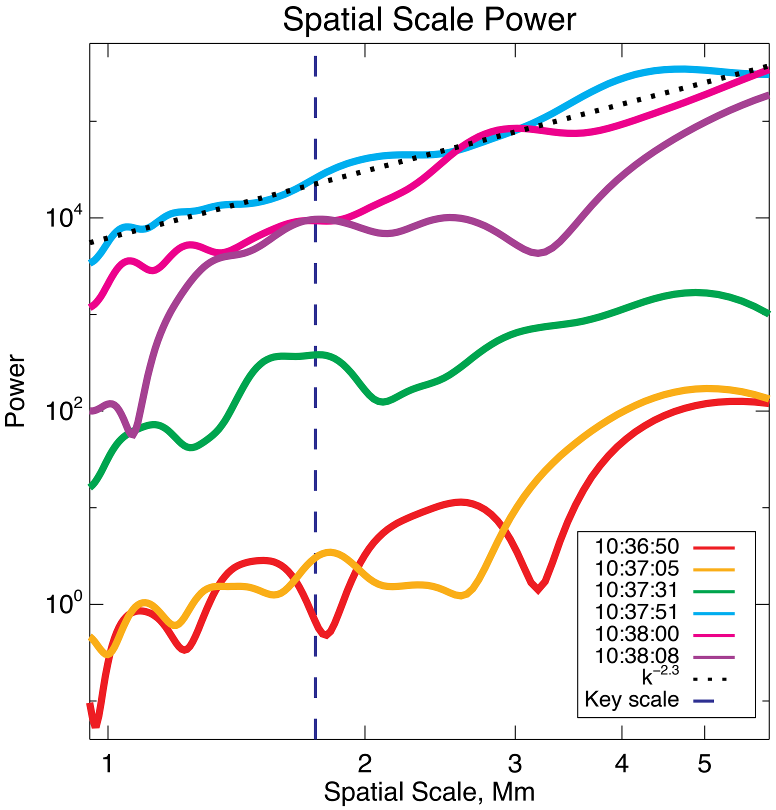


Spatial Scale Power Law

- In turbulence physics, the power law varies depending on the origin.
- Spatial scales reach an end state with a power law of 2.3, consistent with simulations of tearing-induced turbulence (e.g. *Dong et al 2018*).







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Conclusion

ADS link to paper – https://ui.adsabs.harvard.edu/abs/2021ApJ...922..117F/abstract

- Behaviour of spatial scales in flare ribbons consistent with the presence of the tearing-mode instability in flaring current sheet.
- Timing suggests that tearing-mode instability triggers plasma turbulence through a cascade and inverse cascade, producing a spatial power law of 2.3.
- This sheds light on the complex interplay and feedback between reconnection, turbulence and current sheet disruption at flare onset.

- Ongoing work expands this analysis to a larger IRIS flare list – and, eventually, DKIST data (hopefully!).