

Finally, a tearing mode? Quite possibly.

Charles Kankelborg and David McKenzie,
Physics Department, Montana State University

Hannah Alpert, *Yale University*

Sarah Jaeggli, *NASA Goddard Space Flight Center*

Hinode-9, Queen's University Belfast, 2015



Abstract



The solar transition region is a unique laboratory for astrophysical reconnection, owing to its high emission measure, short line of sight integration, and high event rate as compared to the corona. We report a well-resolved explosive event in the solar transition region observed by IRIS, Hinode, and SDO as part of IHOP 252 on April 15, 2014. The event is resolved spatially and temporally in Si iv slit jaw images as a series of brightenings in a bundle of pre-existing loops. In the spectra we see a complex, evolving velocity field indicated by blueshifts, redshifts, and nonthermal line broadenings. Imaging from XRT and AIA shows nearly simultaneous manifestation in all bands, suggesting localized heating. The evidence leads us to conclude that magnetic energy is being converted rapidly to kinetic energy in this event. We discuss the possibility that this is a direct observation of tearing mode reconnection in a transition region current sheet. The combination of multithermal, high resolution imaging and spectroscopy makes this a compelling case for a possible tearing mode in the solar atmosphere.



Outline



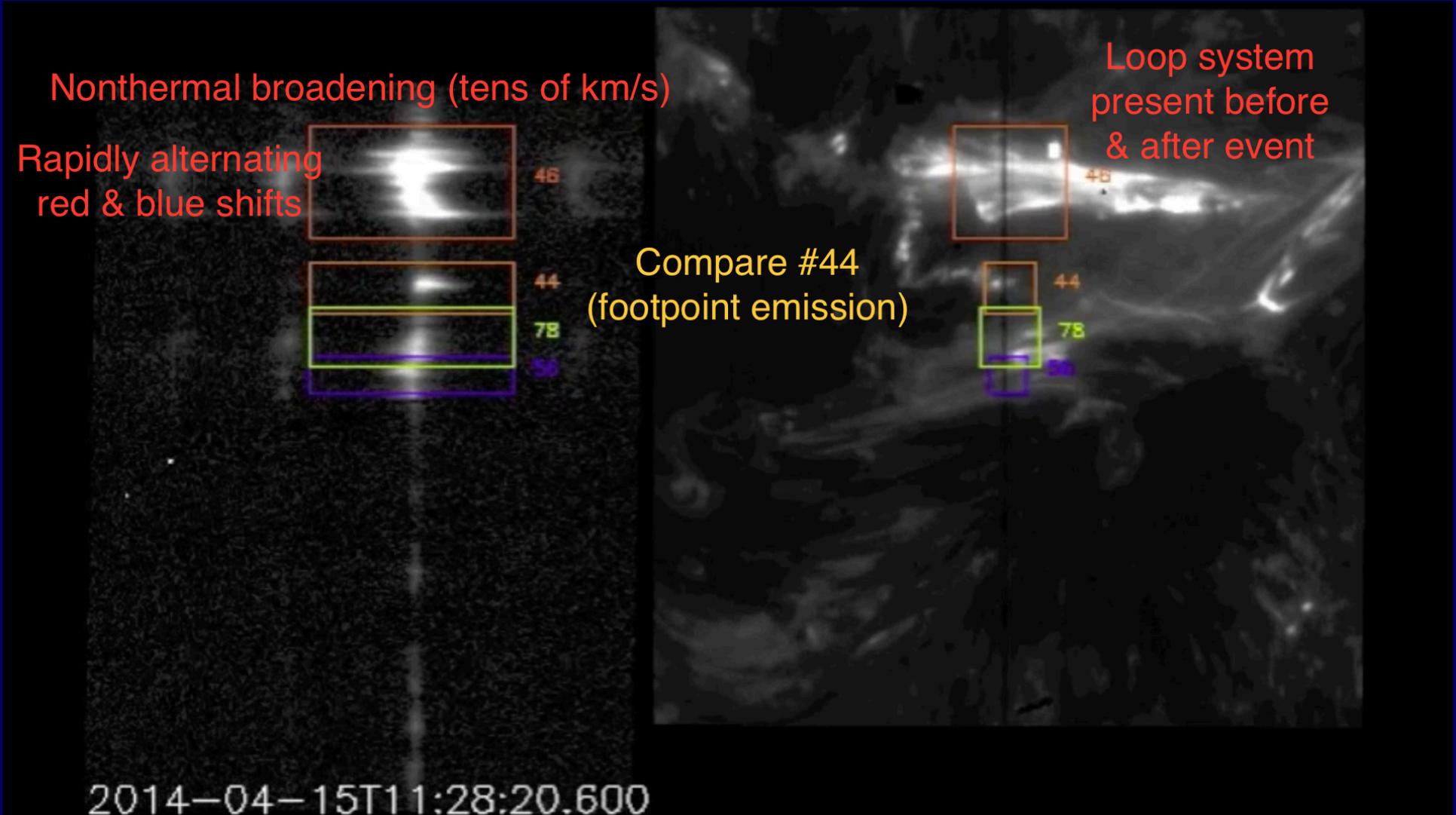
1. Motivation
2. Observations
3. Interpretation: Tearing Mode
4. Analysis (Beginnings)
5. Conclusions

Motivation



Reconnection is central to our interpretation of flares and heating yet, in a sense, elusive.

- Observations of coronal reconnection are mainly indirect, e.g. ribbons, outflows, postflare loops.
- The reconnection region in the corona has low emission measure and is often obscured line-of-sight confusion.
- Consider the **transition region**:
 - High event rate (explosive events)
 - High density in the reconnection region
 - Minimal LOS confusion
- **Can we resolve a reconnection region in the TR?**



Event #46: 11:17-11:33 UT (10% of obs duration)



IRIS Si IV



Si IV profile (left) and SJI (right). Square root scaled.

Hot loops in 94 \AA & 131 \AA connect to
ribbon (#44) crossing IRIS slit.
 1600 \AA channel resembles IRIS Si IV.

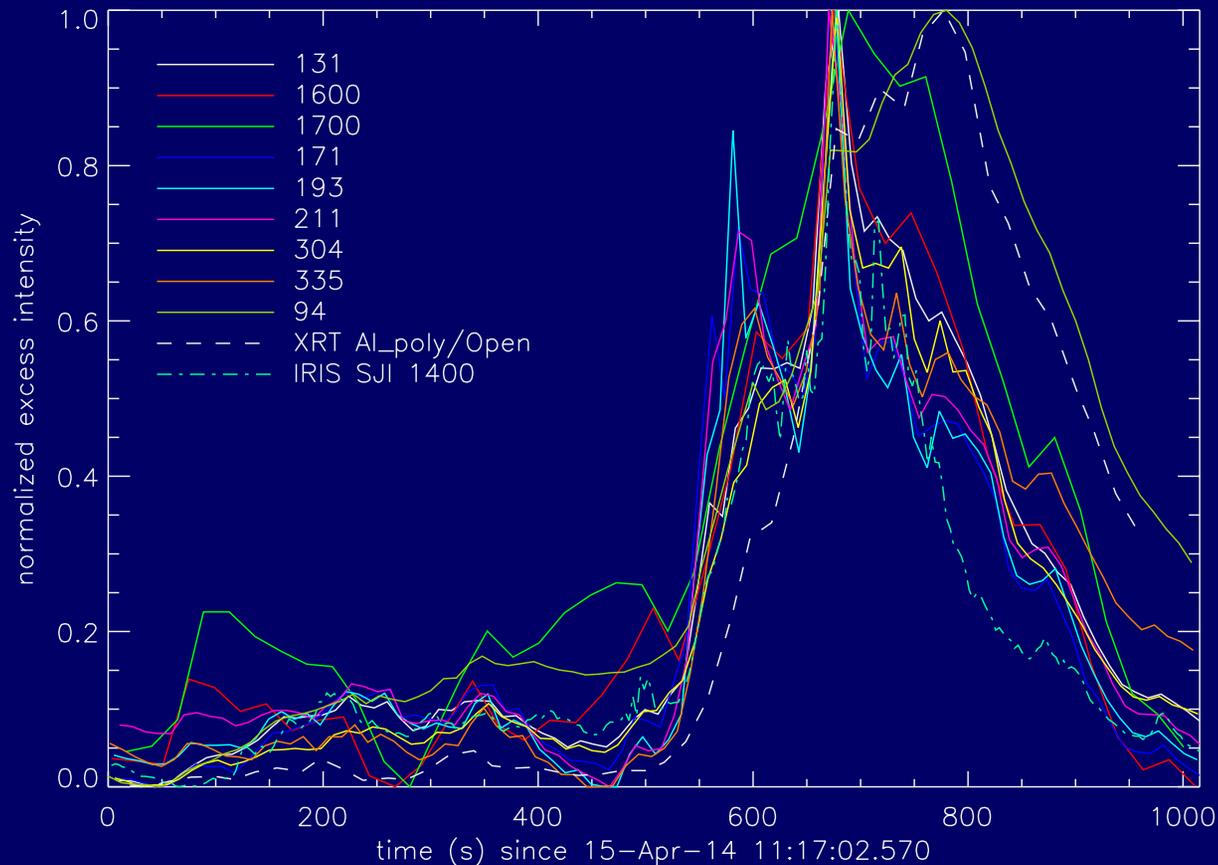


Hinode/XRT Soft X-Ray



XRT Al_poly/Open resembles AIA 94 Å.

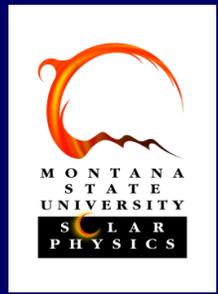
AIA Light Curves

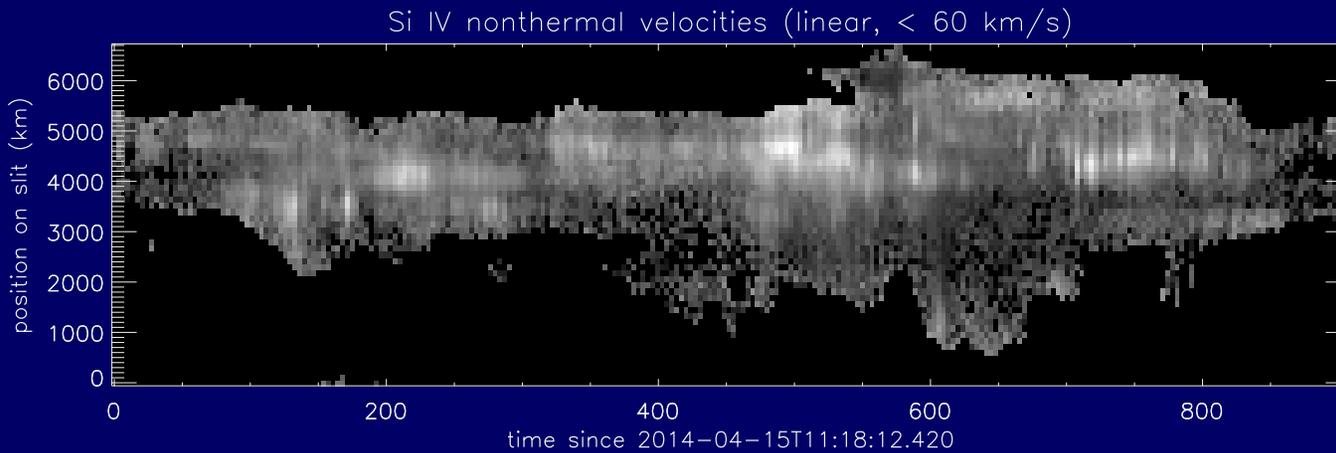
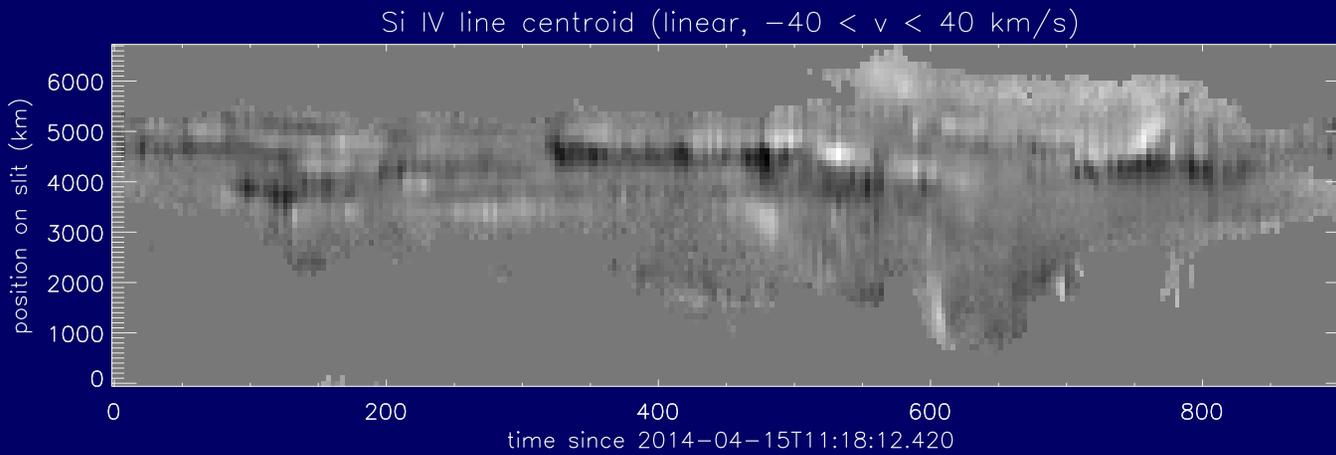
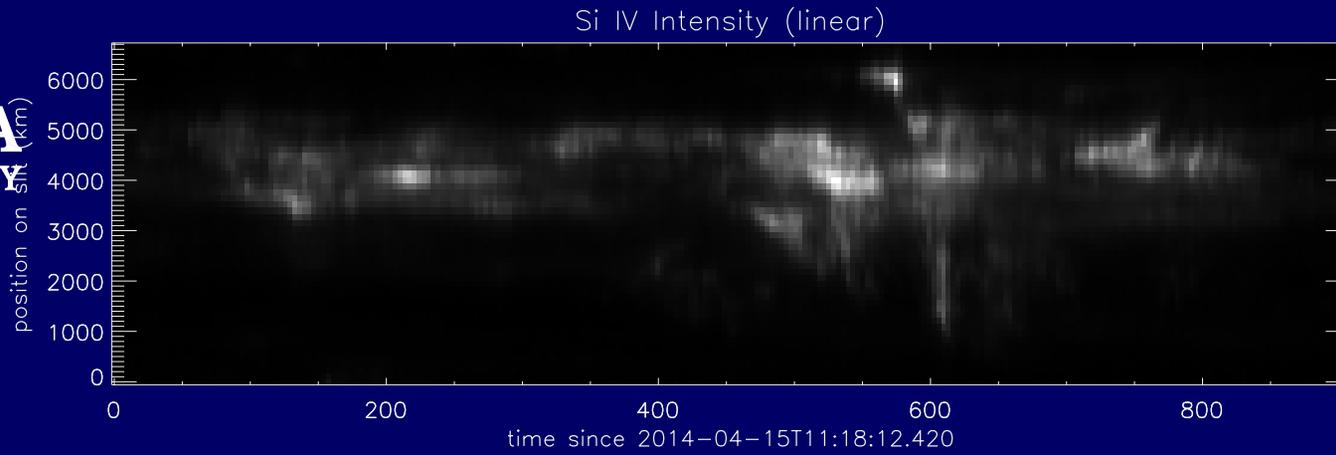


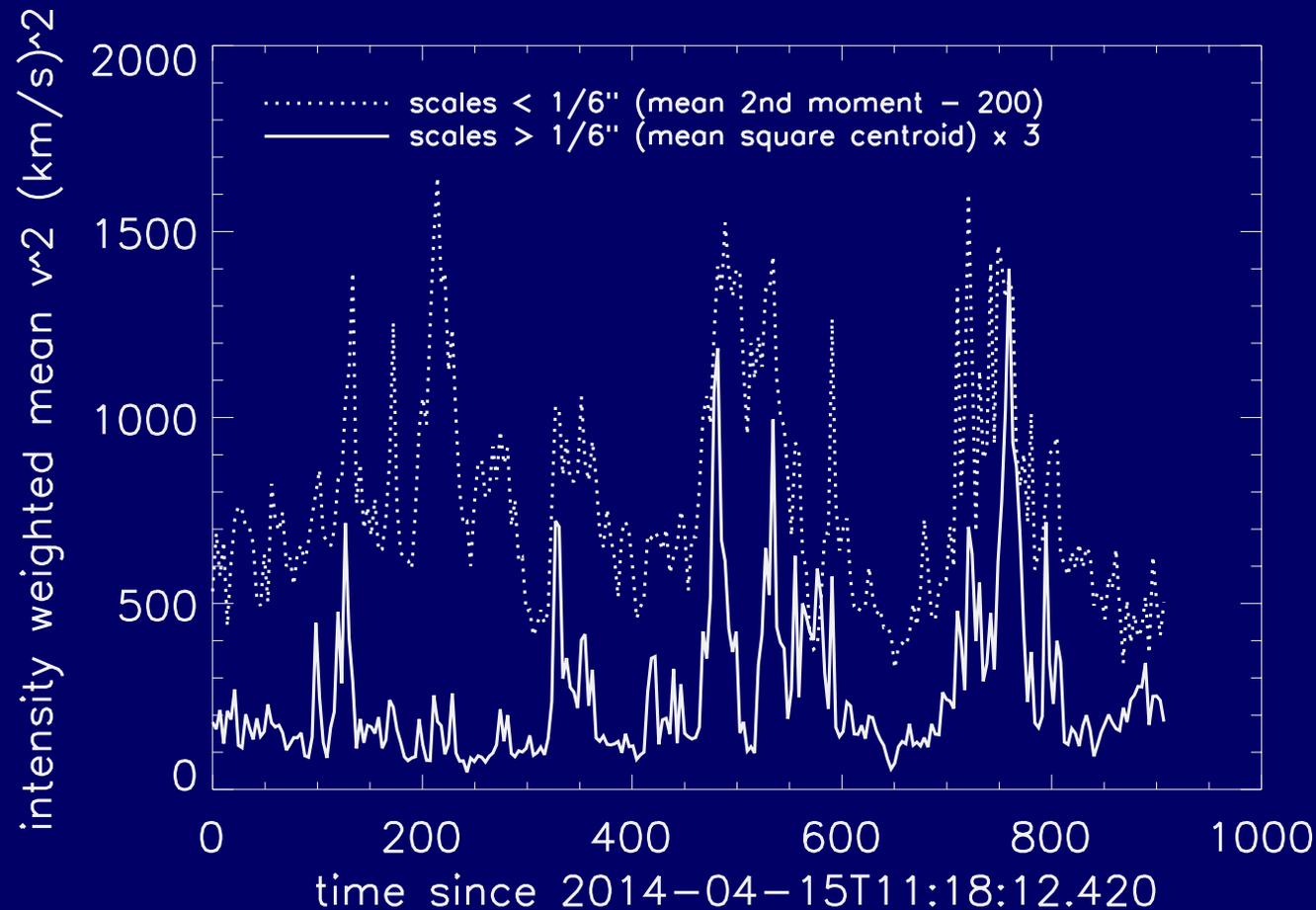
Simultaneous brightening in all channels at 670 s.
Multithermal, perhaps far from ionization equilibrium.
XRT and AIA 94 Å show delayed response.



HMI LOS Magnetic Field







Most of the power $\langle Iv^2 \rangle / \langle I \rangle$ is in sub-pixel scales.
 Power at both scales changes rapidly, and in unison.

Conclusions

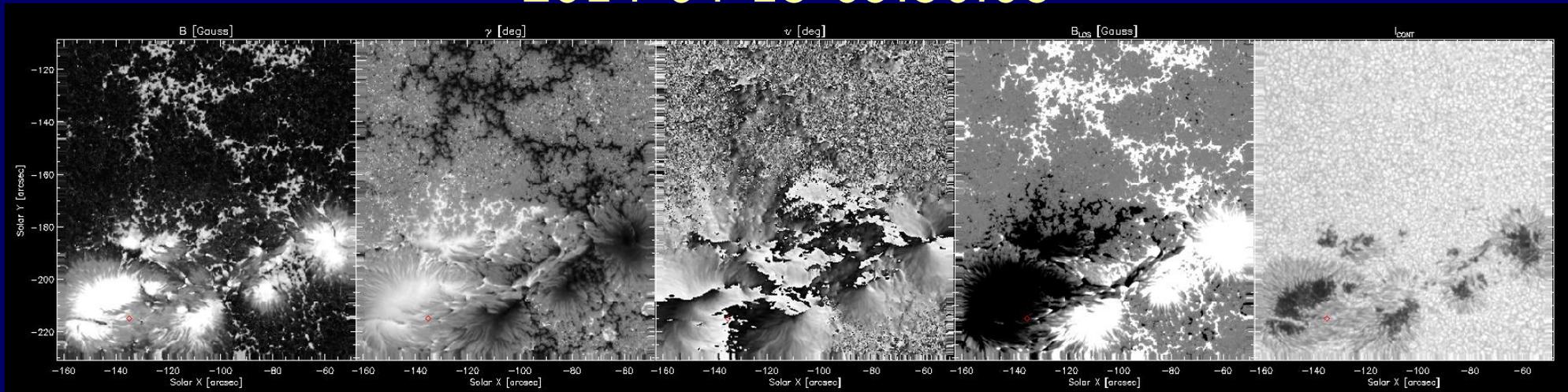
1. The locus of reconnection is routinely, directly observable in the TR.
2. We interpret this event as a tearing mode in its nonlinear phase.
3. Most of the nonthermal kinetic energy is at scales < 120 km.
4. There is a persistent, slowly varying flow pattern at ~ 1 Mm scale, BUT
5. Rapid (< 3 s) fluctuations occur simultaneously across all scales!



Backup Slides

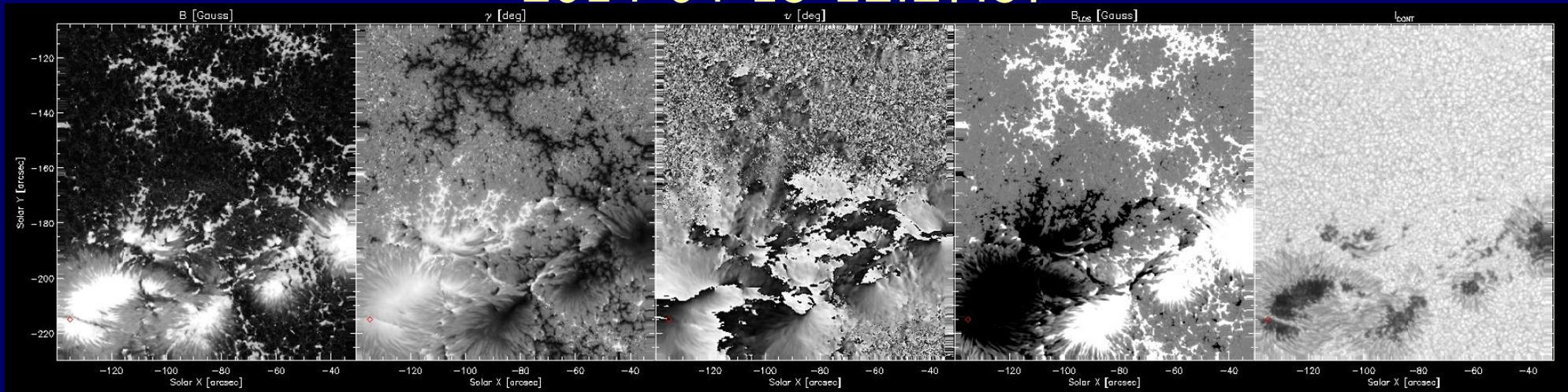


2014-04-15 09:56:08



Hinode SOT/SP

2014-04-15 12:27:57



Emission external to reconnection region:

X Postflare loops	Emission in all channels precedes footpoint brightening.
X Reconnection outflow	Bidirectional flows do not trace back to a single remote reconnection site.
X Footpoint emissions	Loop morphology; red & blue juxtaposed and alternating. Contrast event #44 (ribbon with redshifted spectrum; crenulated morphology).

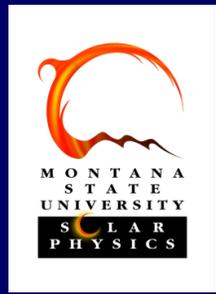
Emission external to reconnection region:

X Alfvén waves launched by reconnection near footpoints	SJI shows initiation near middle, not at either end.
X Response to overlying hot reconnection	We see a ribbon (#44) connected to hot loops, but this idea fails to explain juxtaposed red & blue shifts.

Emission in the vicinity of the reconnection region:

X Single X-point	Morphology and evolution are too complex.
X Many independent events	Correlated motions in SJI suggest that the events are strongly coupled. Timescales consistent with coupled evolution.
? Tearing mode	Tentative interpretation.

Back of Envelope...



Fastest-growing mode $k_M \sim 1/l$, apparent growth rate $\omega_M = 0.3 \text{ s}^{-1}$. In linear tearing mode theory,¹

$$k_M l L_u^{1/4} = 1.4, \quad \omega_M l^2 = 0.6 \eta L_u^{1/2},$$

Where l is current sheet thickness, $L_u = l v_A \eta^{-1}$ is the Lundquist number, and η is resistivity.

Caveats:

- What we observe is likely **nonlinear** development.
- $\langle I v^2 \rangle / \langle I \rangle$ introduces time dependence through $I(y, t)$; is this appropriate for estimating rise-time ω_M ?

¹Furth *et al.* (1963); see Priest & Forbes (2000).