

UV and HXR Analysis of a Two Ribbon Flare: A Tale of Two Ribbons?

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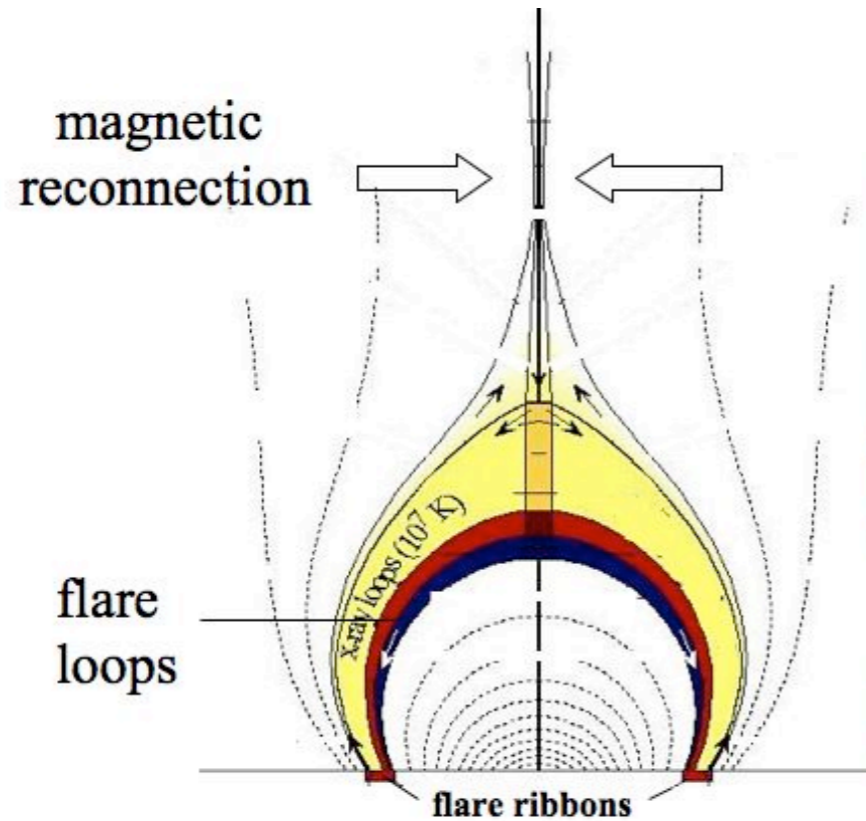
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Overview

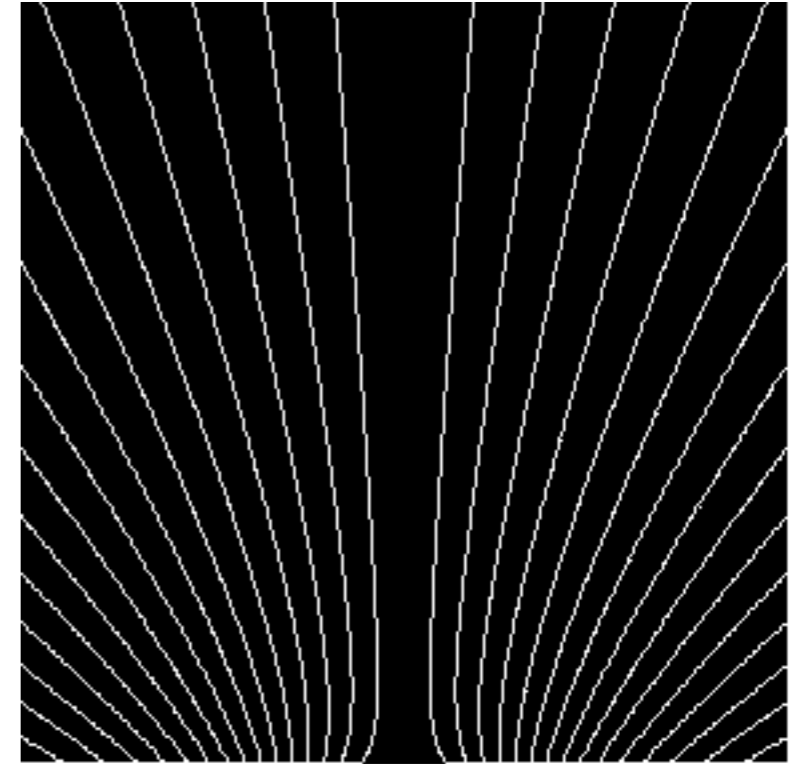
- Reconnection in Solar Flares
- Observations
- Ribbons Vs Kernels
- Comparing UV & HXR Motions
- Enter Reconnection Rates
- Some Energetics
- Conclusions

Magnetic Reconnection in Solar Flares



(adapted from Forbes & Acton, 1996)

2D



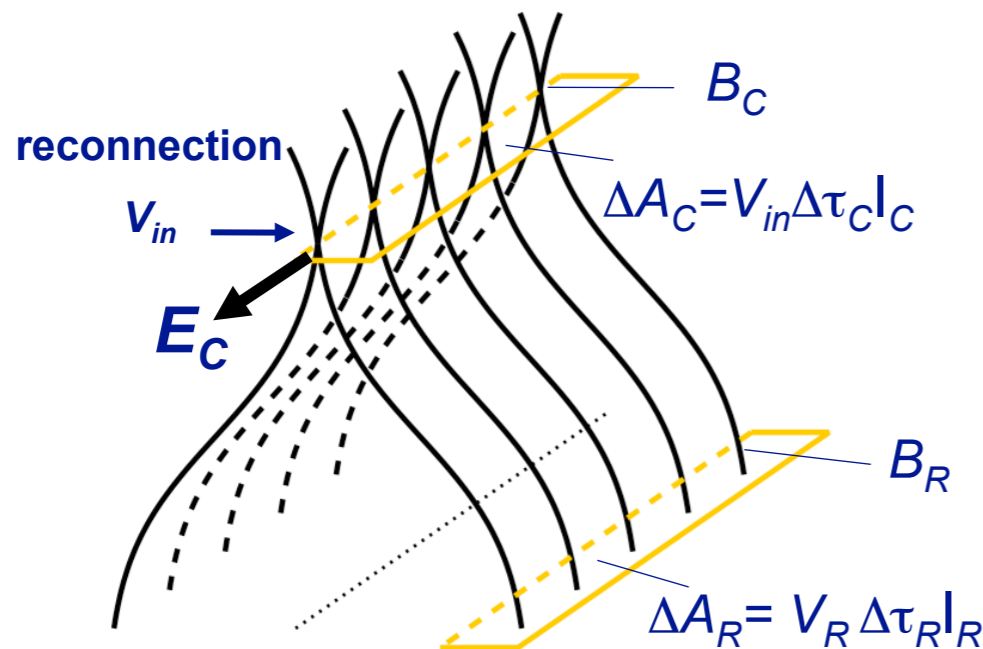
(Forbes)

- Standard Model: CSHKP
- Magnetic field lines come together and reconnect, changing the field configuration
- Less energy stored in new configuration.
- Process repeats, with reconnection occurring higher in the corona- so foot-points spread out perpendicular to the PIL.

**Carmichael, 1964 ; Sturrock, 1968 ; Hirayama, 1974 ; Kopp and Pneuman, 1976
Forbes & Acton, 1996 ; Priest & Forbes, 2000**

Magnetic Reconnection in Solar Flares

- Where this energy goes:
- Thermal & non-thermal Xray emission in foot-points in chromosphere
- UV from heating in chromosphere by energy flux along the flux tubes



Can measure the reconnection rate by:

$$\dot{\Phi} = \frac{\partial}{\partial t} \left(\int B_c dA_c \right) = \frac{\partial}{\partial t} \left(\int B_R dA_R \right)$$

Magnetic Reconnection in Solar Flares

- **2.5D**

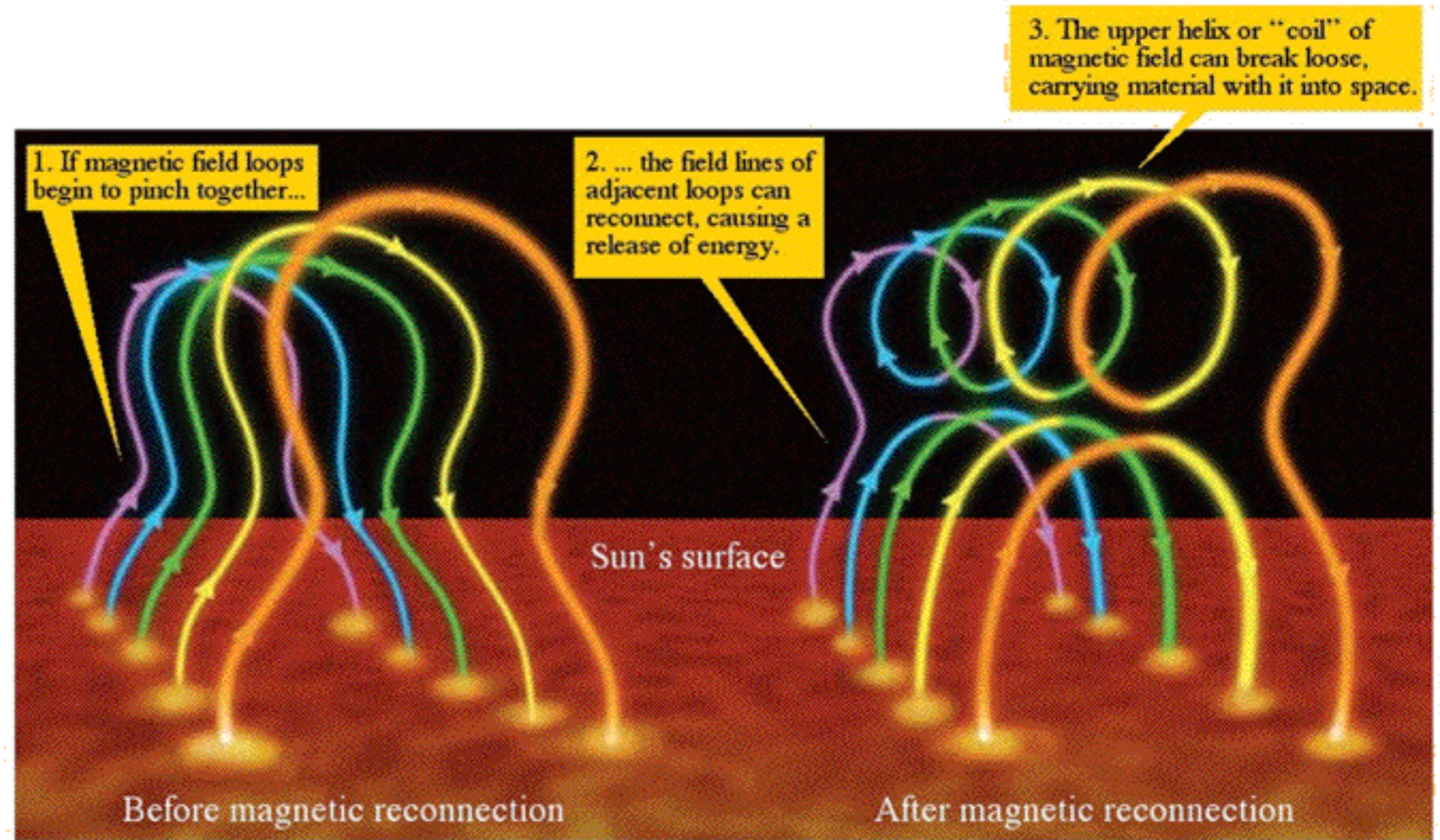


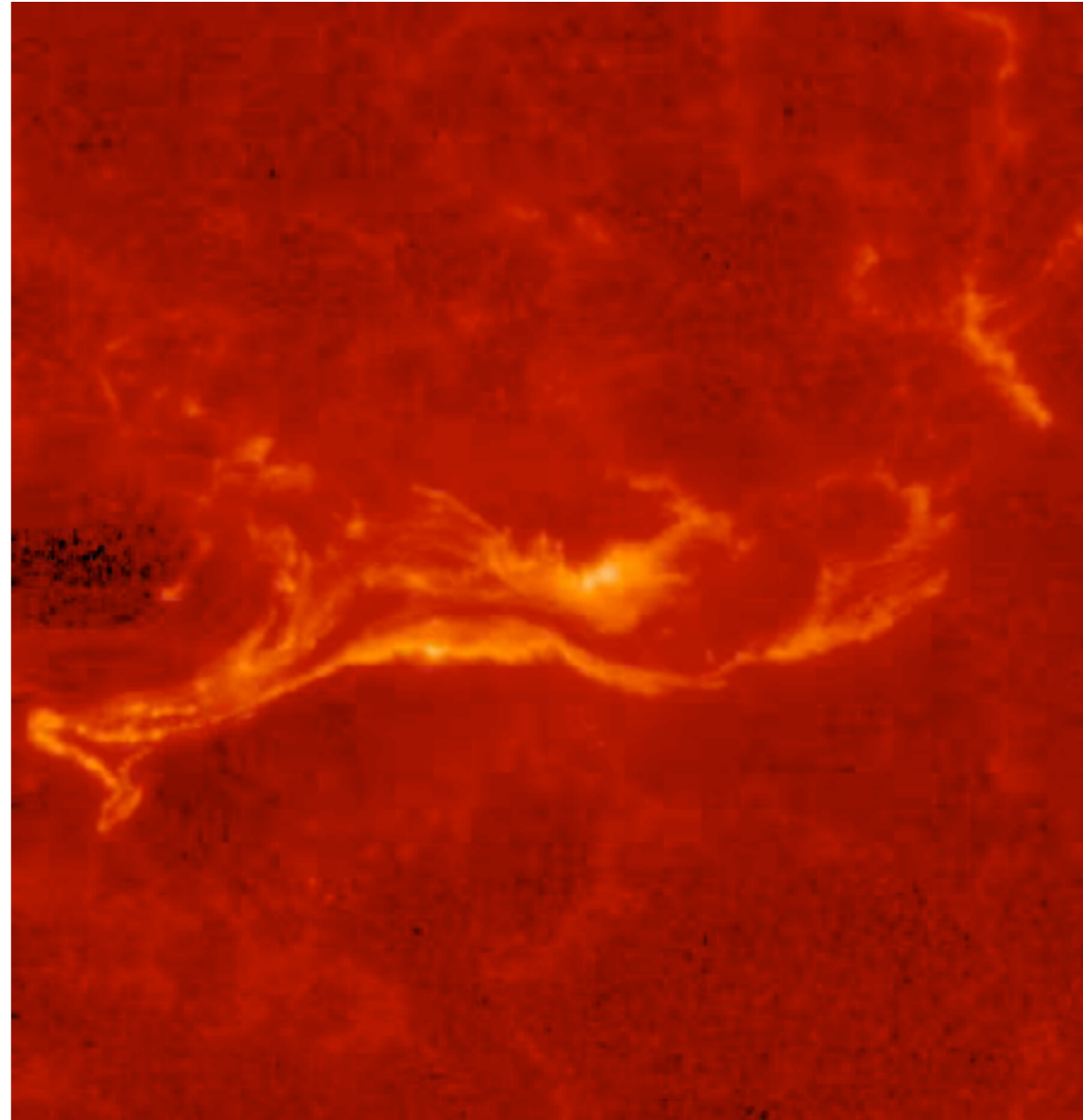
Figure 16-25b
Universe, Eighth Edition
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(Freedman and Company, 2008)

- Parallel & Perpendicular Spreading. The ‘zipper effect’ seen in two ribbon flares.
- Two ribbon flares show UV ribbons with 2.5D motion, as well as X-ray kernels with motions

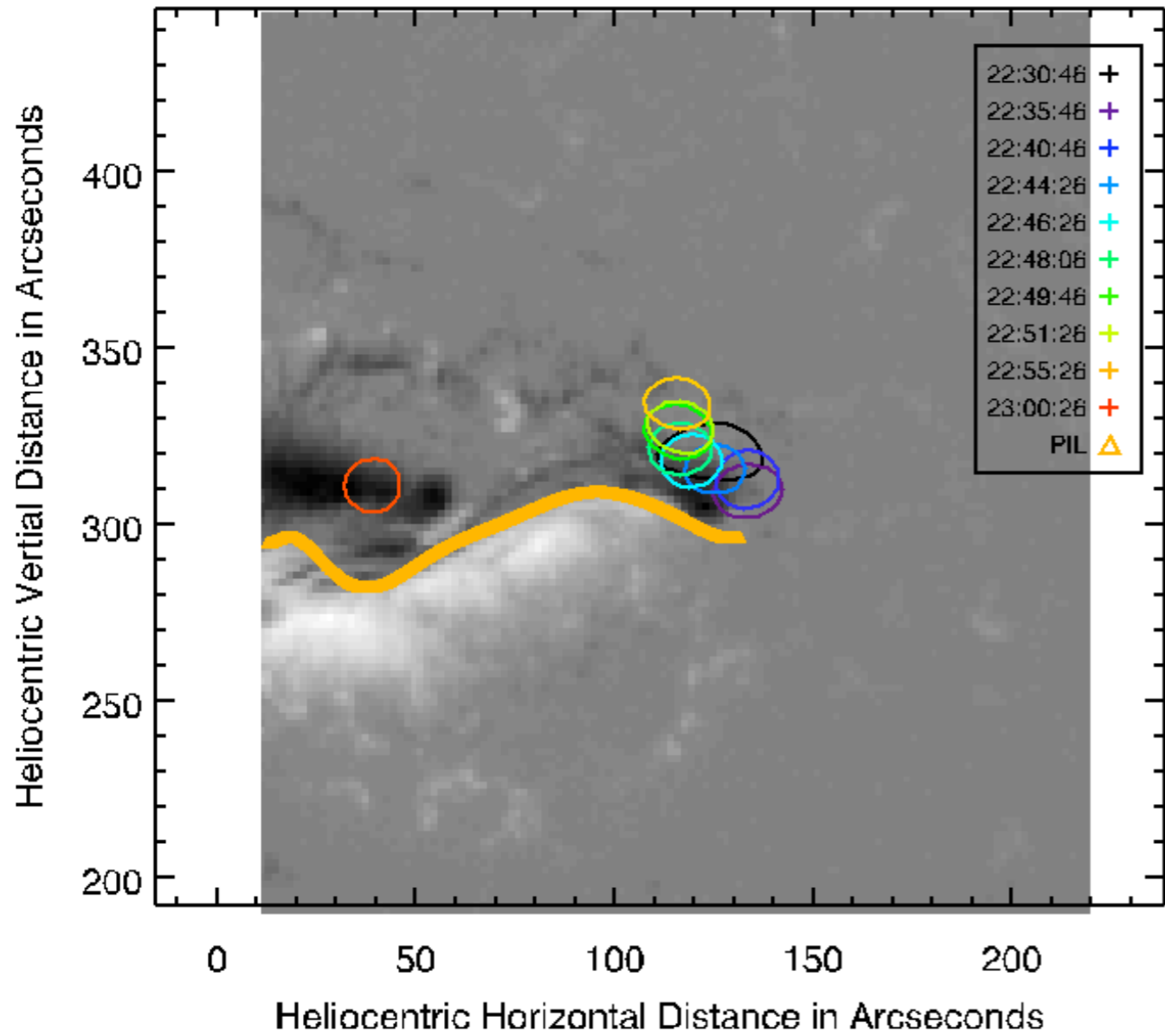
Fletcher & Hudson, 2001 ; Kitahara & Kurokawa, 1990 ; Moore *et al*, 2001 ; Su *et al*, 2007 ; Lee & Gary, 2008 ; Qiu, 2009

Observations

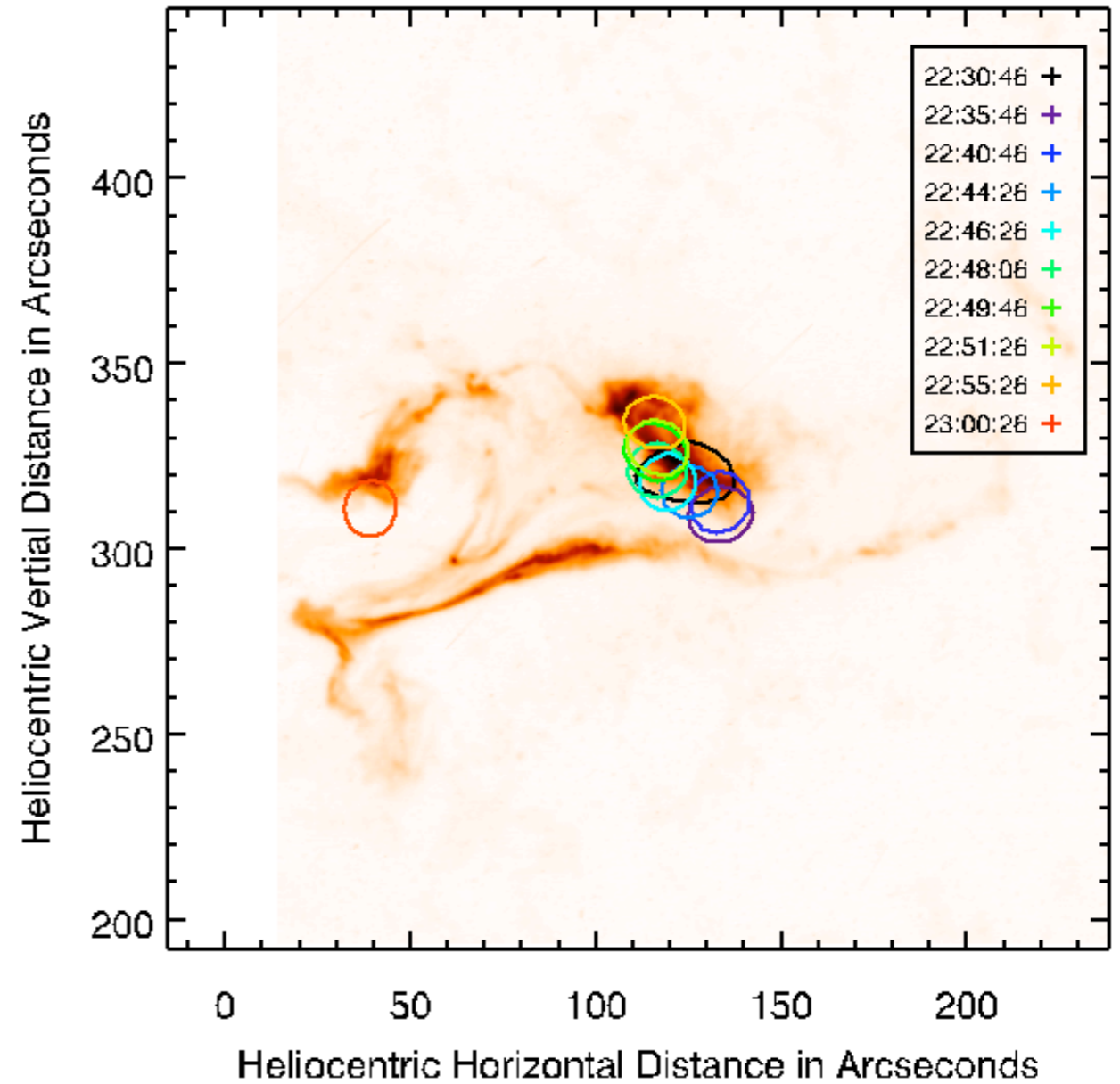


Observations

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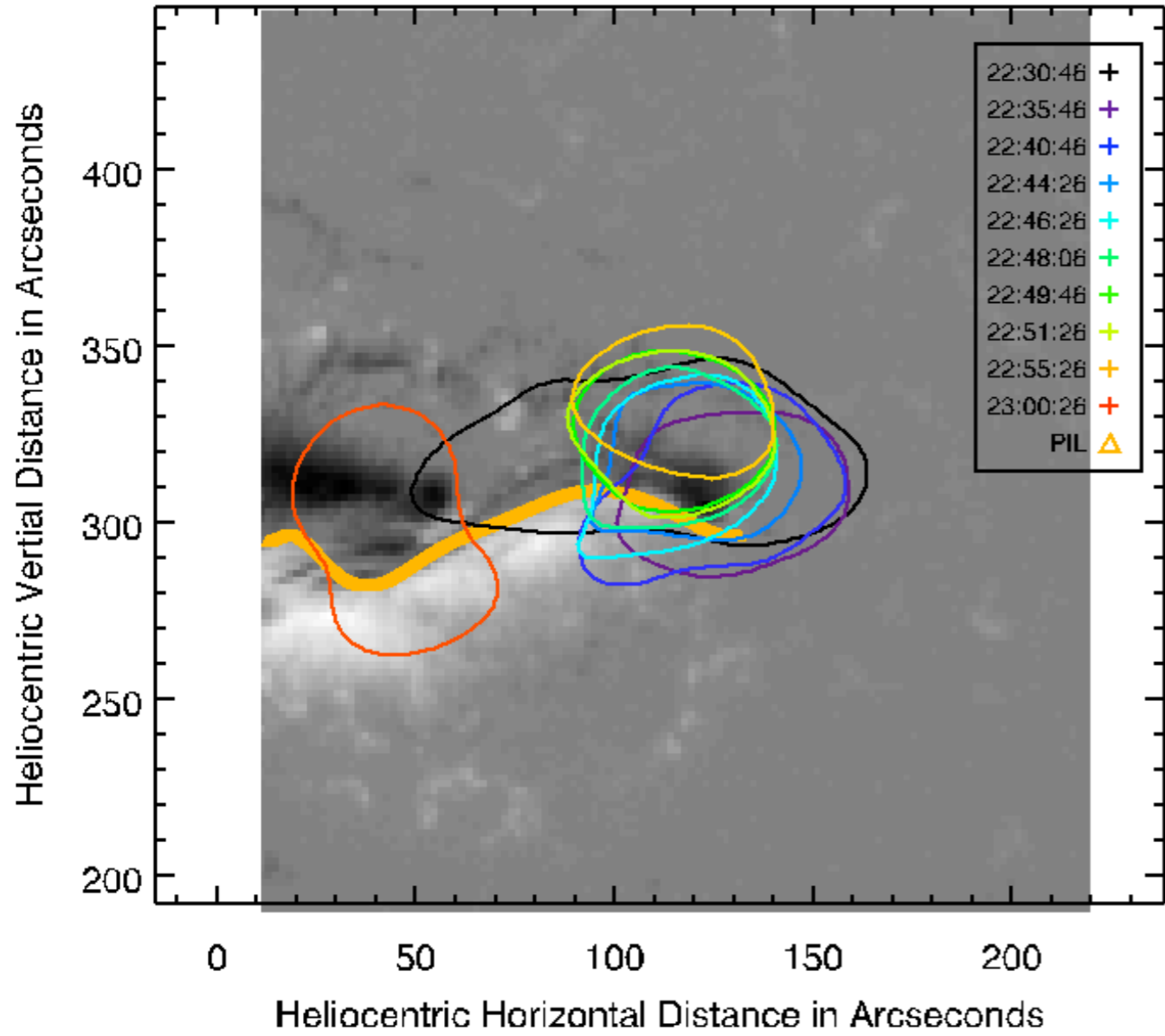


TRACE 1600Å Emission & 25 keV X-Ray Contours

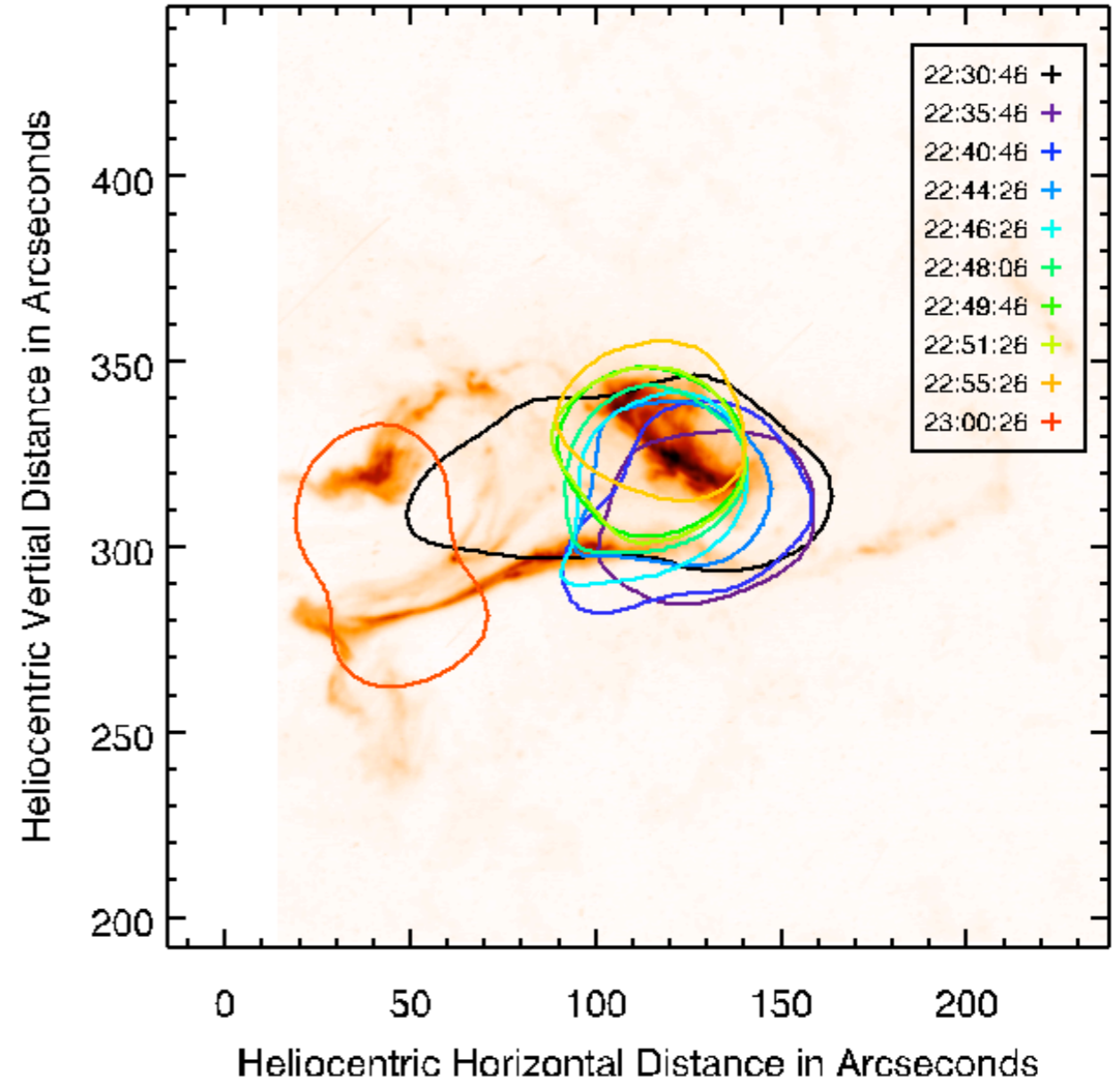


Observations

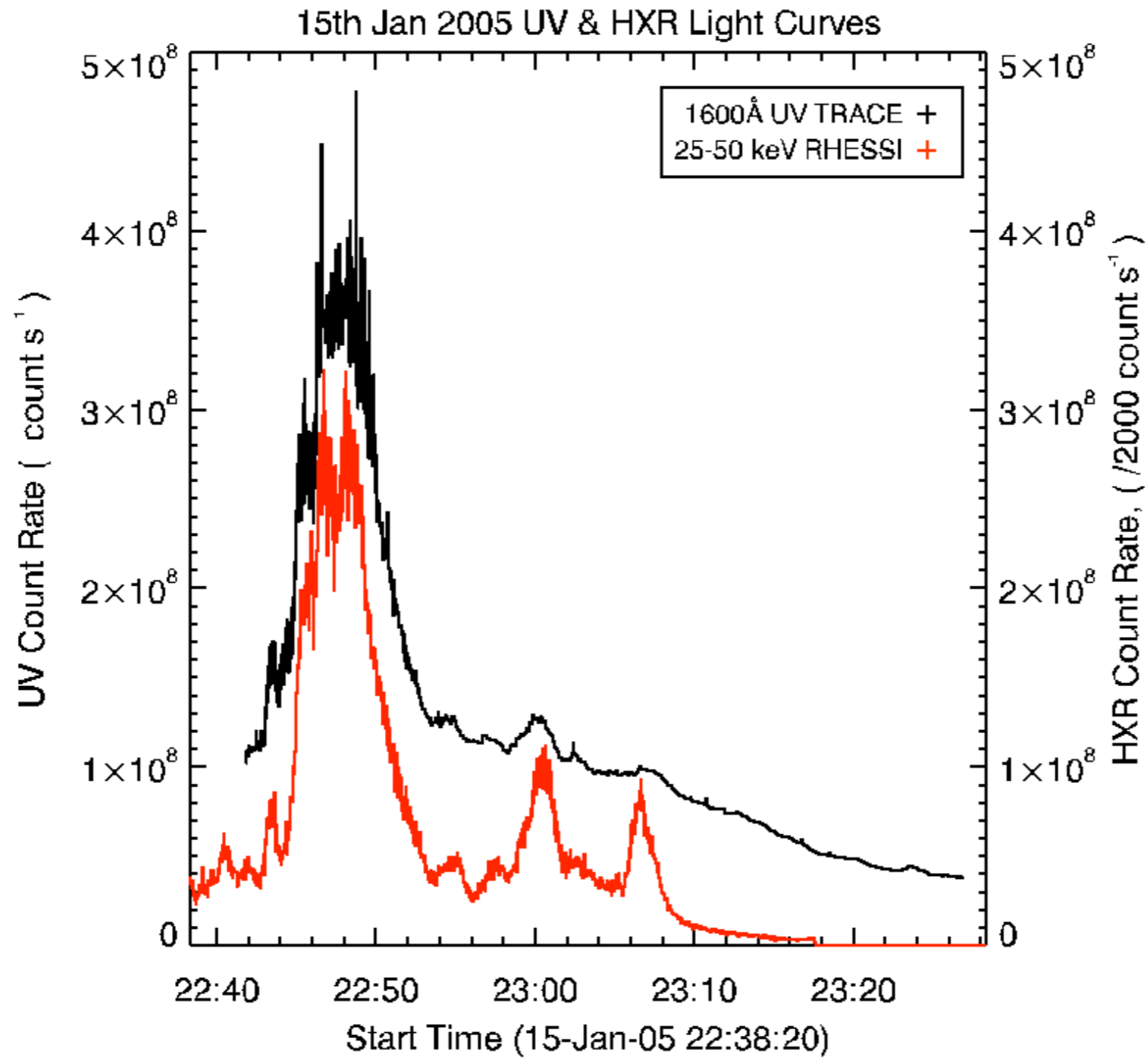
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TRACE 1600Å Emission & 25 keV X-Ray Contours



Light Curves



- Evidence No.1 of same source for UV & HXR emission
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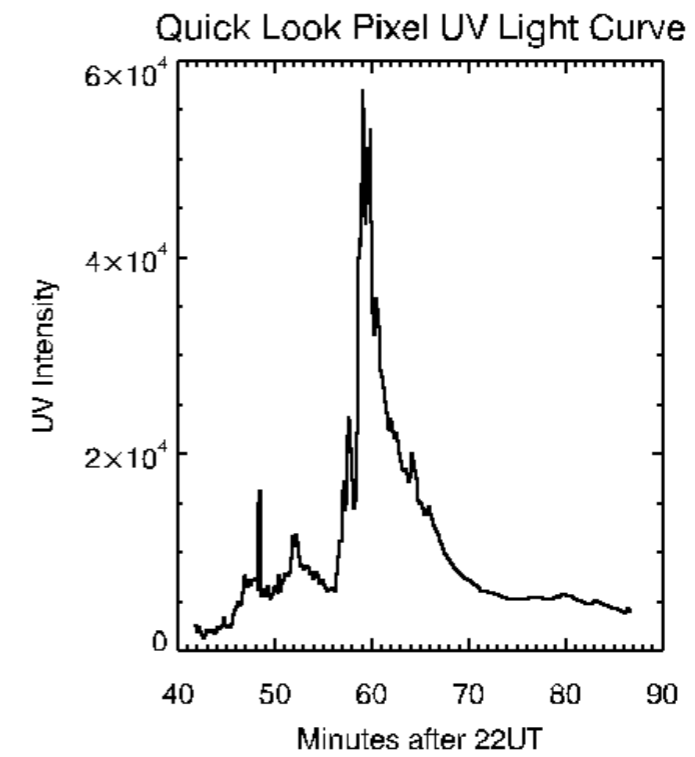
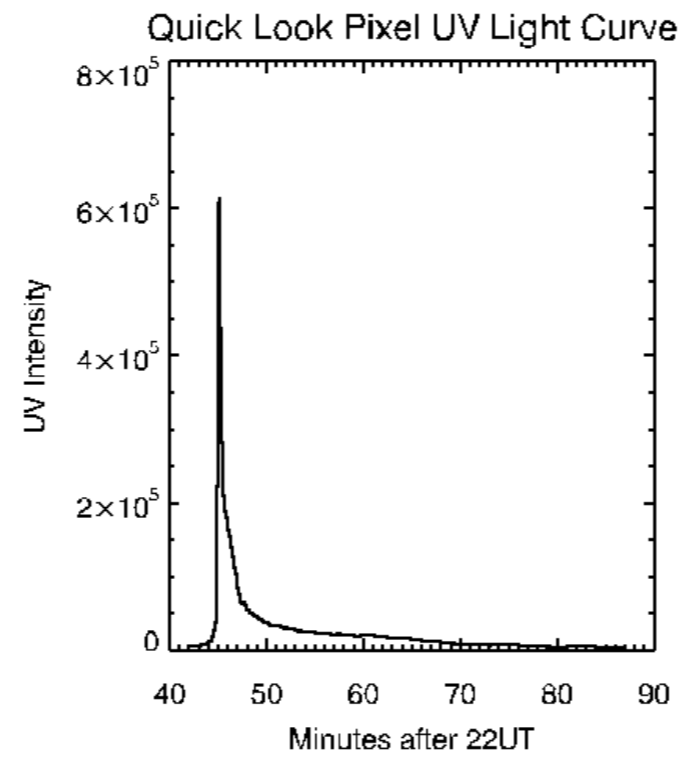
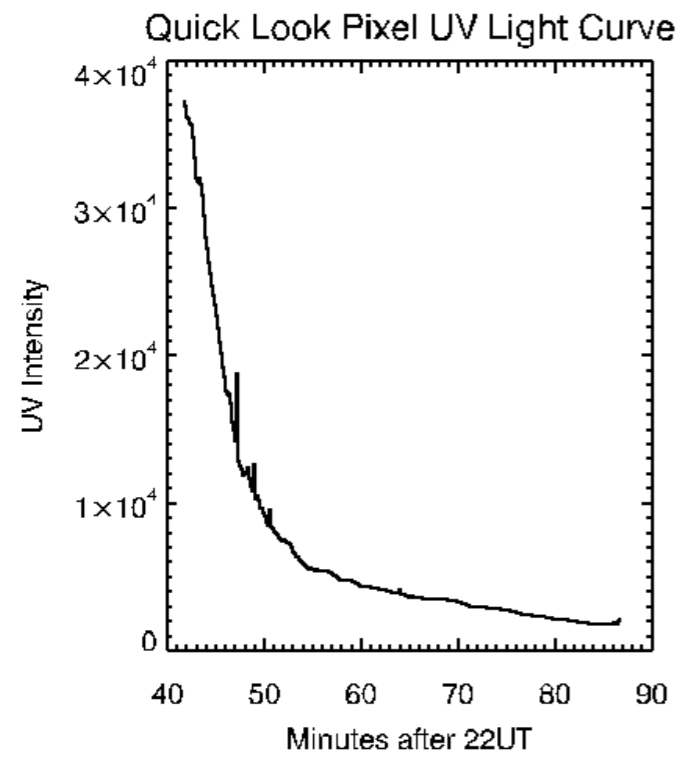
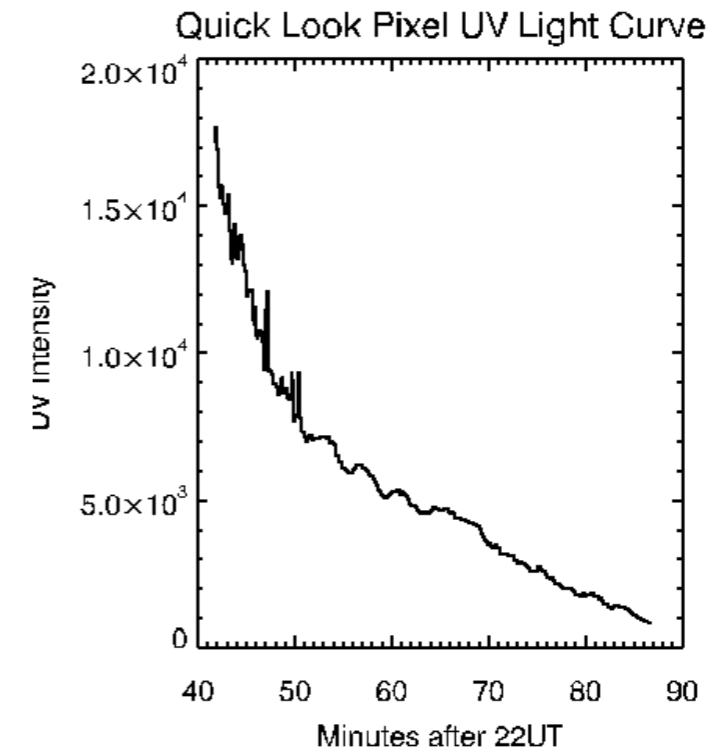
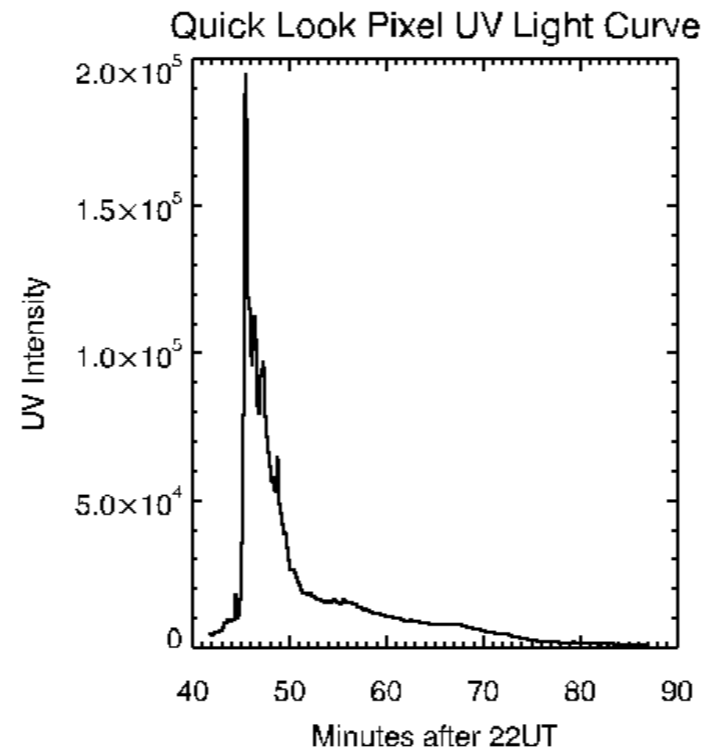
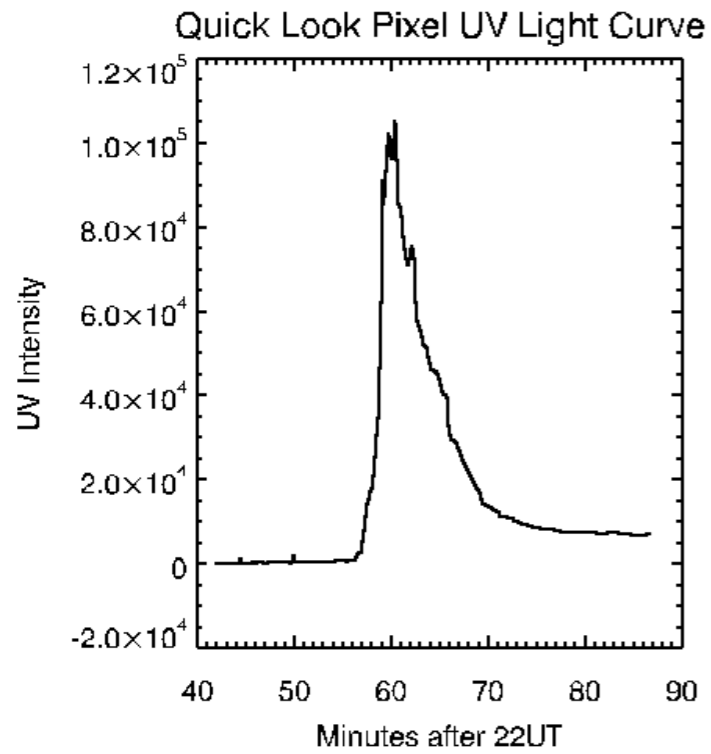
Ribbons Vs Kernels?

- Can see from images that UV ribbons but HXR kernels-why?
- Theory was that UV emission had a long decay phase, so that these regions remained brightened for several minutes as opposed to short X ray timescales.
- Basic equation:

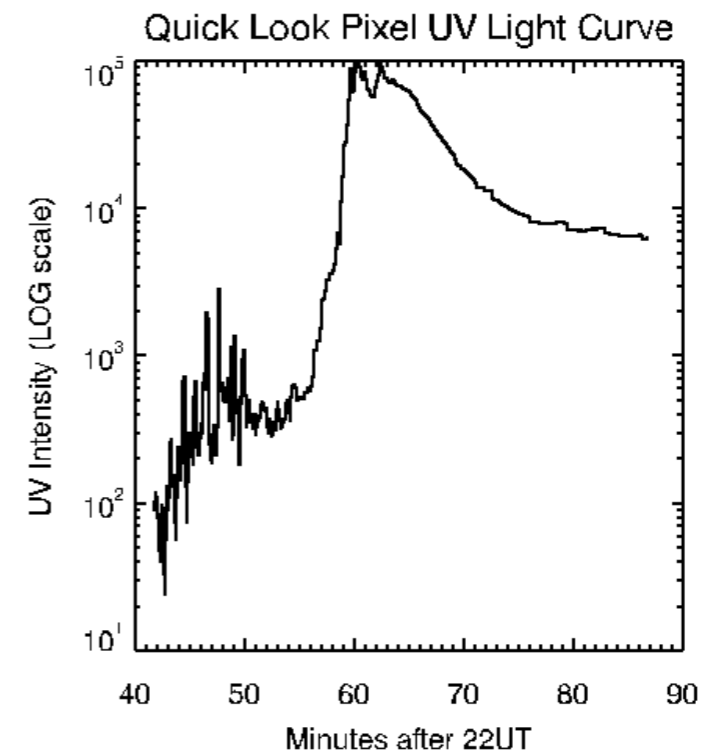
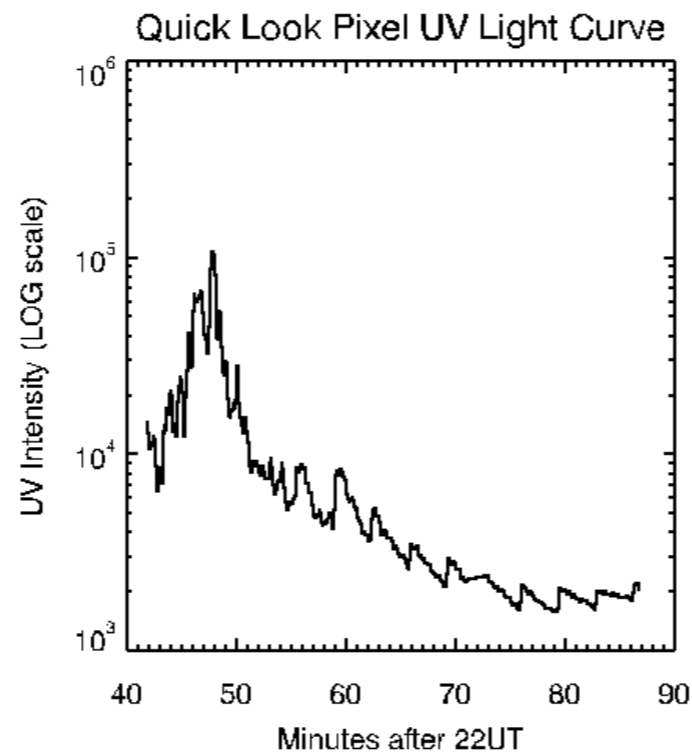
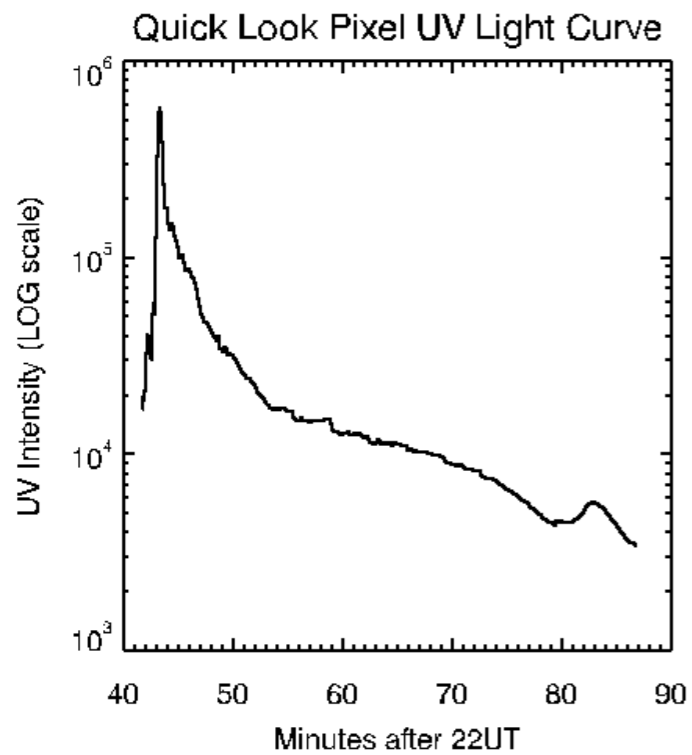
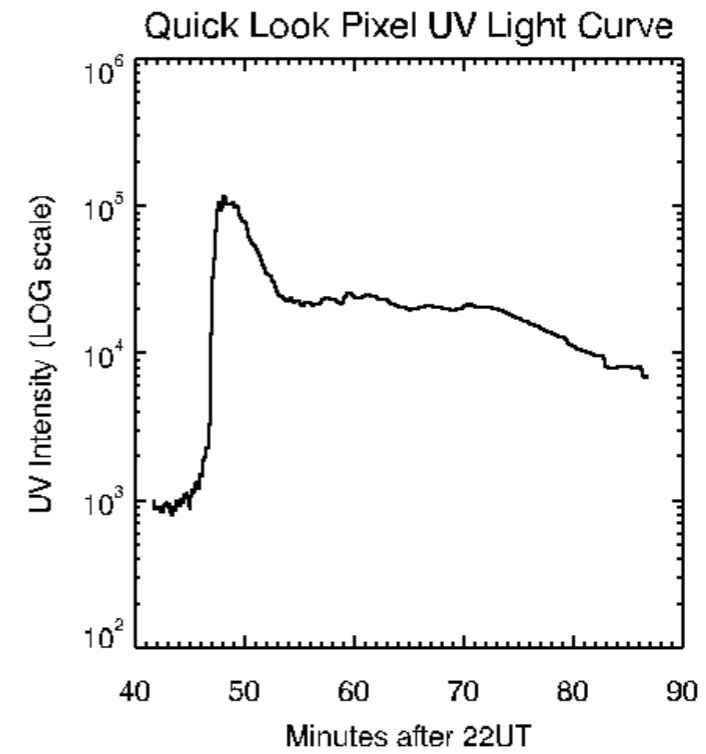
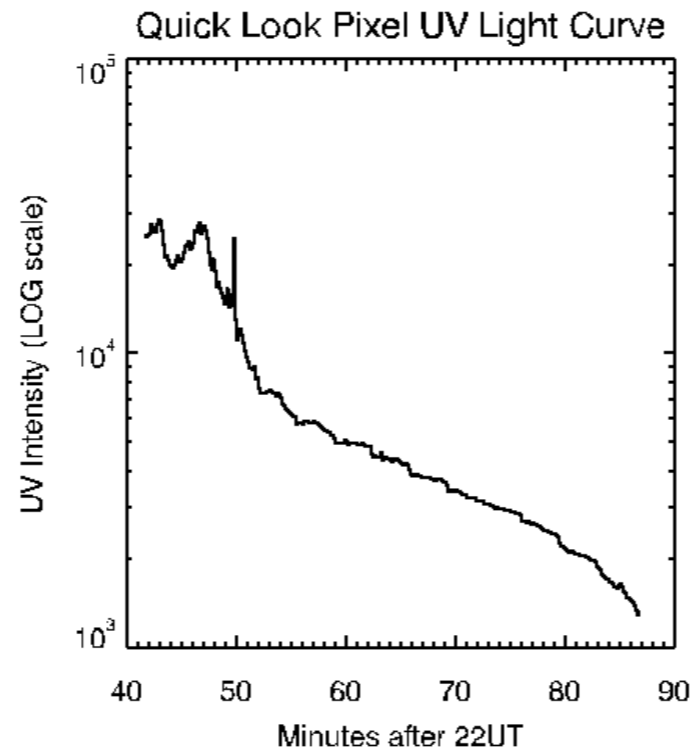
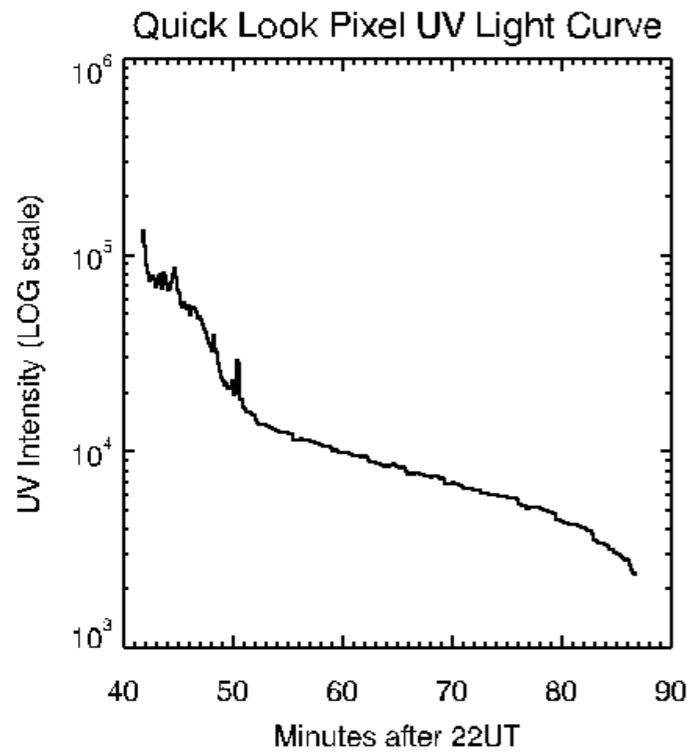
$$C(t) = C_o \exp \left\{ \frac{-(t - T_o)}{\tau} \right\}$$



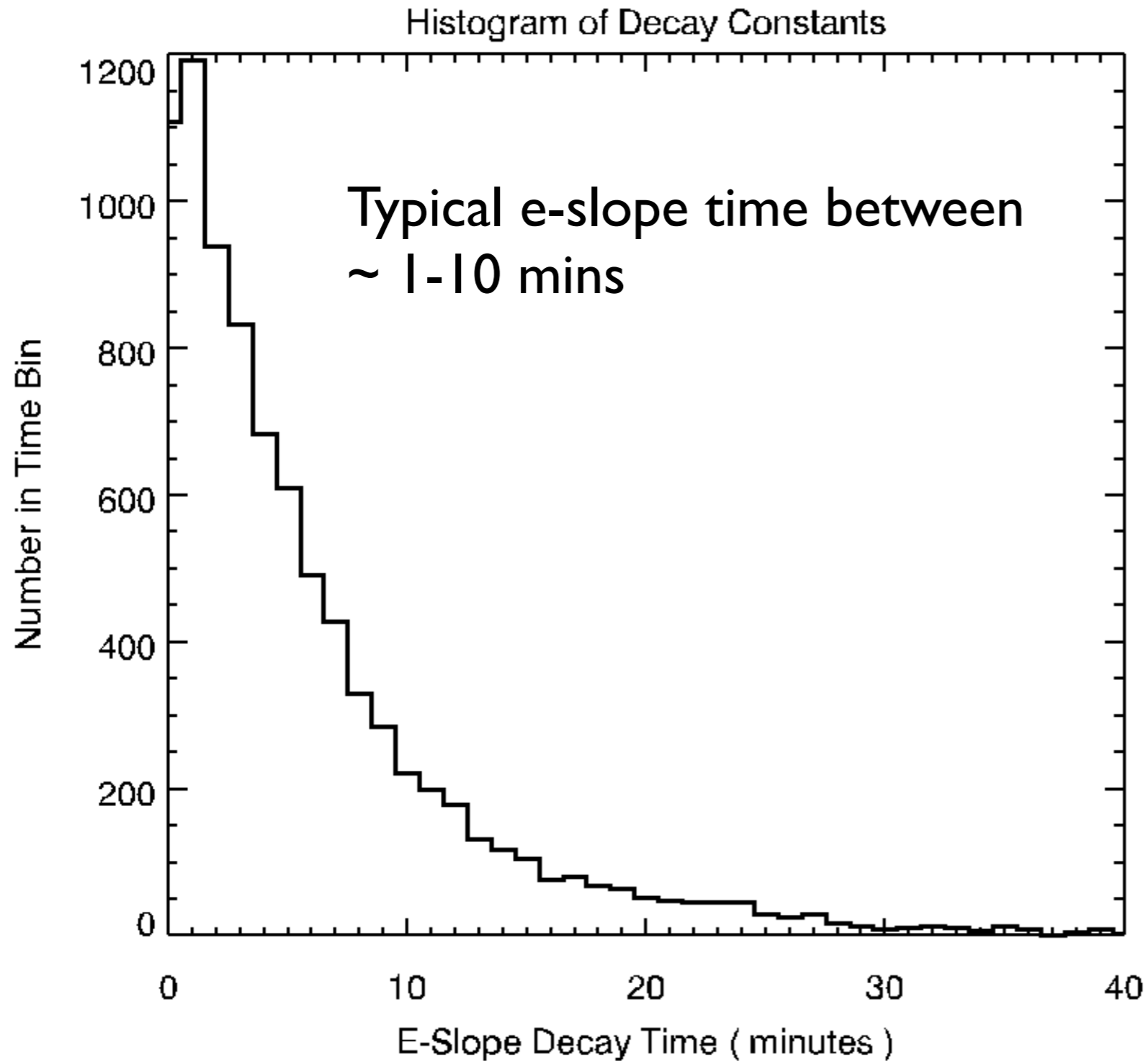
Ribbons Vs Kernels?



Ribbons Vs Kernels?

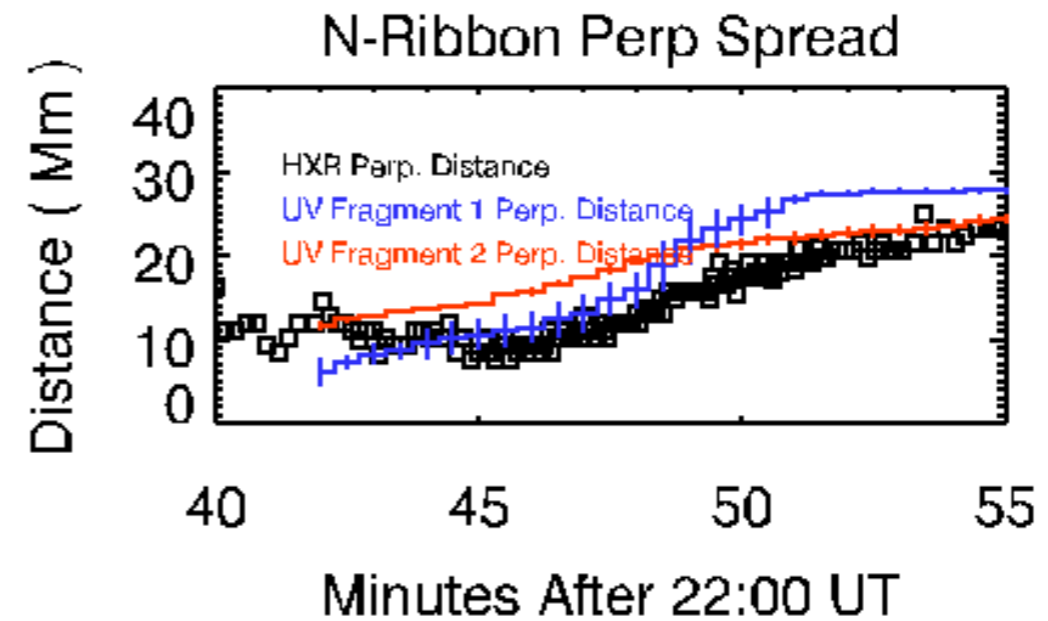
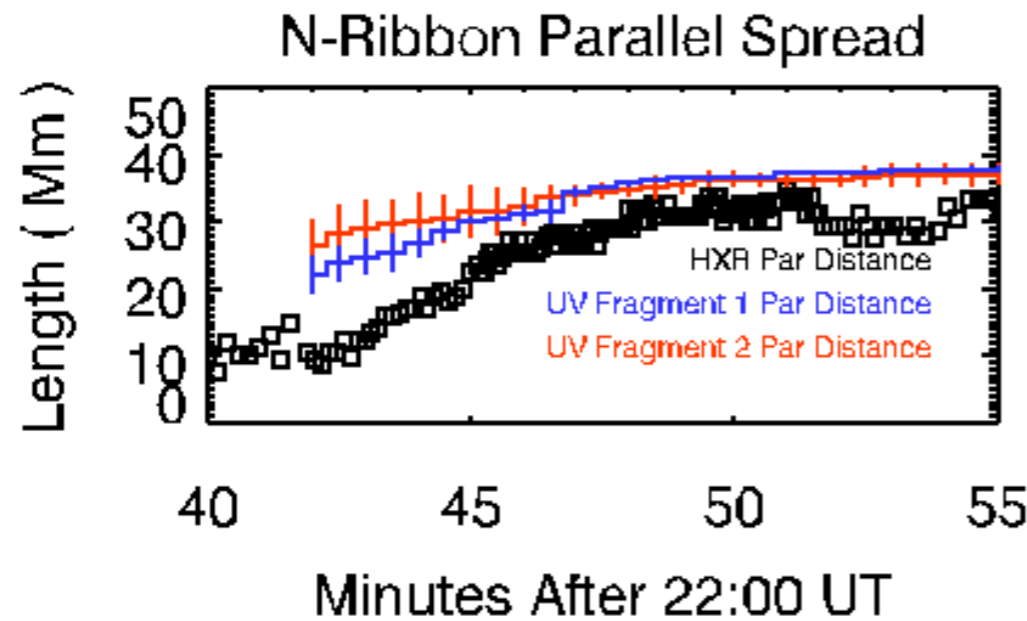


Ribbons Vs Kernels?

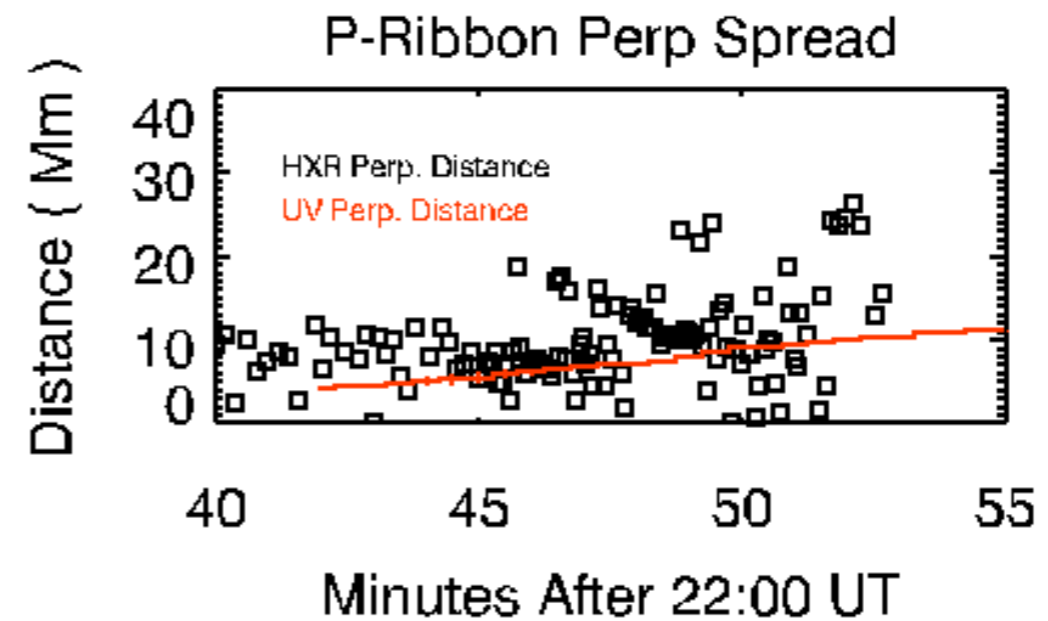
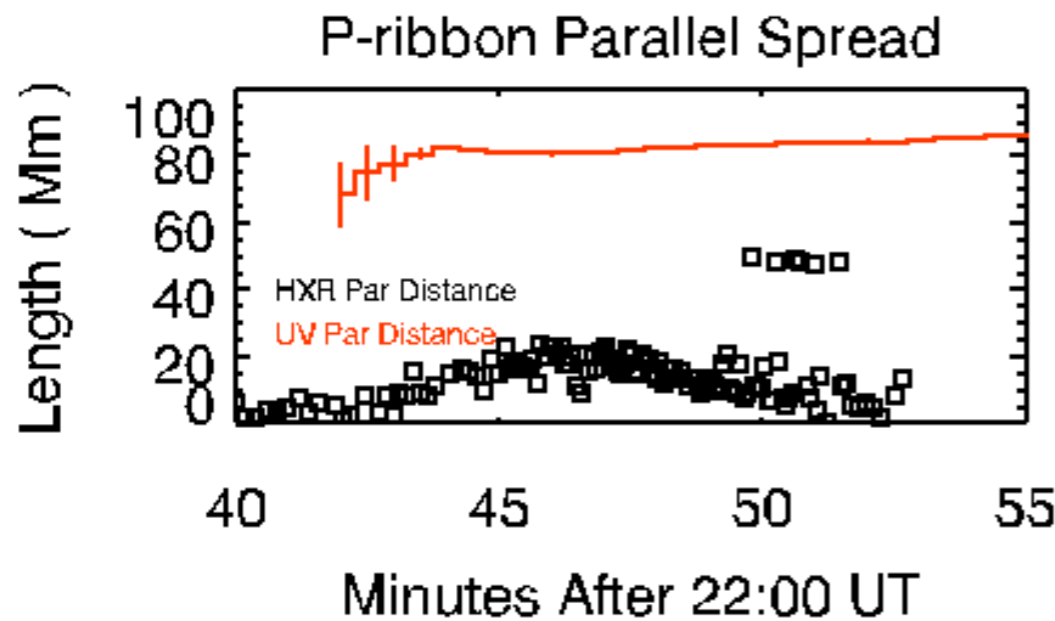


- So, in reality, UV sources are probably small 'moving' foot-points, which have a long decay forming ribbons in the observations.
 - Explanation for UV & HXR being from same source at the end of magnetic field lines.
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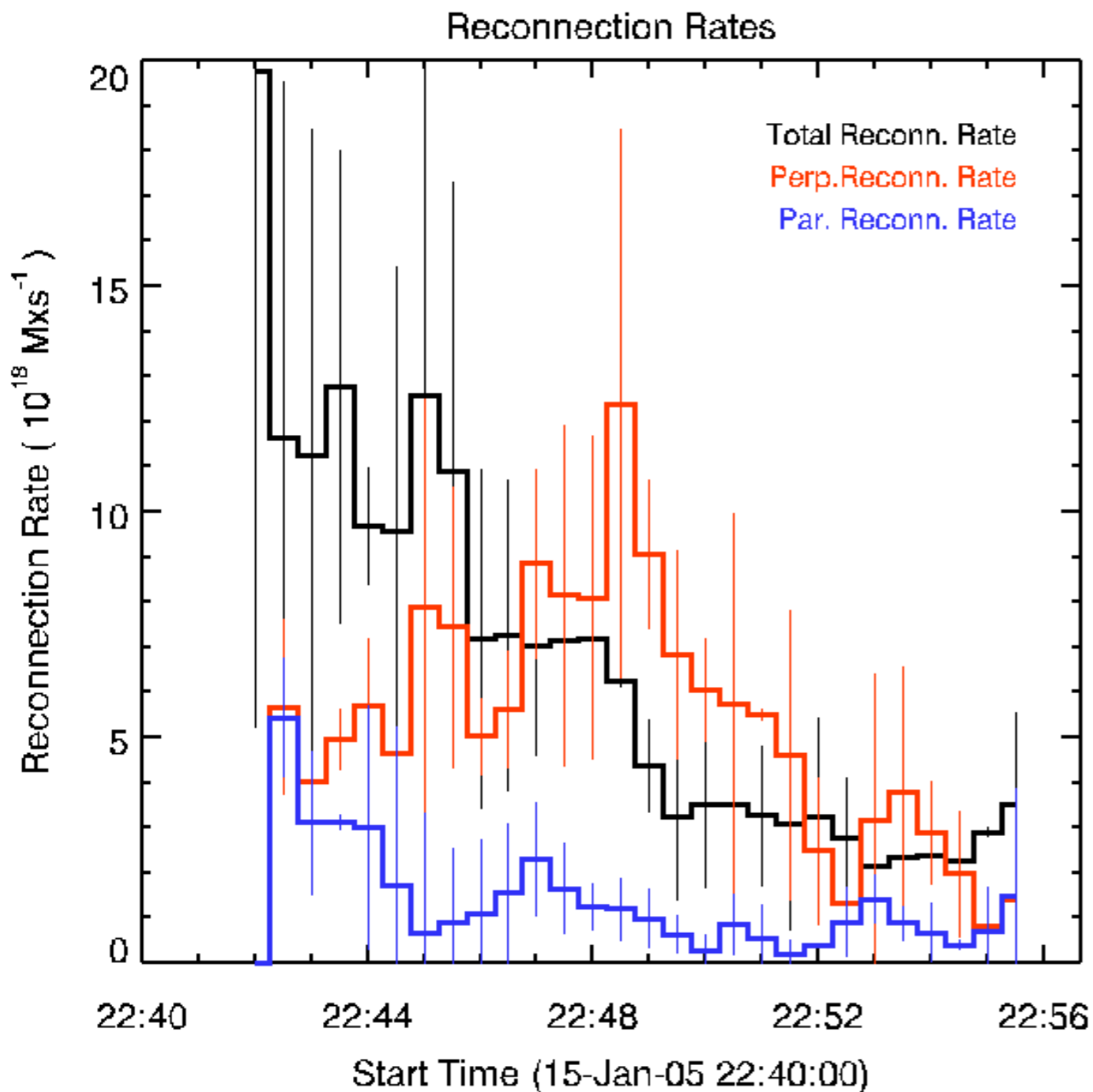
Comparing UV & HXR Motions



Evidence No.2 of the UV & HXR emissions coming from the same source.



Enter Reconnection Rates

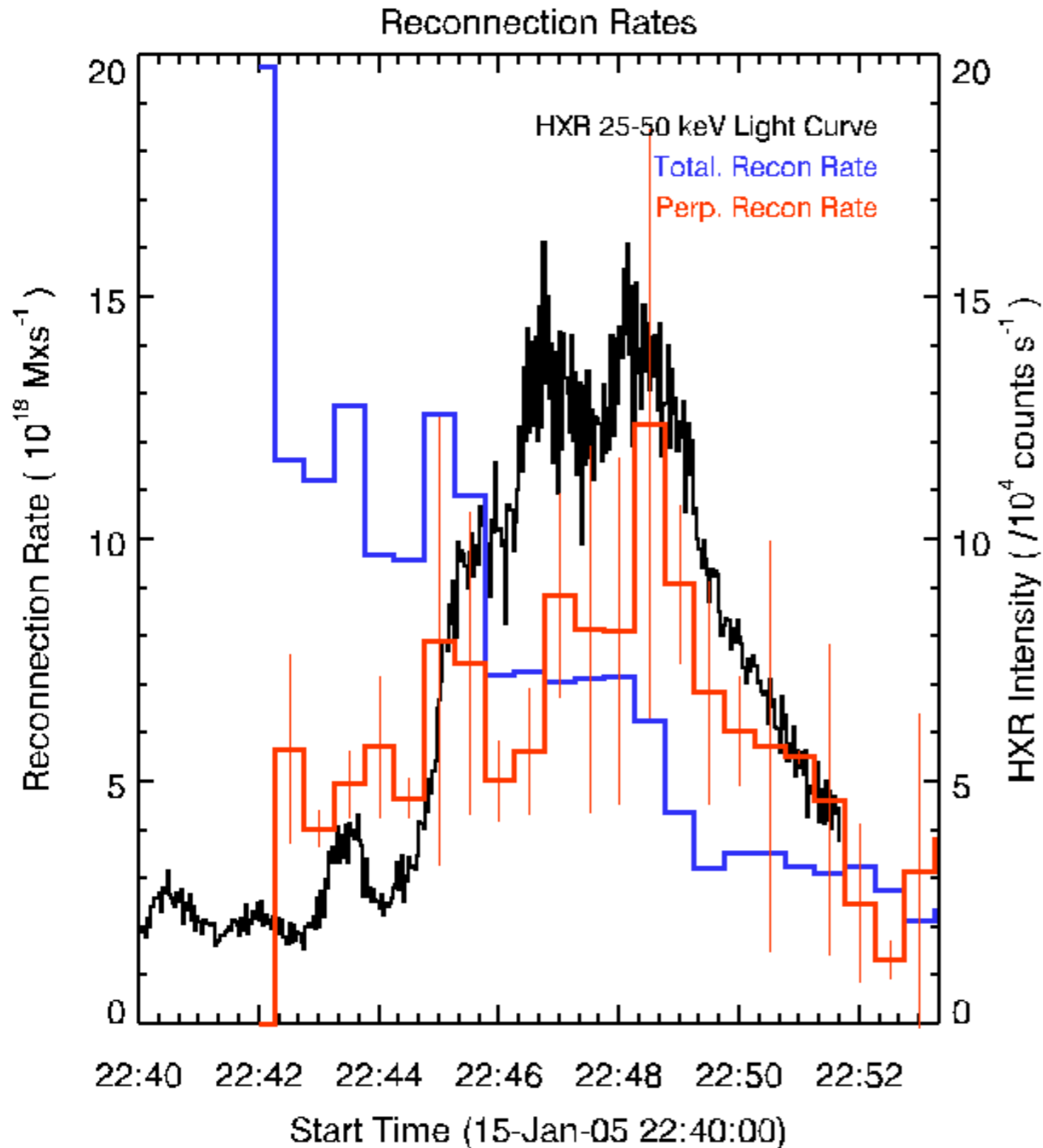


- From the separation into parallel + perp ribbon motions I could decompose the reconnection rates.
- Suggests that parallel reconnection dominates early in the flare, and is then overtaken by the perpendicular reconnection in the peak and main phase of the flare

$$\dot{\Phi} = \dot{\Phi}_{\parallel} + \dot{\Phi}_{\perp}$$

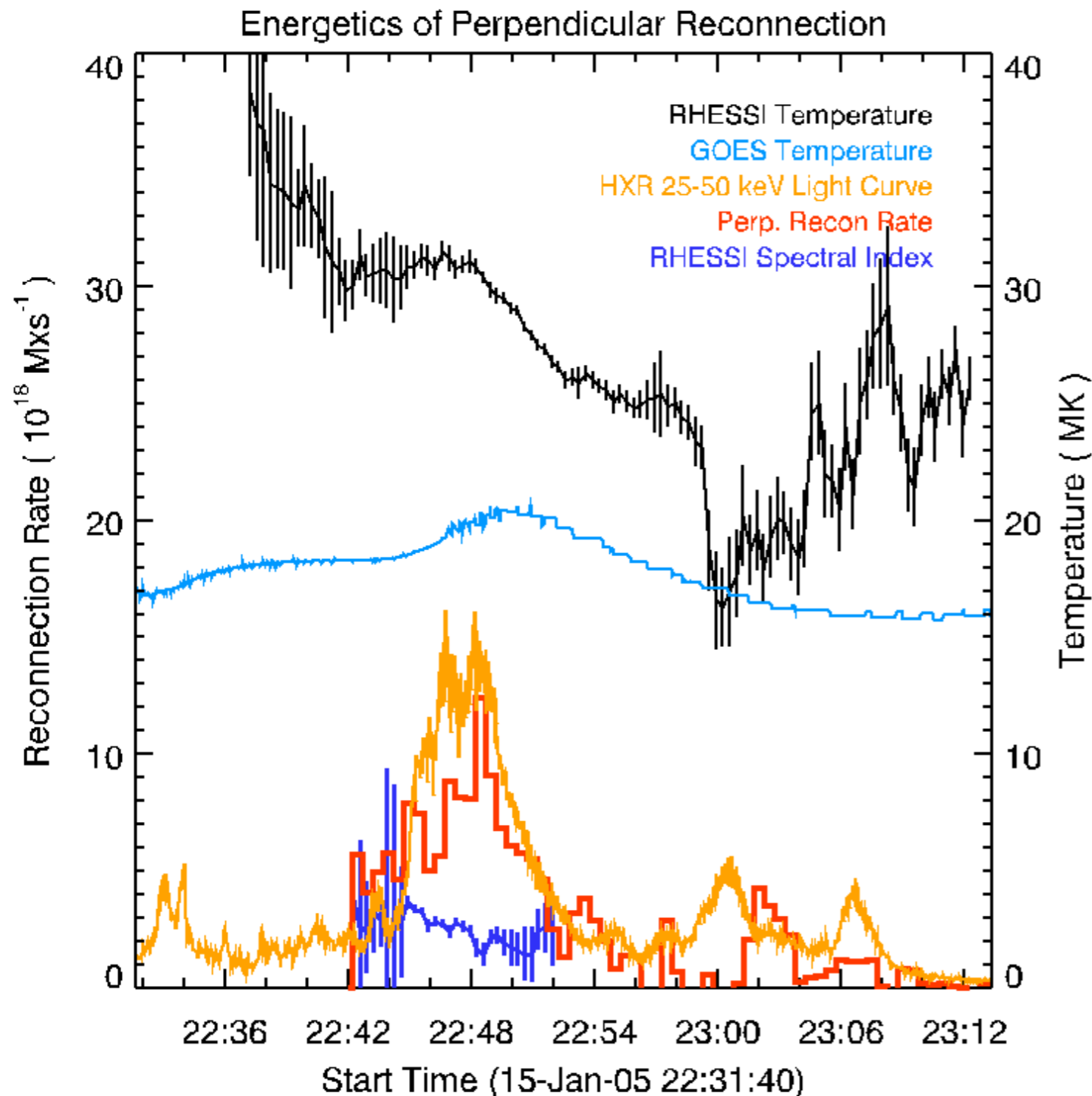
$$\dot{\Phi} \approx \frac{\partial l_{\parallel}(t)}{\partial t} \langle B(t) \rangle l_{\perp}(t) + \frac{\partial l_{\perp}(t)}{\partial t} \langle B(t) \rangle l_{\parallel}(t)$$

Enter Reconnection Rates



- Suggests that the perpendicular reconnection sequence produces more HXR (and UV) emission.
- Indication that energetics related to reconnection pattern.

Some Energetics



- Decreasing spectral index during the peak of the flare means that non-thermal x-ray emission is dominating.
 - Indicates perpendicular reconnection more efficient at non-thermal emission than parallel reconnection.
 - In fact, parallel reconnection seems to only have thermal emission (but this needs further study)
 - Reconnection pattern is connected to the energetics of flares.
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Conclusions

- UV better for some observations- more dynamic range/ better resolution. So, good to have UV & HXR observations together.
 - UV emission is probably foot-points, appearing as ribbons
 - UV emission can act as a proxy of electron precipitation sites.
 - Can use UV emission to infer Reconnection rates.
 - Ribbon motion shows evidence of the 2.5D model of reconnection- ribbons lengthened then widened.
 - Reconnection pattern is connected to the energetics.
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Acknowledgements

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