Recent Flare Observations and Global Energetics: *How does reconnection fit?*

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Outline

Topics:

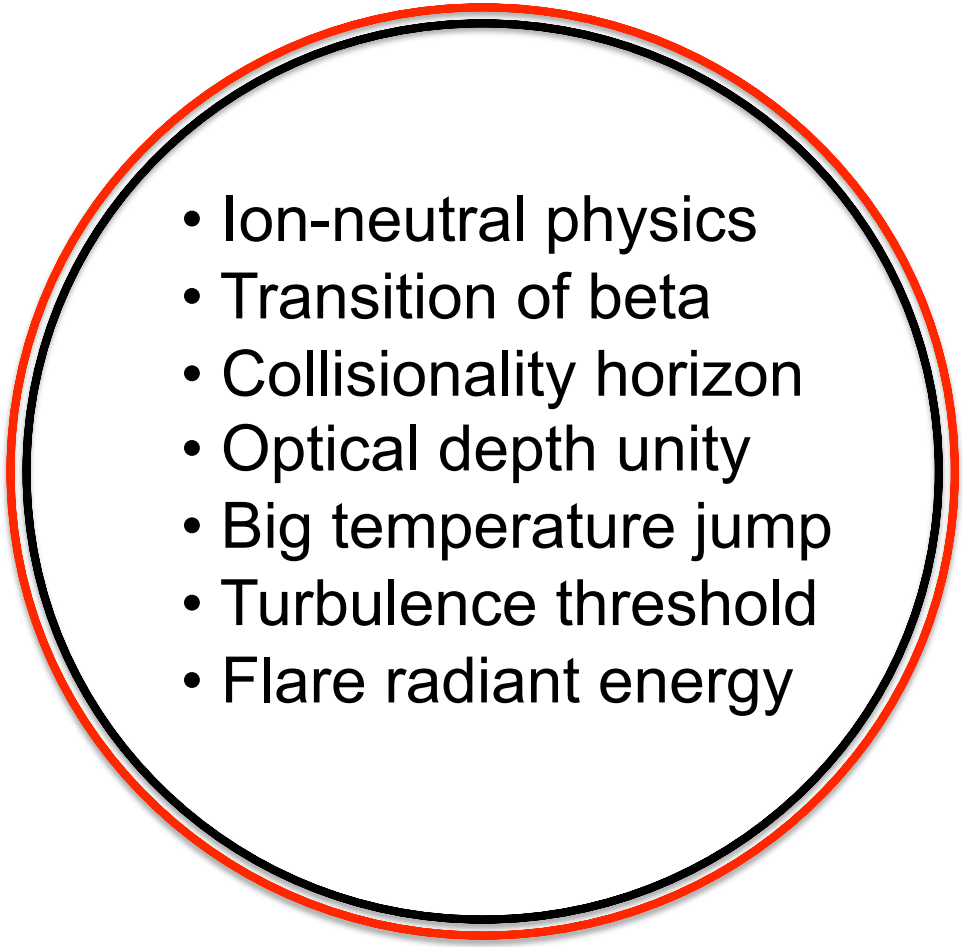
Conceptual framework

New observations

Role of reconnection

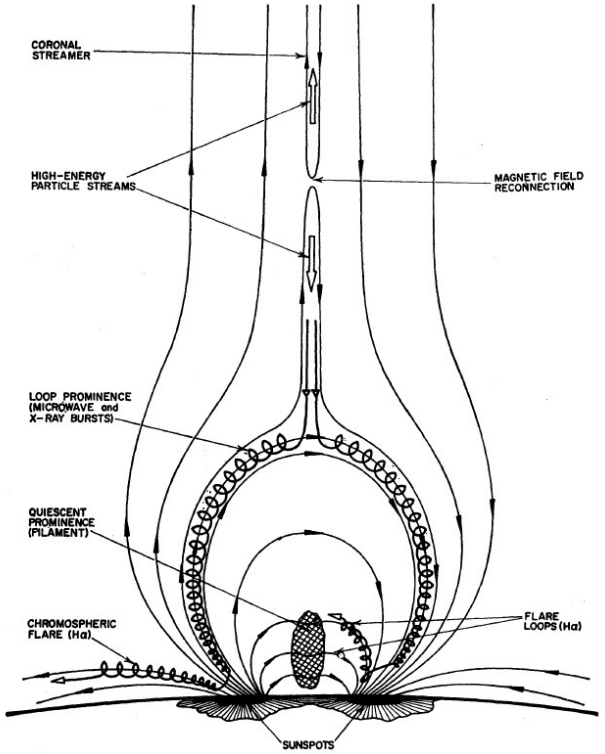
Thesis: Not enough attention is paid theoretically to the observable global properties of the flare process.

The photosphere-corona interface region

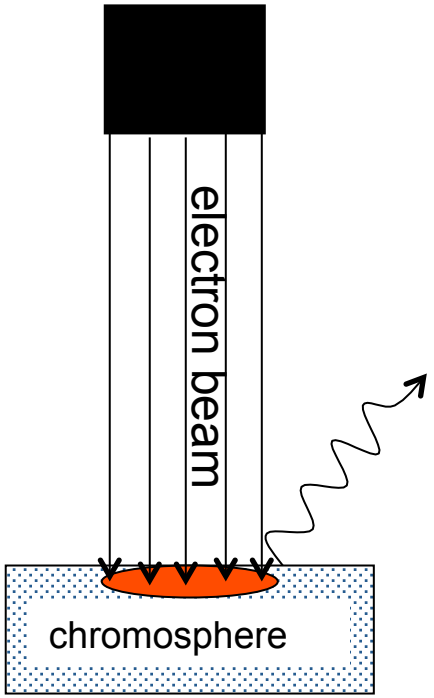


Inexplicably, this physics-laden domain (the chromosphere/TR) is often taken as a boundary for numerical simulations!

How does flare energy flow?



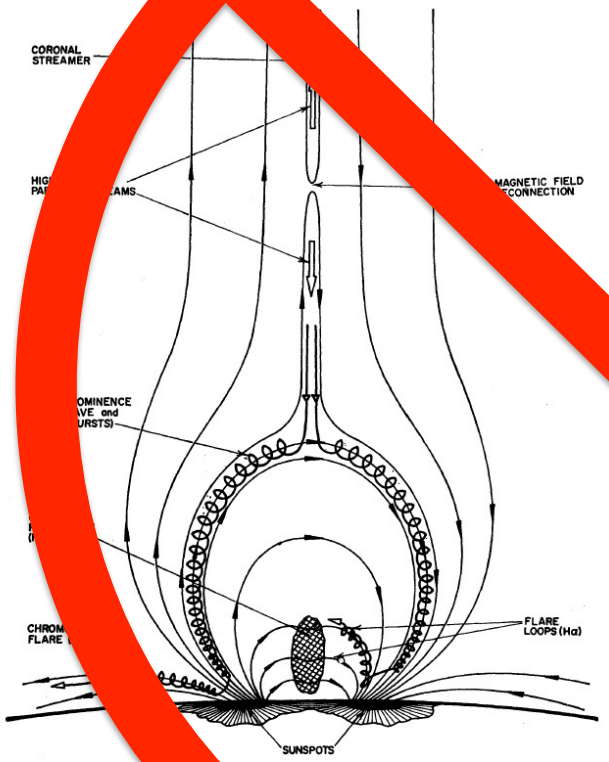
Strauss & Papagiannis, ApJ 164, 369 (1971) – basically, “CSHKP”



Kane & Donnelly, ApJ 164, 171 (1971) – basically, the “thick-target model”

Critique of standard models

- There is no self-consistency between the particle and fluid pictures. Basically the paradigms ignore one another.
- The existing models have difficulty with energy conservation, and don’t address momentum either.
- The pre-existing current sheet and the black box are purely *ad hoc.*



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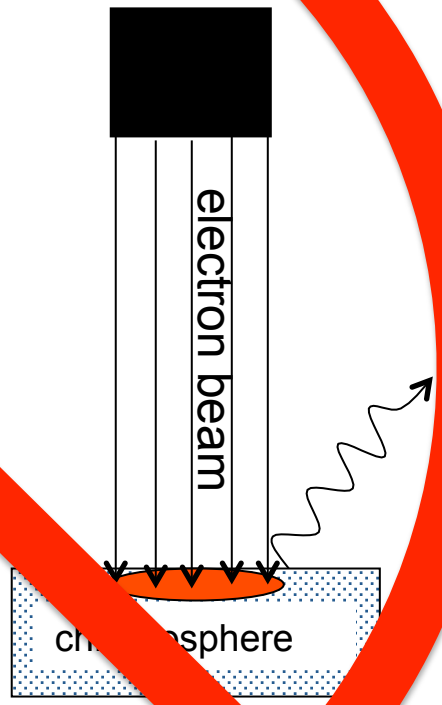


Kane & Donnell[illegible] 164, 171 (1971) – basic[illegible], the “thick-target model”

The Aly-Sturrock conjecture

- A “least upper bound” for the excess of the magnetic free energy of a stellar corona would be comparable to the energy of the fully open field (paraphrased from Aly, 1984).

- There may be ways around this (six lines of argument; see Forbes, 2000, or the Shibata & Magara LRAA article). But – apologies to Shakespeare - ‘The theorist doth protest too much, methinks!’

- But it makes intuitive sense: field-aligned currents add magnetism and should inflate the field geometrically as they store energy (Low & Lou, 1991; Georgoulis et al., 2012).

Implosion Conjecture

• Flare energy-release time scales are much shorter than the time scales for energy build-up

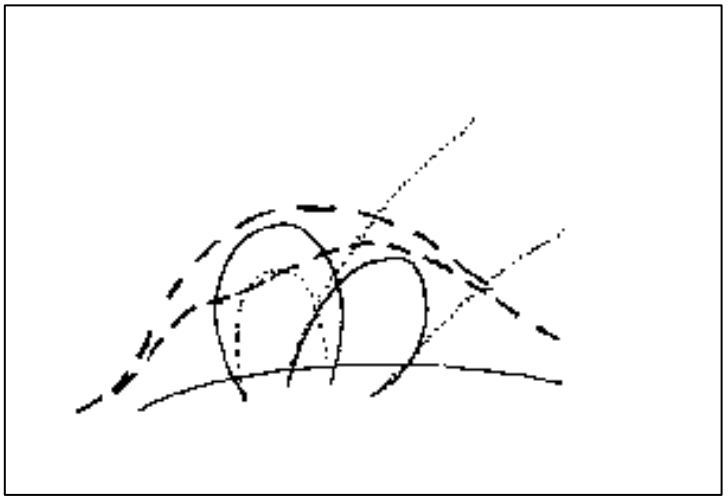
• The Alfven speed in the photosphere is low, so there can be little real-time energy transfer

• The total magnetic energy increases if the scale increases, as is seen in the Low & Lou exact solutions

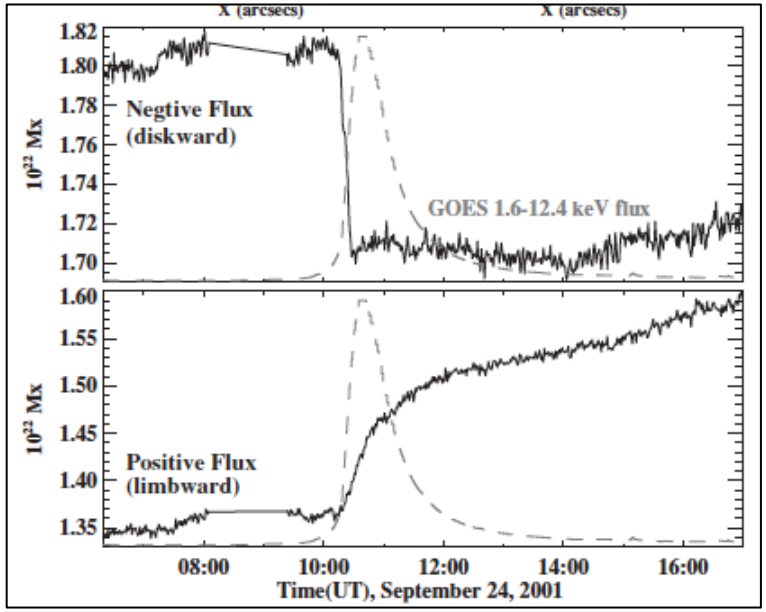
• Within the volume of energy storage, a shrinkage of the B^2 level surfaces must occur in some parts of the volume circumscribing the required energy E^*:

$$E^*(\Delta t) < \int_{V^*} \left(\frac{B^2}{8\pi}\right) dV \sim \frac{B^2}{8\pi}\frac{4\pi}{3}(\Delta t v_A)^3$$

The Magnetic Implosion



Hudson, ApJ 531, L75 (2000)



Wang & Liu, 2010

In this cartoon, the heavy dashed lines show “magnetoisobars,” which must collapse into a smaller structure when the flare happens.

The observations show an inward tilt of the photospheric vector field, matching the time of energy release. (e.g. Liu & Wang, 2009)

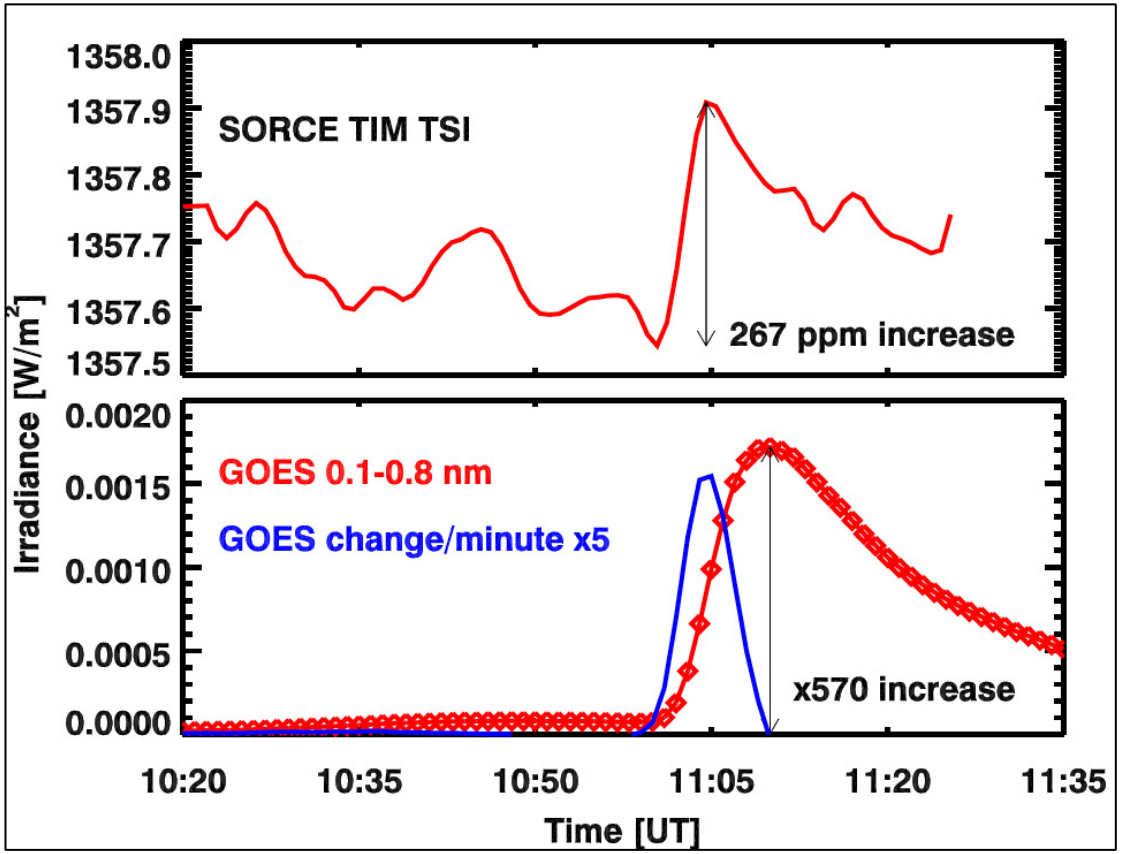
Recent observational results

(1) Flares observed in total irradiance and the impulsive phase

(2) White-light flare heights

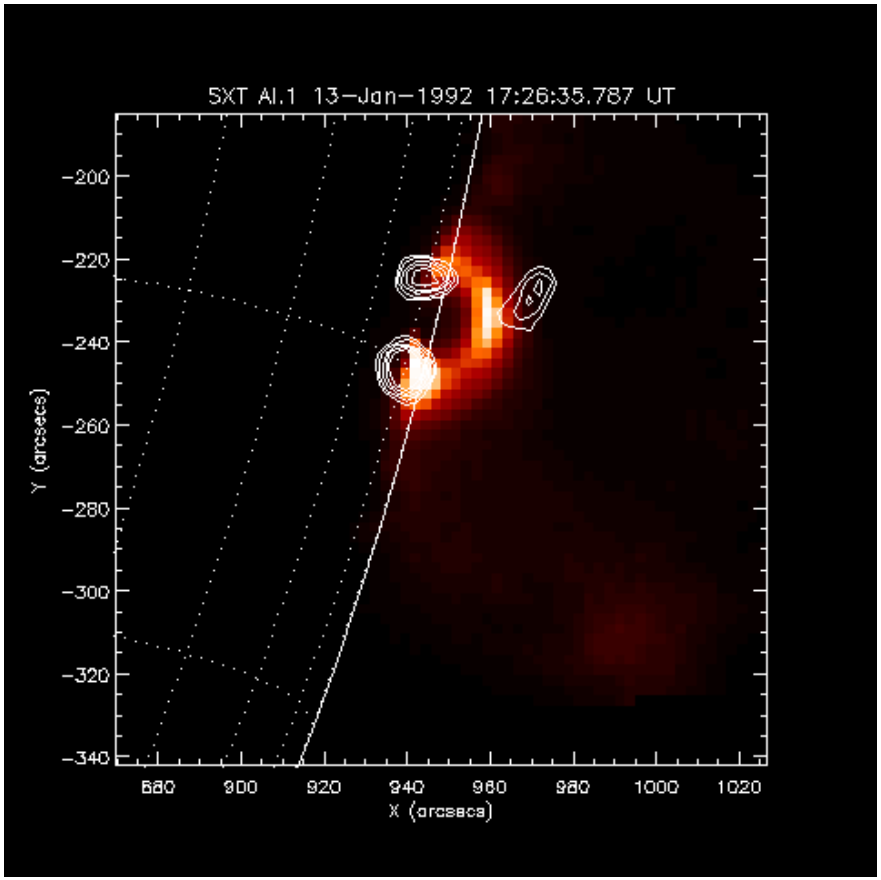
(3) The implosion itself

Bolometric detection

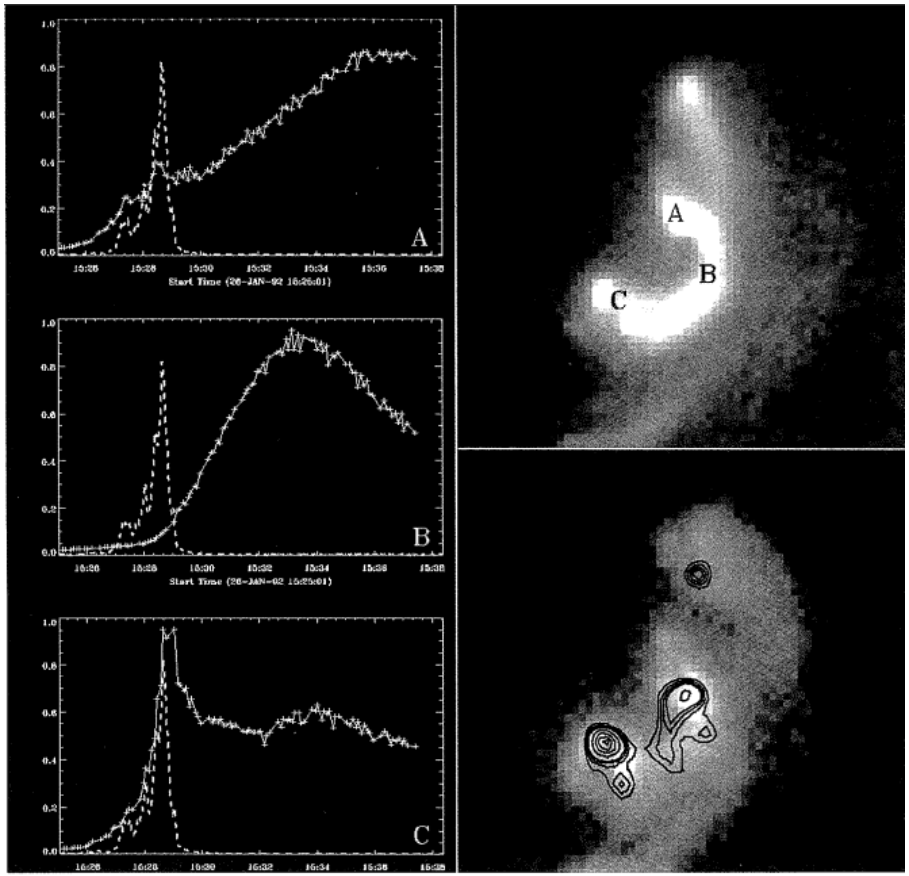


- Woods et al. (2003); Kretzschmar (2011)
- The impulsive phase is energetically dominant

Impulsive soft X-ray footpoints

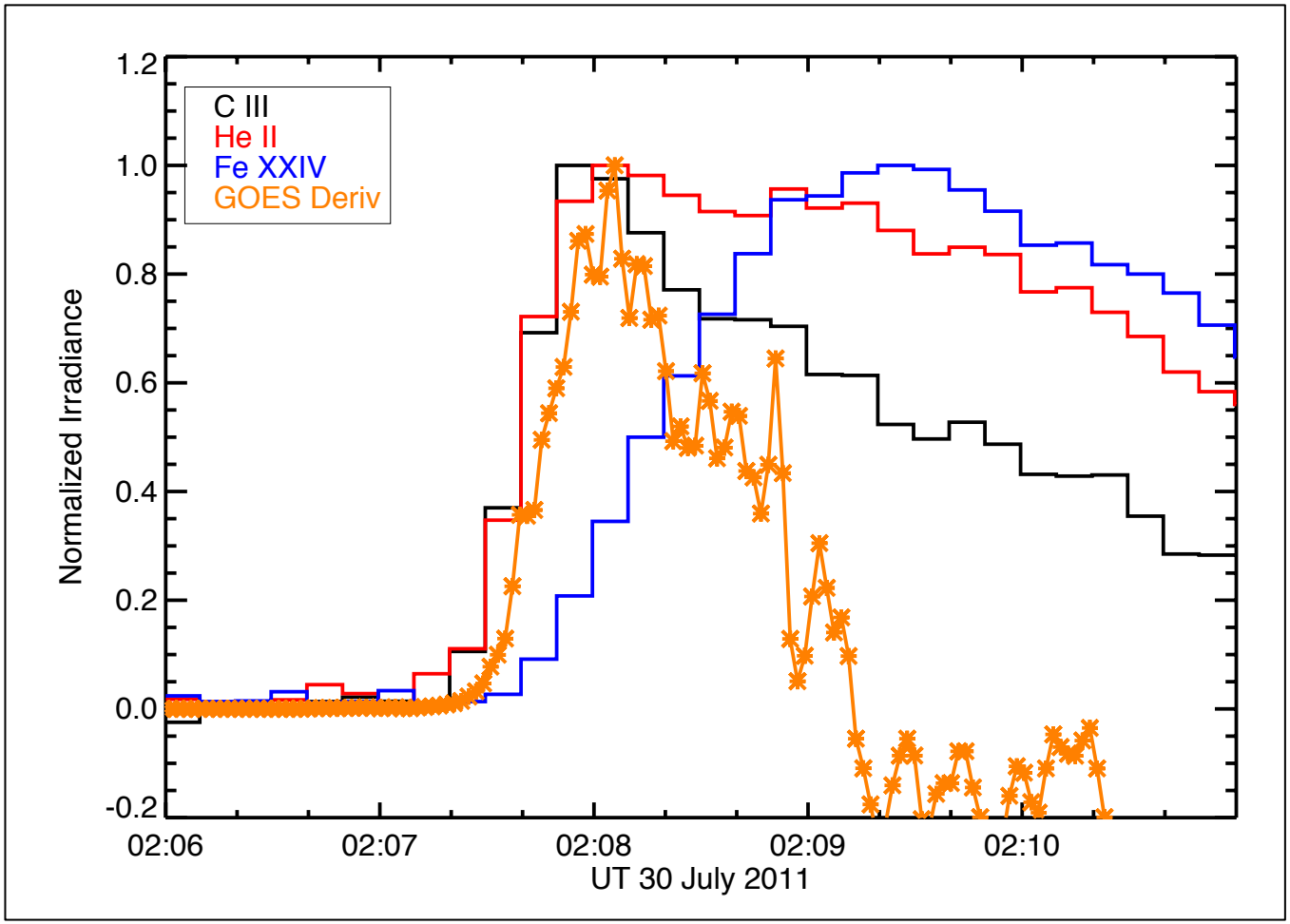


Above-the-loop-top
(Masuda et al. 1994)



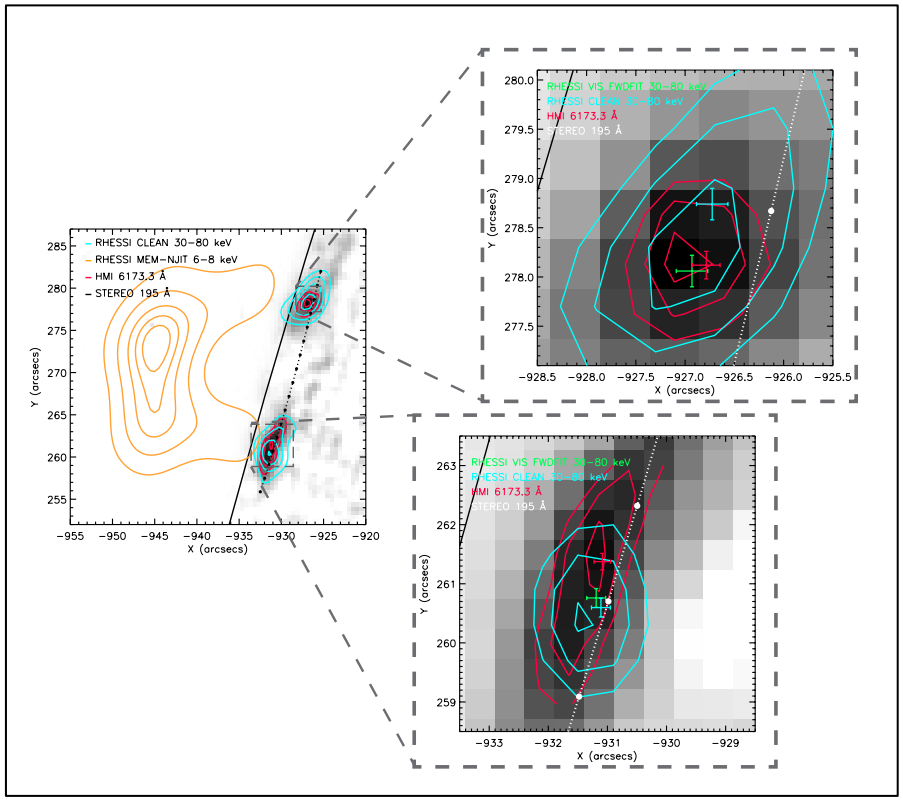
Impulsive footpoints
(Hudson et al. 1994)

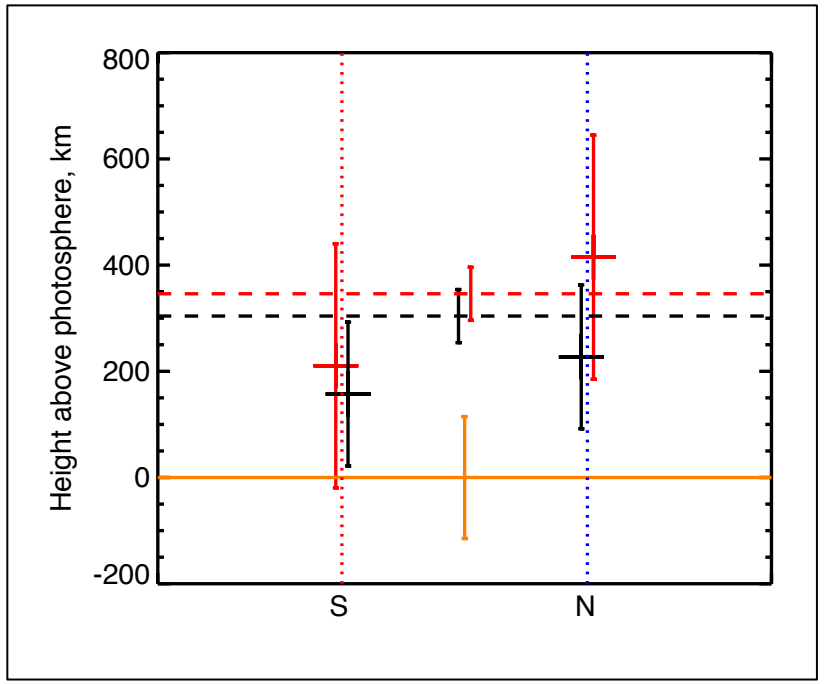
Impulsive soft X-ray footpoints



SOL2011-07-30 (EVE and GOES)

Where does flare energy appear?

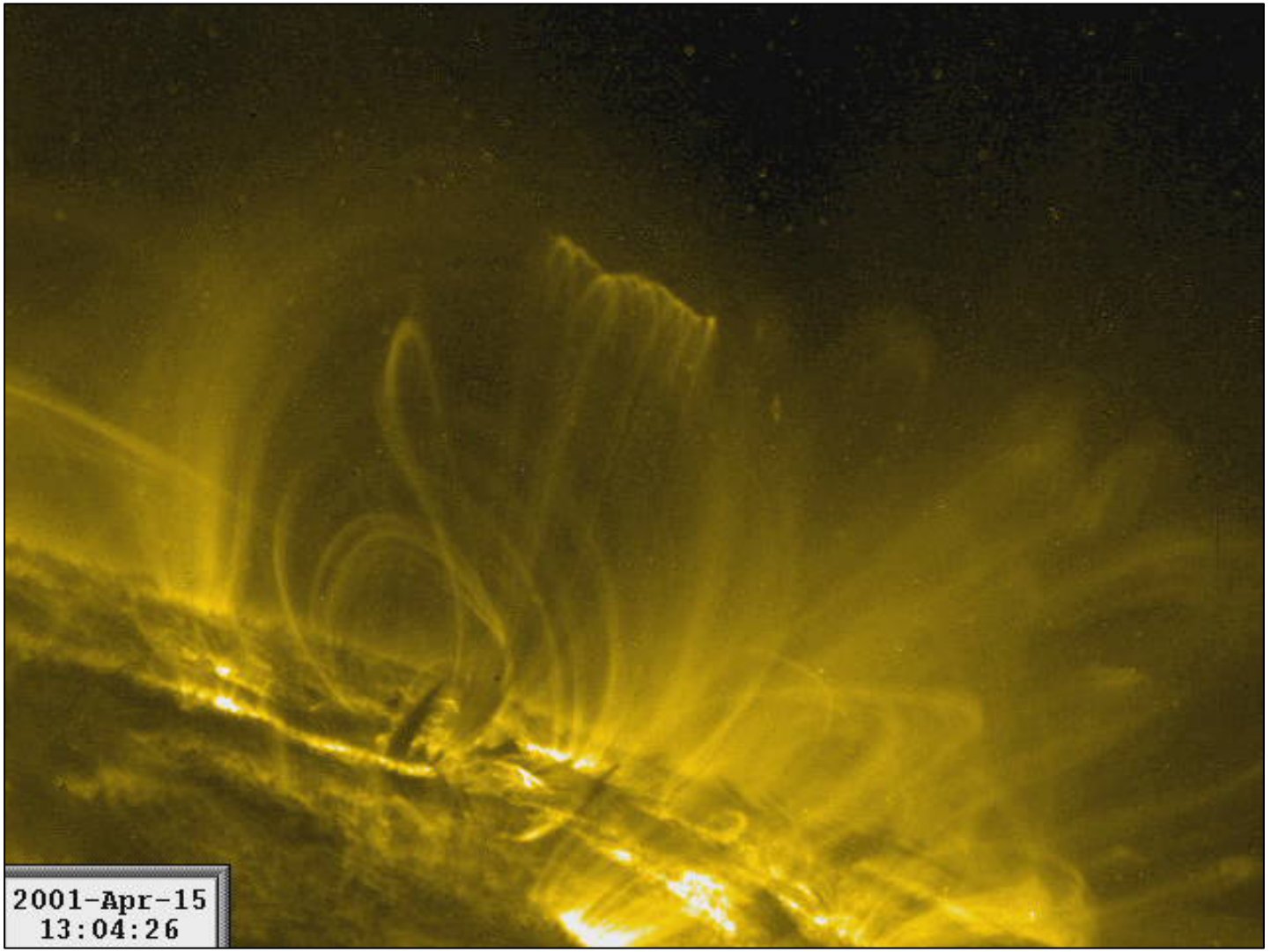




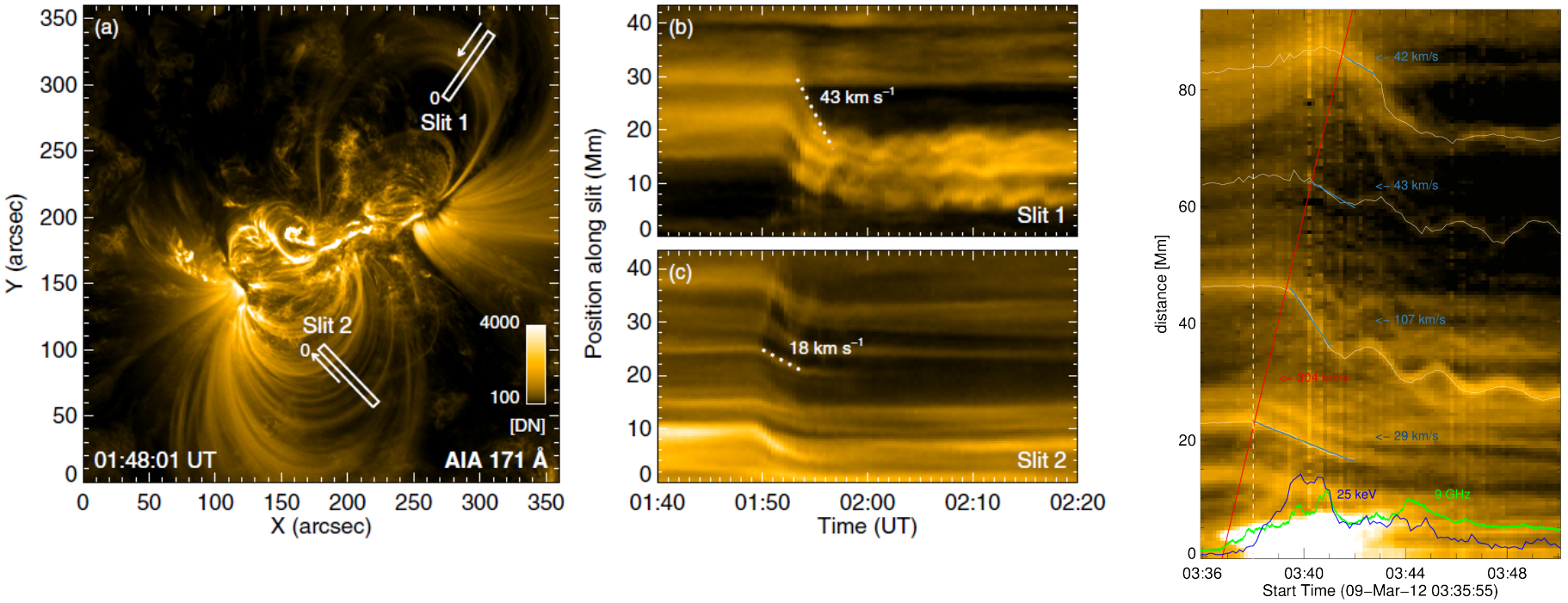
Martínez Oliveros et al., ApJ 753, 26, 2012

A surprising result: the first absolute height determination of hard X-ray and white-light emission shows them *both* to be near or at their respective $\tau = 1$ heights. This is inconsistent with the thick-target model! Flare SOL2011-02-24.

Favorite movie



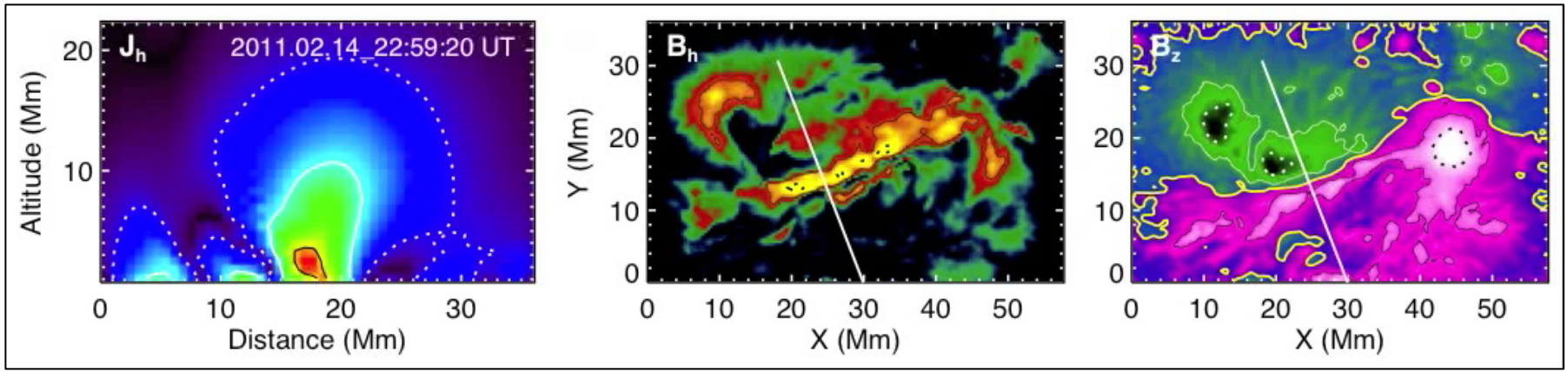
The flare implosion

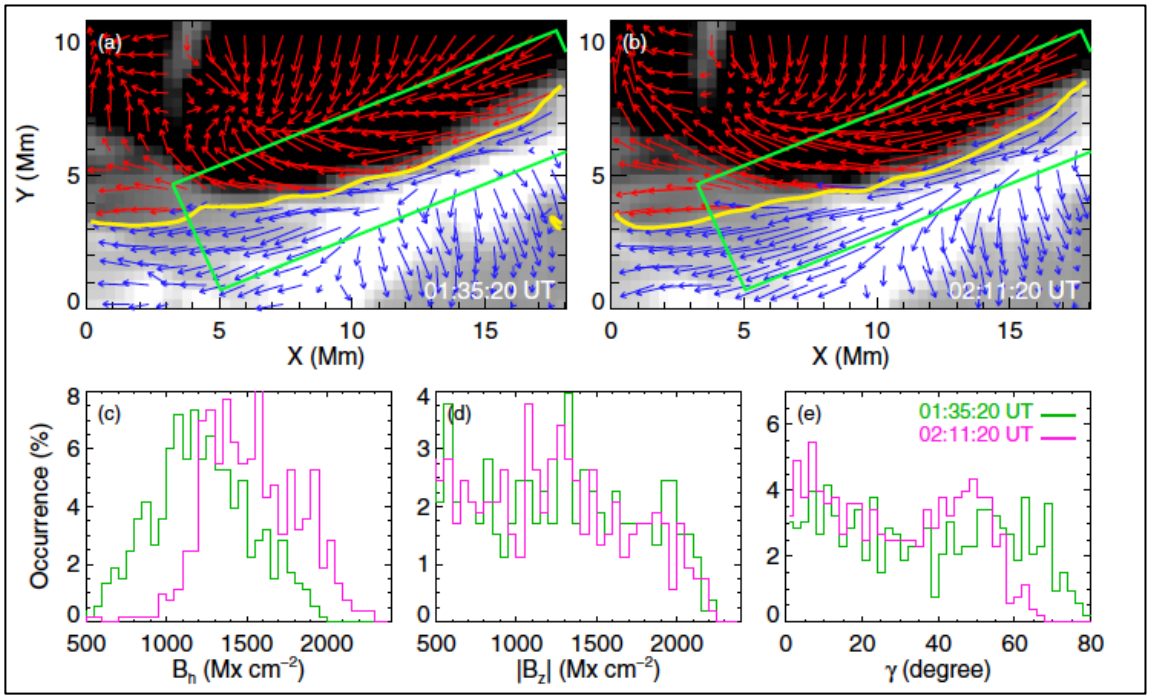


SOL2012-03-09 (Simões et al., 2013, ApJ 777, 152)

- The implosion commences in the AR core
- The excitation of large-scale wave structures proceeds outwards

Sun et al. 2012





Within the green box the horizontal field increases suddenly, while the vertical field doesn't change

Implosion or reconnection?

• We have good evidence for implosions coinciding with primary flare energy release.

• In my view, i**mplosion is the basic flare process**. Reconnection happens as needed, and may or may not be important.

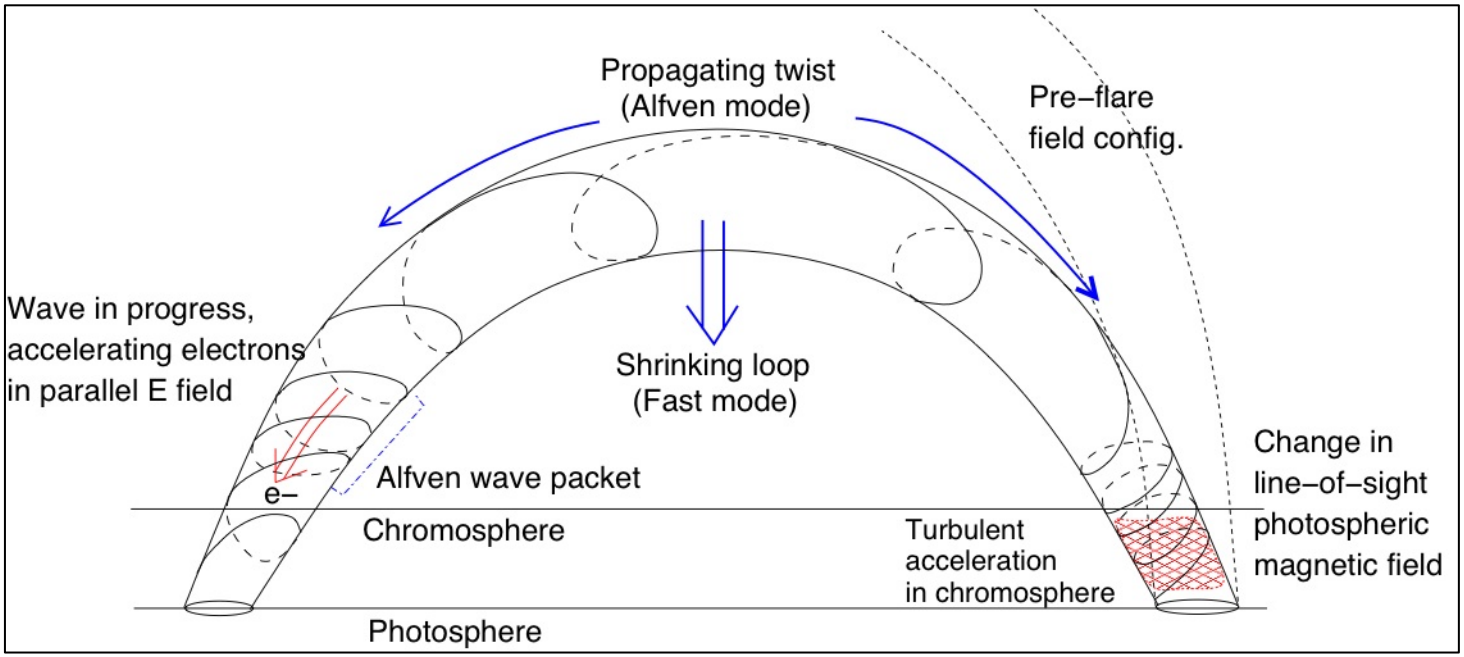
• The cartoons currently favored do not provide sound guidance for observers.

Conclusions

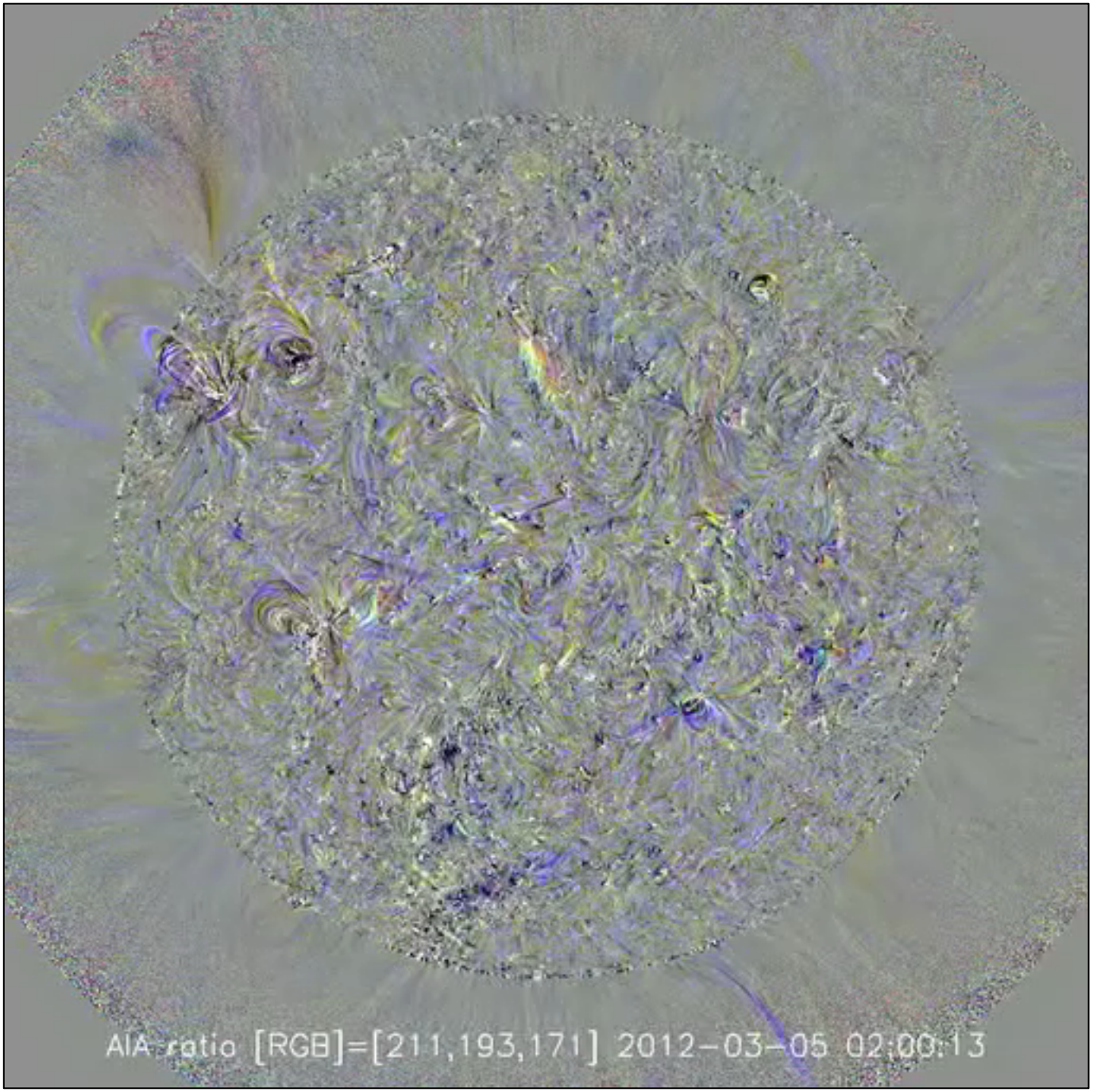
- The observational frontier of understanding is the “interface region”.
- New tools for understanding the magnetic structure in the low corona may soon expand our knowledge:
  - Incorporating 3D geometry (Malanushenko)
  - Imaging spectroscopy of gyroresonance (FASR)
- Wave energy transport in the flaring volume needs improved understanding.

Thanks!

Trying to fit large-scale waves into the global picture



Fletcher & Hudson, 2008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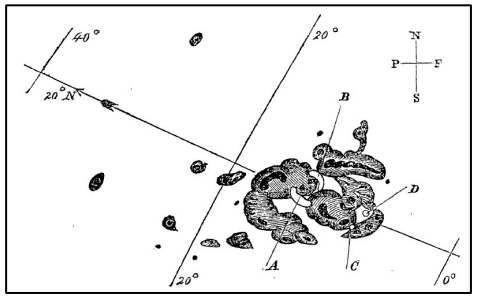
Carrington Flare energetics

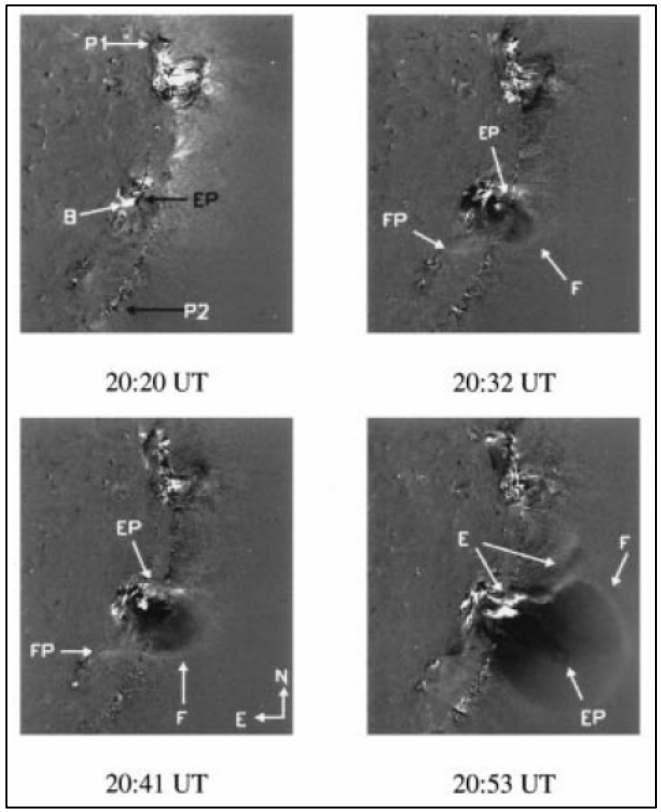


- WL area ~ 200 MSH*
- Flare duration ~ 300 s
- Flare intensity 2x solar

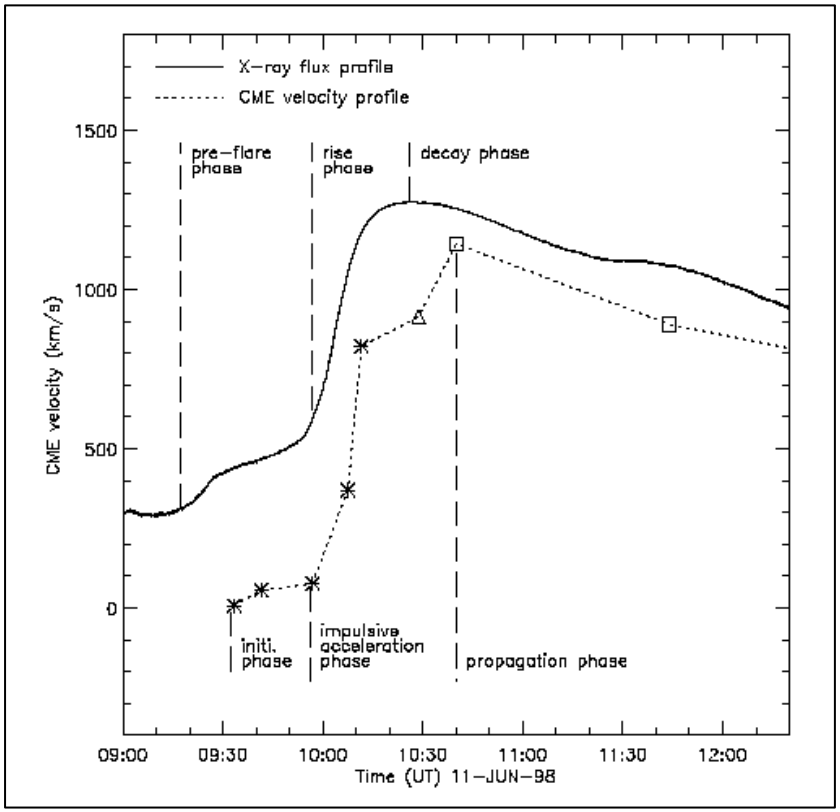
Energy ~ 2 x 10^{32} erg

A reasonable modern interpretation of this simple result is that the radiant energy in the flare's impulsive phase dominates the flare energy – do modern data confirm this?

Compact sources of CMEs



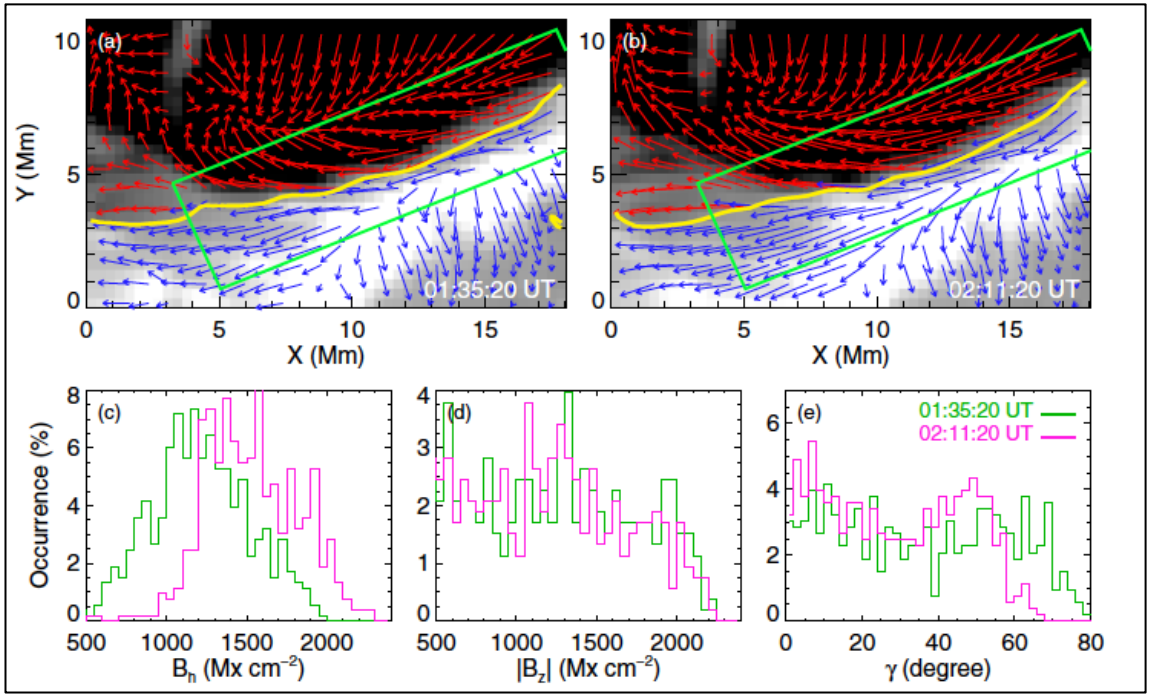
Dere et al., 1997

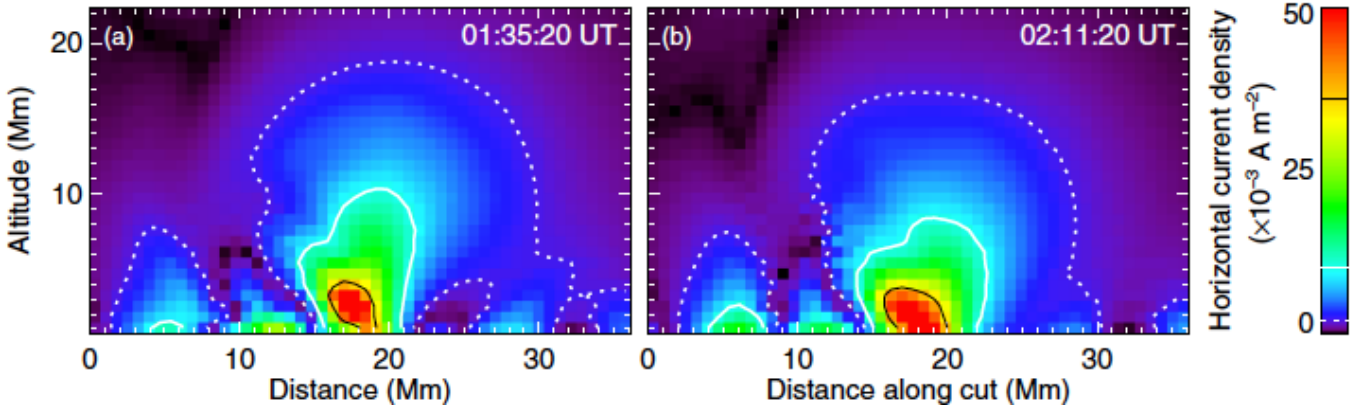


Zhang et al., 2001

* See also “dimming”: Hudson & Webb, 1997; Harra & Sterling 2001

Sun et al. 2012





Recent observational results

- *The impulsive phase dominates the energy release*

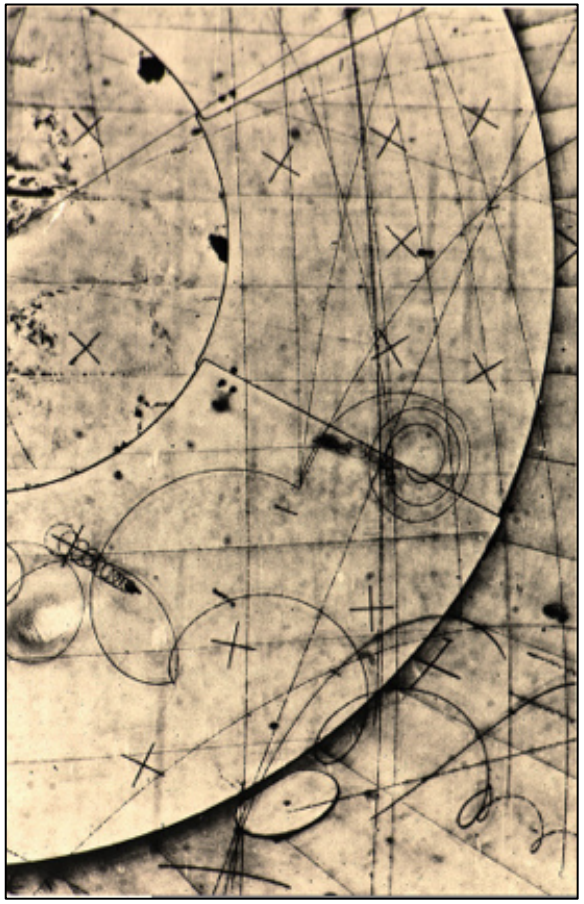
- *Implosion and oscillation (Simões et al., 2013)*

- *Hard X-ray flare height (Martinez-Oliveros et al., 2012)*

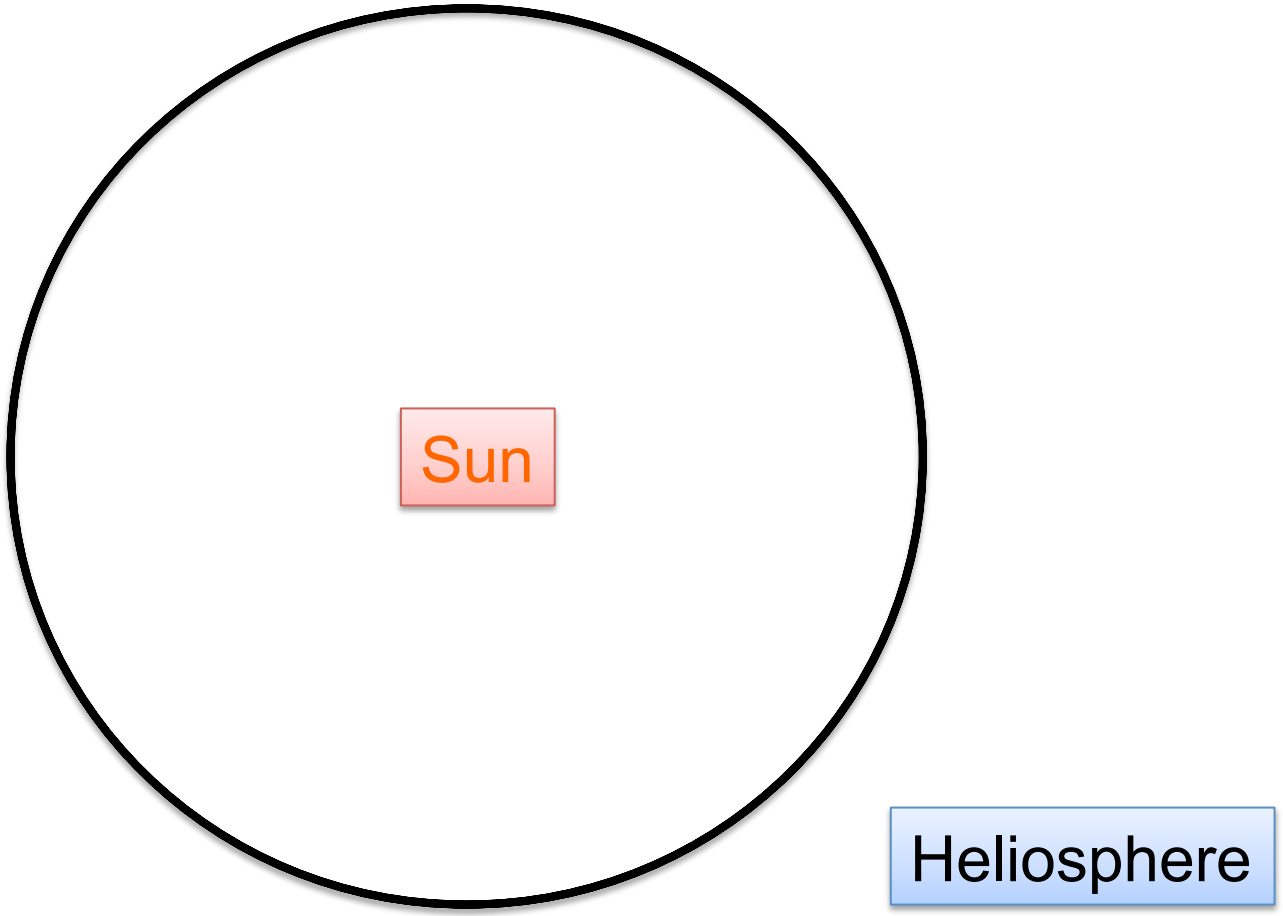
- *HMI observations of coronal sources*

- *Interior acoustic waves*

MHD



Not MHD


Sun
Heliosphere