

Plasma Implosions in the Solar Atmosphere

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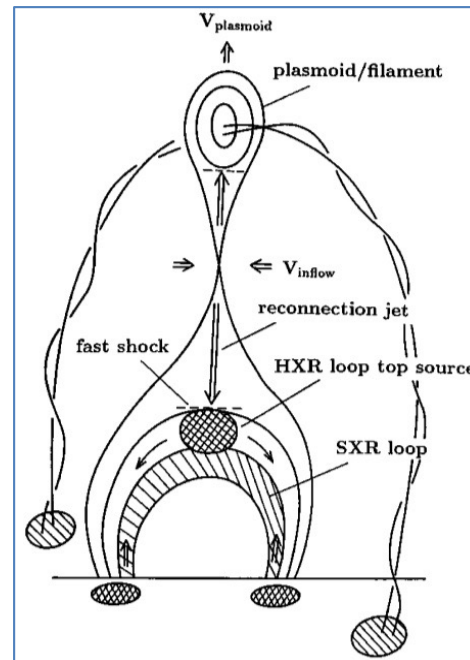
*An eruptive flare **adds** free magnetic energy to the corona. How can this result from an instability?*

Yohkoh and Shibata-sensei

- *Yohkoh*/SXT gave us our first comprehensive movie descriptions of flare plasma dynamics in its natural X-radiation
- During the decade of the 1990s, Shibata-sensei and I frequently met at ISAS, and I learned a great deal from him!

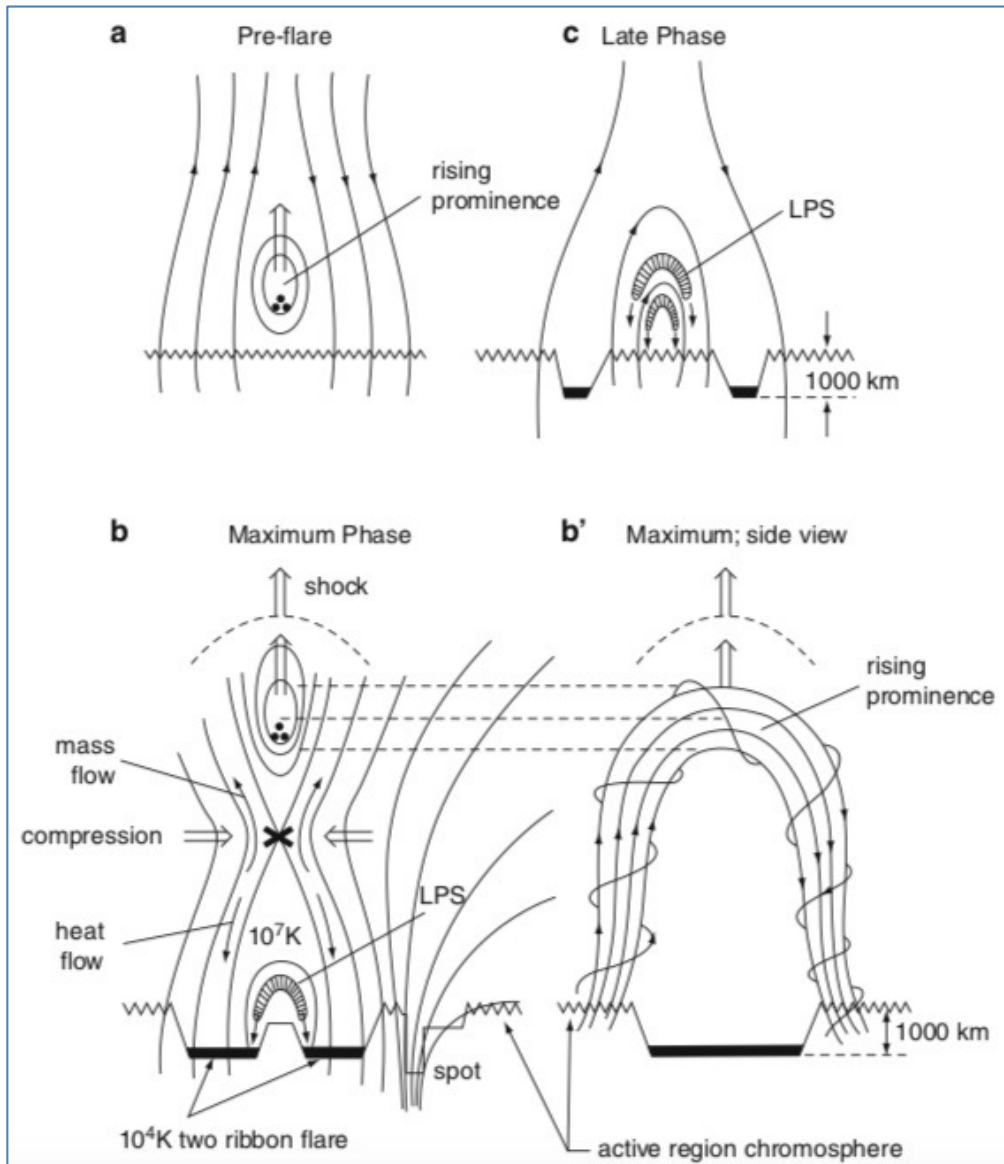
Yohkoh and Shibata-sensei

- *Yohkoh/SXT* gave us our first comprehensive movie descriptions of flare plasma dynamics in its natural X-radiation
- During the decade of the 1990s, Shibata-sensei and I frequently met at ISAS, and I learned a great deal from him! **Mainly**



of course!

The Hirayama model (1974)



Specific features **confirmed**:

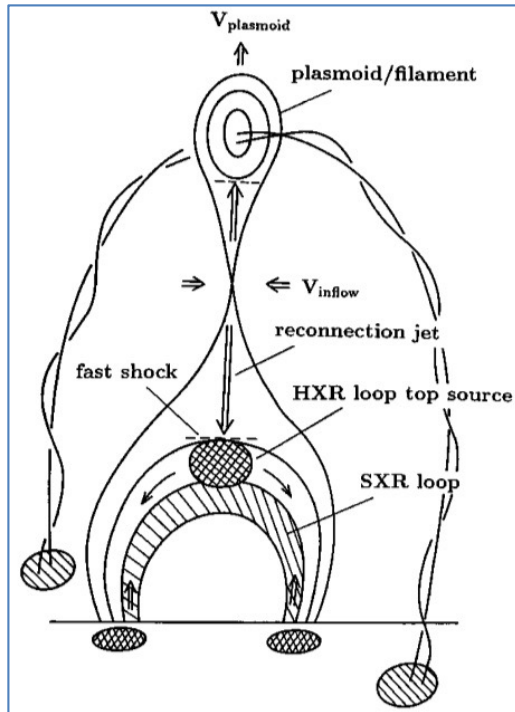
- Filament channel
- Plasmoid
- Coronal overpressure
- Loop formation

Omissions TBD

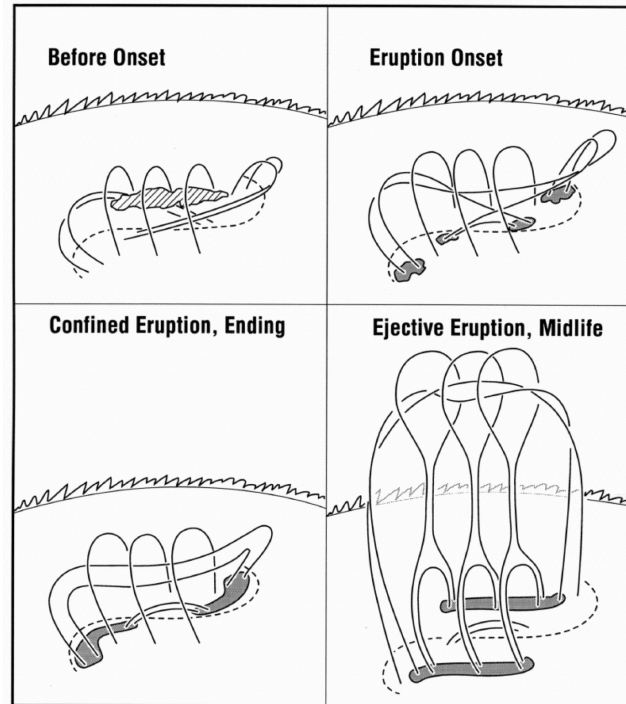
- Plasma instability
- Particle acceleration

856 citations

Yohkoh-era flare cartoons

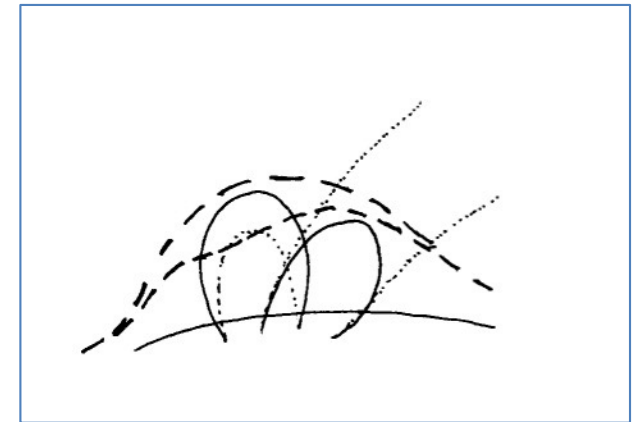


Shibata 1995
(451)



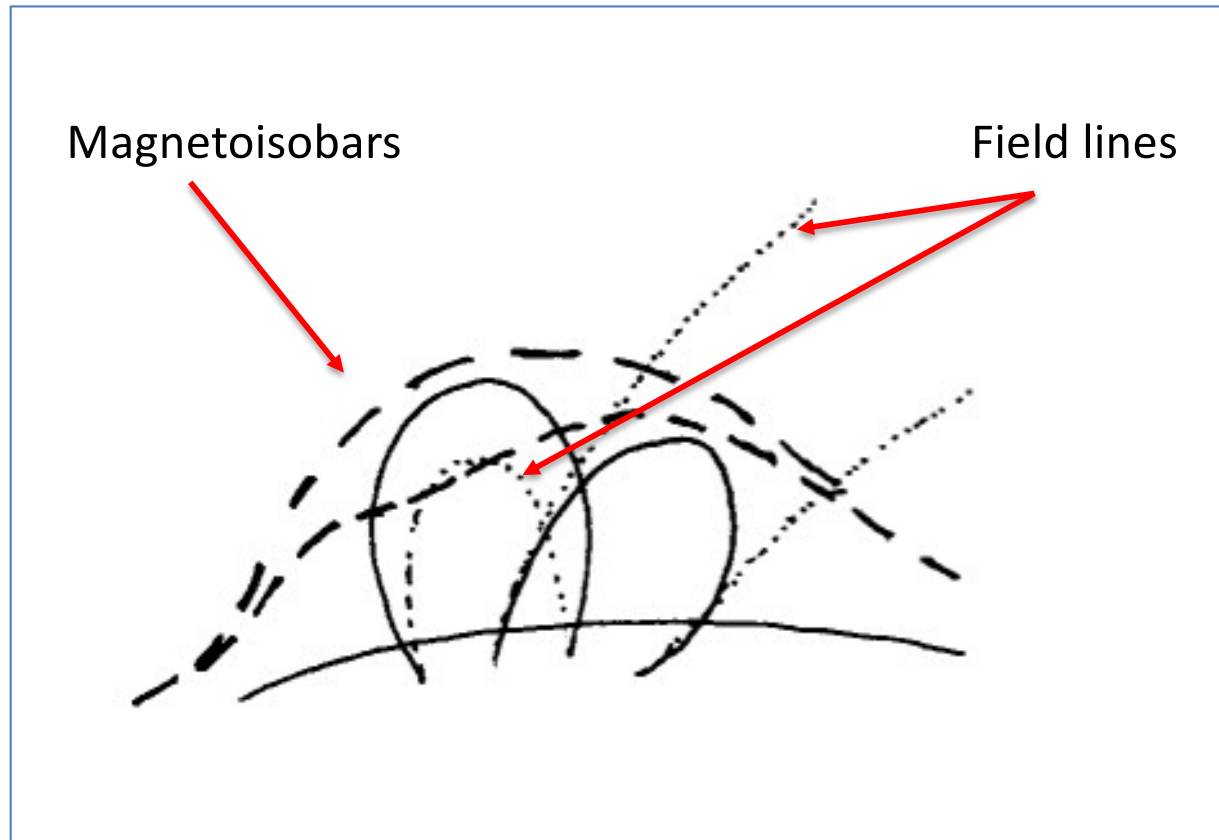
Moore 2001
(695)

$$\int B^2 dV < \int B_0^2 dV$$

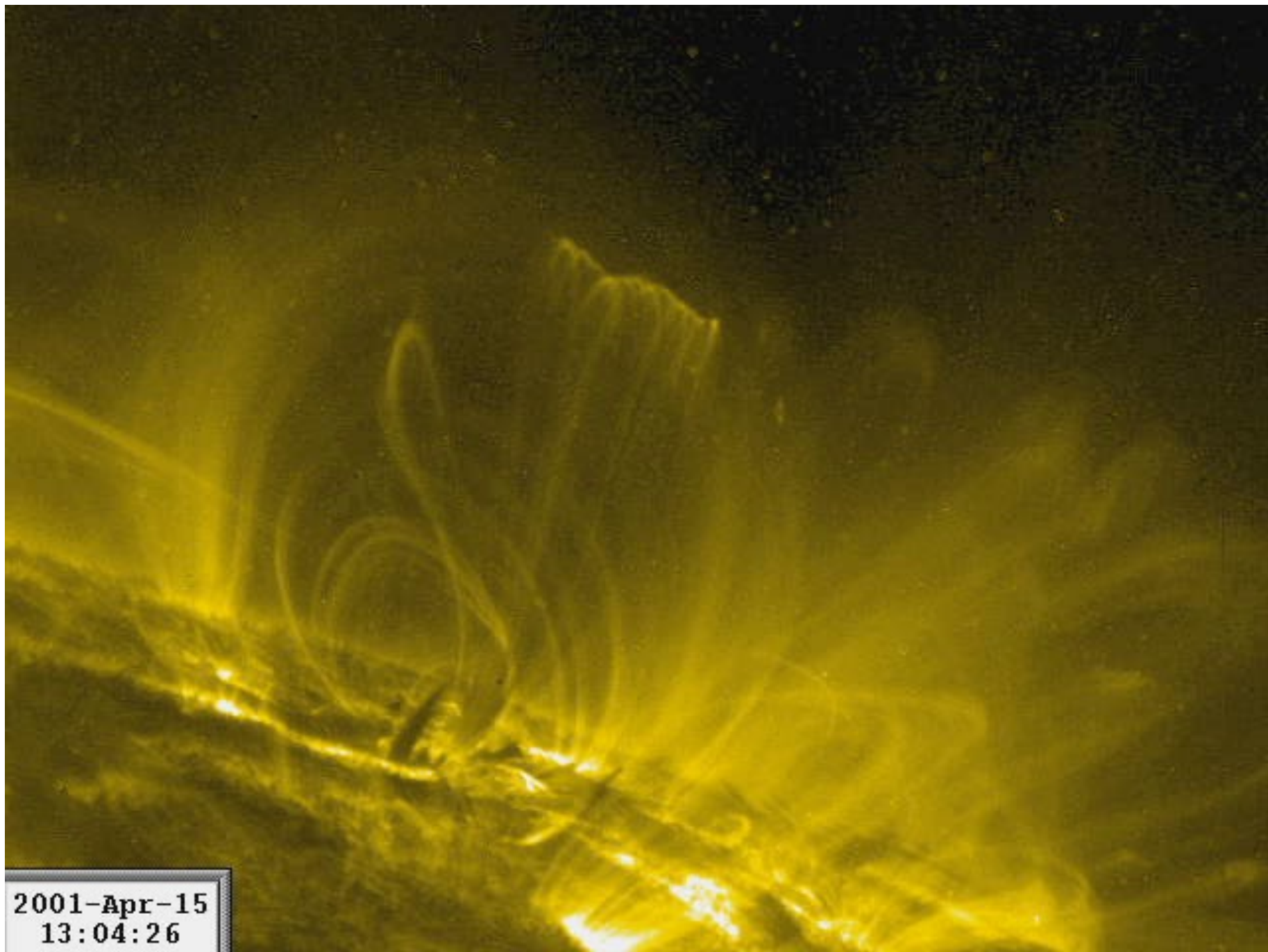


Hudson 2000
(140)

Cartoon explanation

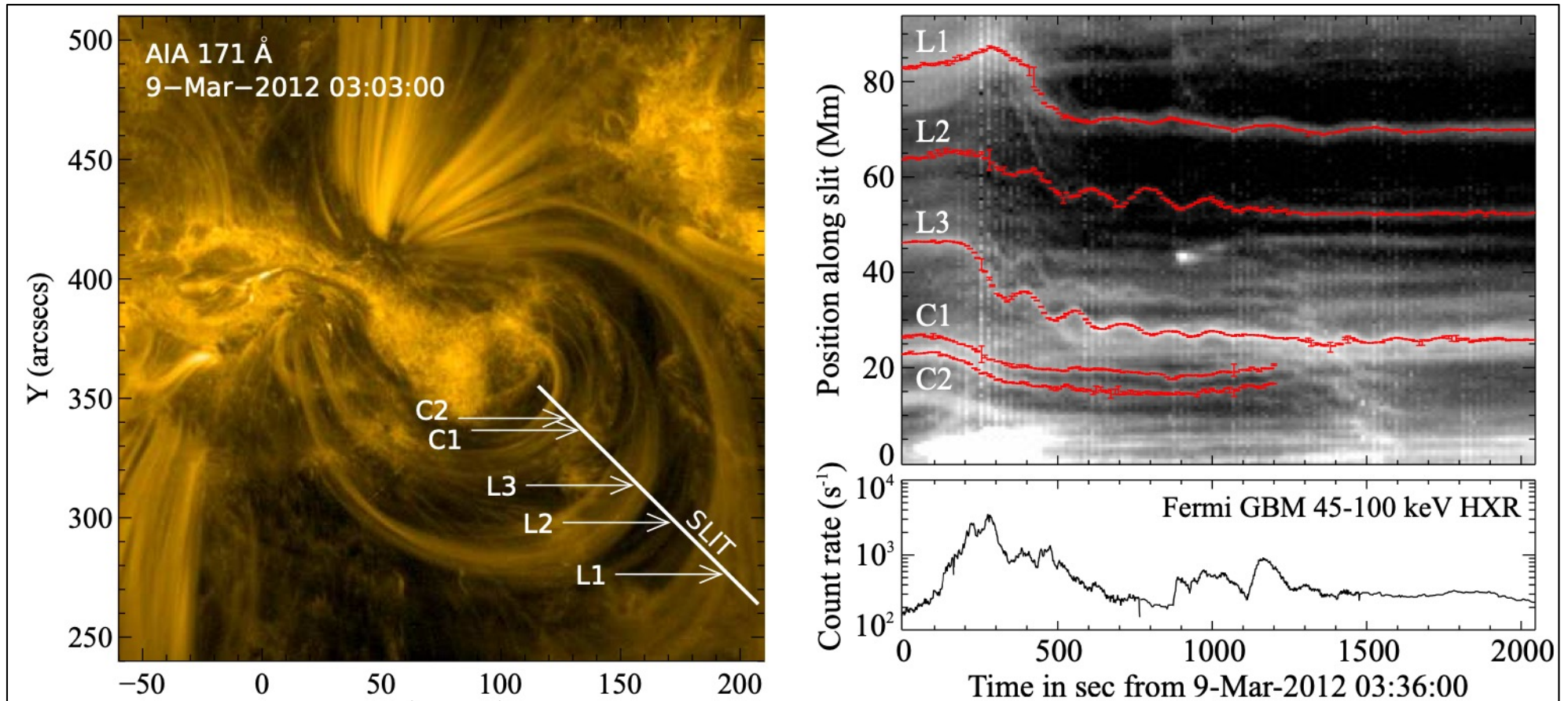


- This cartoon does not describe local properties (“reconnection”); it simply demonstrates conservation of energy
- Field lines shown in before/after steady states (solid, dotted)



2001-Apr-15
13:04:26

Implosion, Flare, QPP, Dimming, Wave, HXR



Simões *et al.* 2013; Russell *et al.* 2015

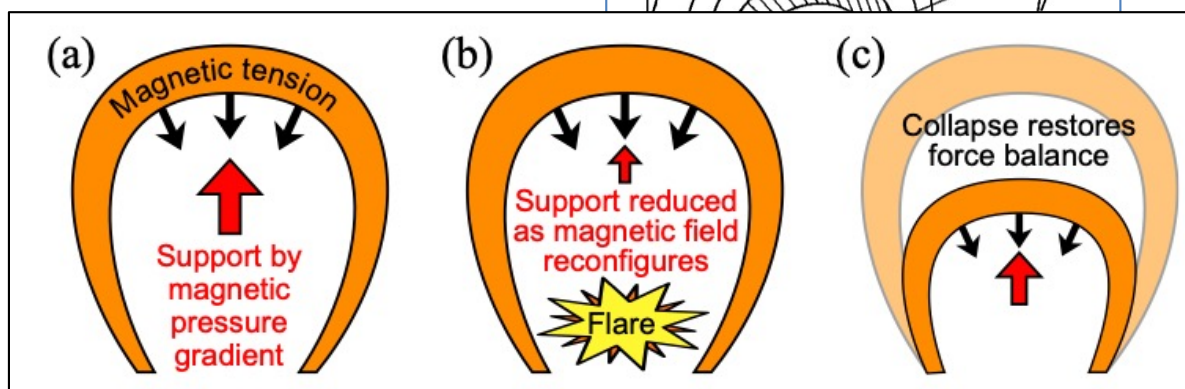
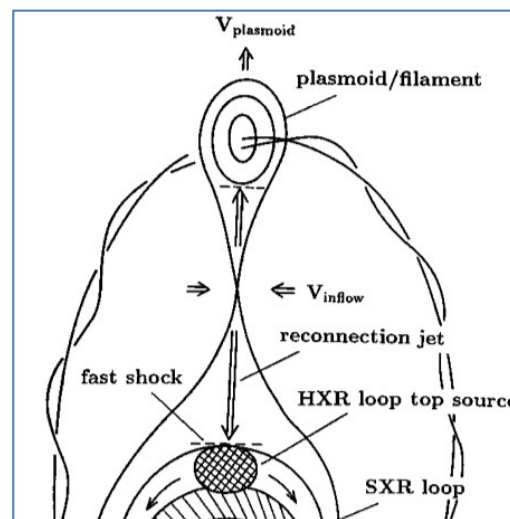
- The Russell paper shows how all of these phenomena fit nicely together

Cartoon conclusions

- The implosion is fundamental, because it represents conservation of energy
- The Hirayama-Shibata-Moore (CSHKP) cartoon describes the later flare development
- The implosion cannot always be detected because it is in the (invisible) magnetic field
- Plasmoid eruption is a consequence, not a cause

Cartoon conclusion:

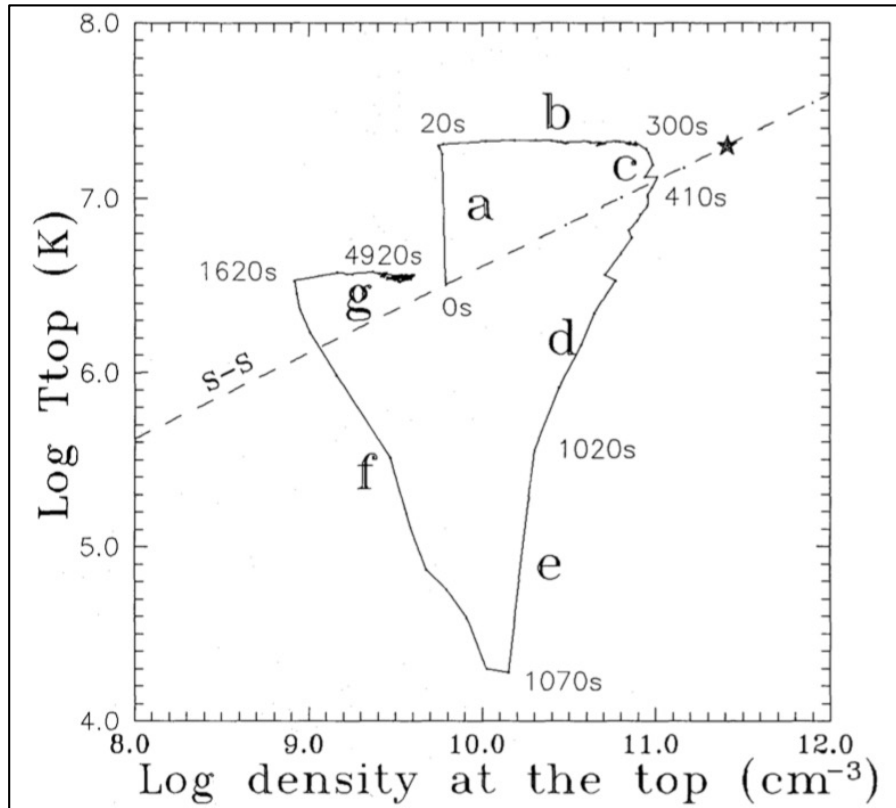
The pressure reduction from the implosion drives the plasmoid



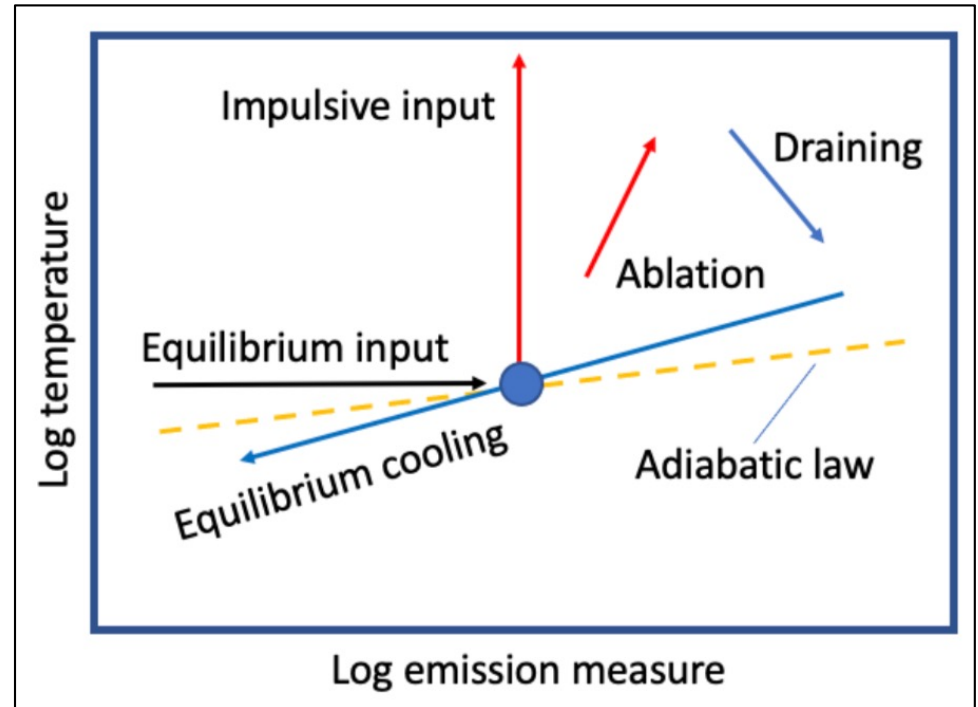
New (old) evidence for “tether-cutting”?

- Isothermal interpretations of GOES soft X-ray data invariably show “Hot Onset Precursor Events” (HOPEs) - only recently described
- The basic plasma evolution of a flaring loop does not predict this pattern
- The result is a pre-flare horizontal branch in (T,EM) diagnostic plots

The (EM, T) diagnostic diagram for a flaring loop

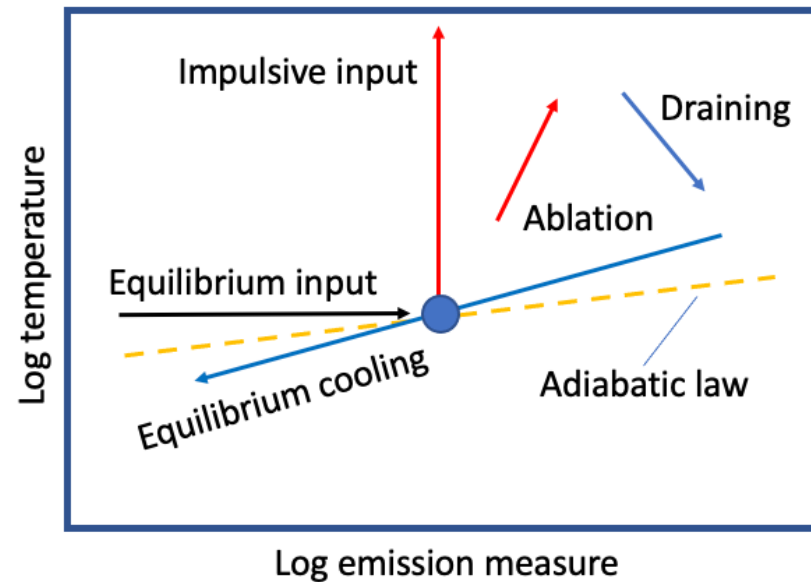
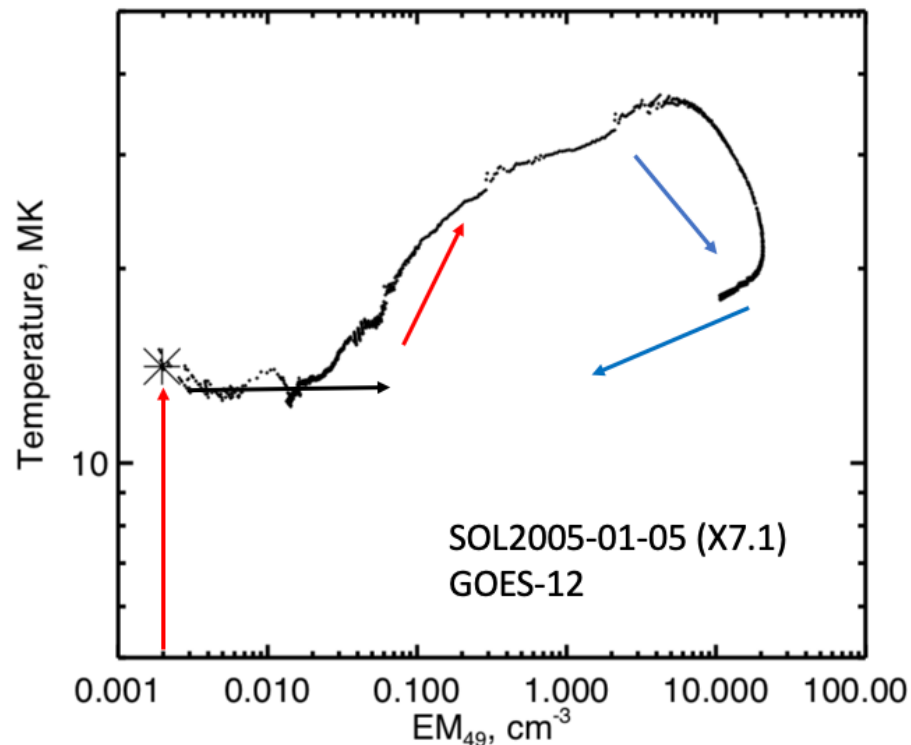


B. Sylwester 1976
Jakimiec et al. 1992



The (T, EM) point moves around a loop, in the directions labeled

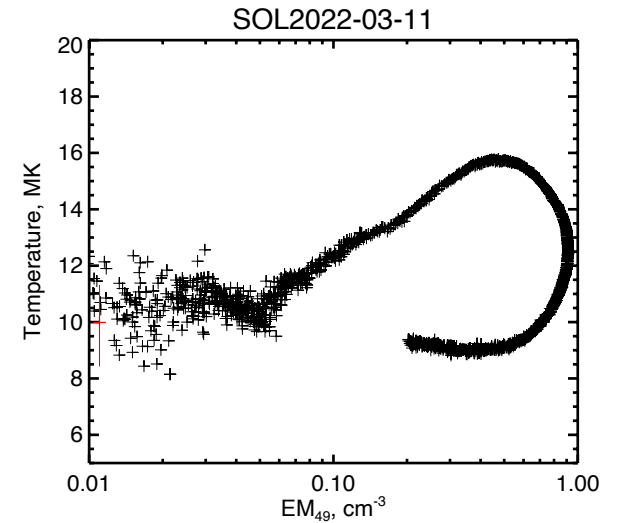
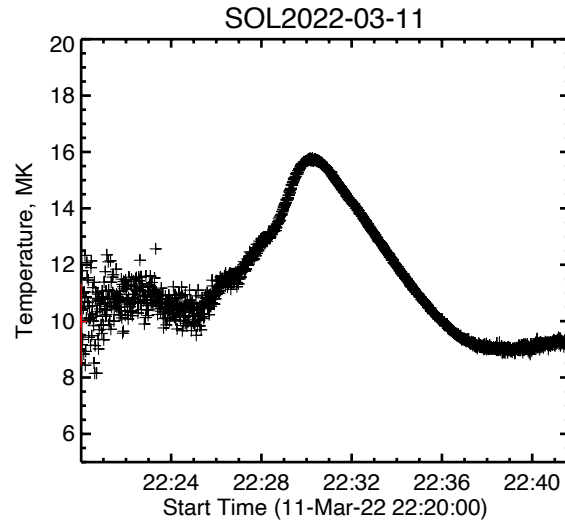
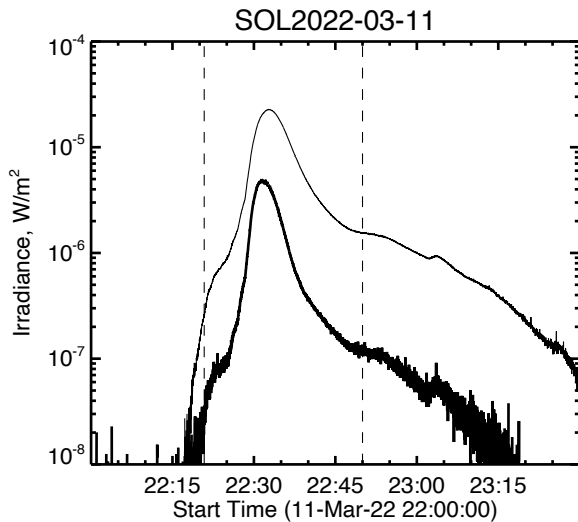
The (EM, T) diagnostic diagram for a flaring loop



What the diagram shows:

- Neupert-like loop behavior
- Equilibrium decay
- Hot onset: EM increase at constant T
- * Hot onset: dT/dt unresolved (red arrow)

Excellent recent example



[T, EM]

- The HOPE (horizontal branch of [T, EM]) is almost always present
- Temperature tends to be fixed at 10-15 MK
- Emission measure rises roughly linearly
- HOPE appears before the impulsive phase

Why are hot onsets important for the global physics?

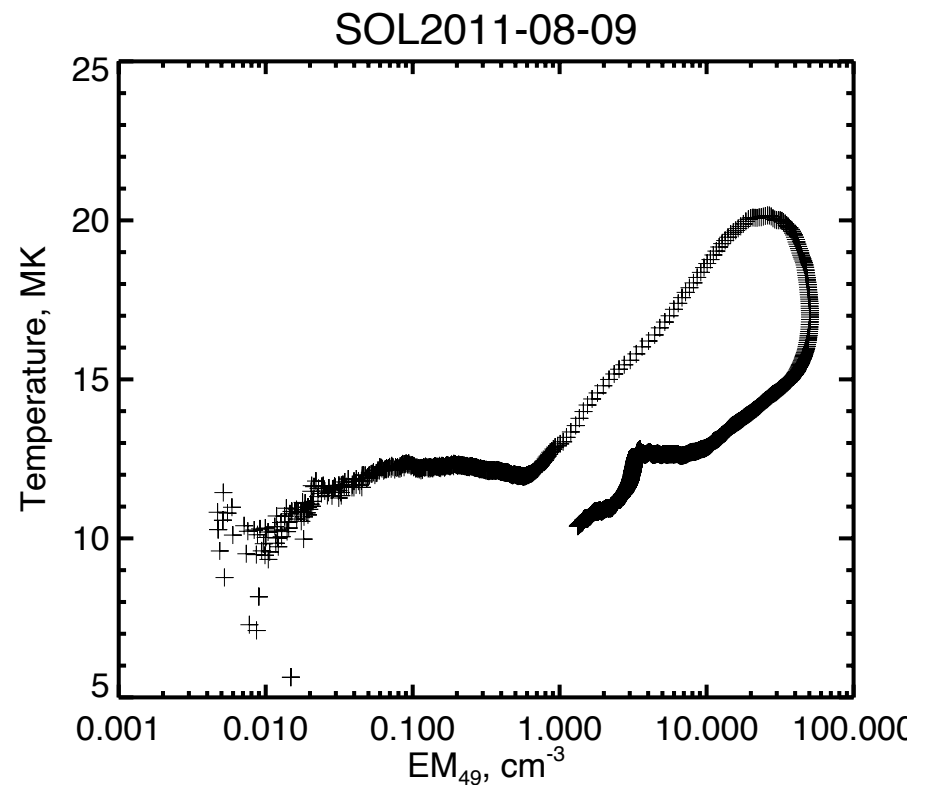
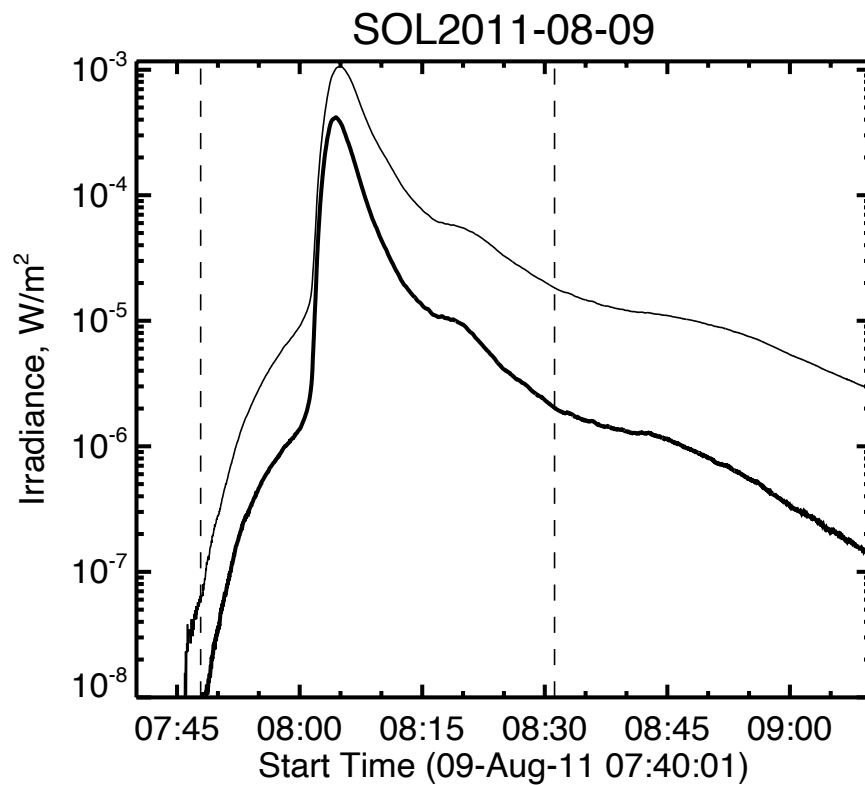
- The HOPE energy release is different from the standard flare pattern. We do not know yet whether it is steady-state or microflaring, but it is not “pre-heating” since $dT/dt \sim 0$
- Some AIA observations show that it may occur along the PIL that is going to flare, though not at the flare site necessarily
- A *Yohkoh* view of a single event (SOL2001-09-24) is in Fárník et al. 2003, and many other HOPE examples are elsewhere in the literature

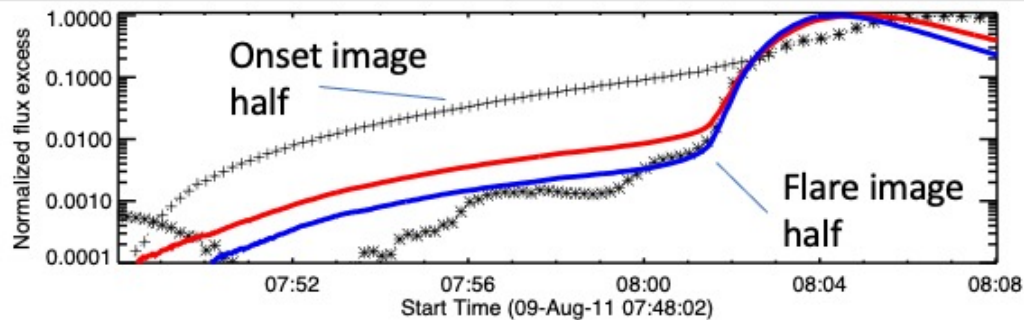
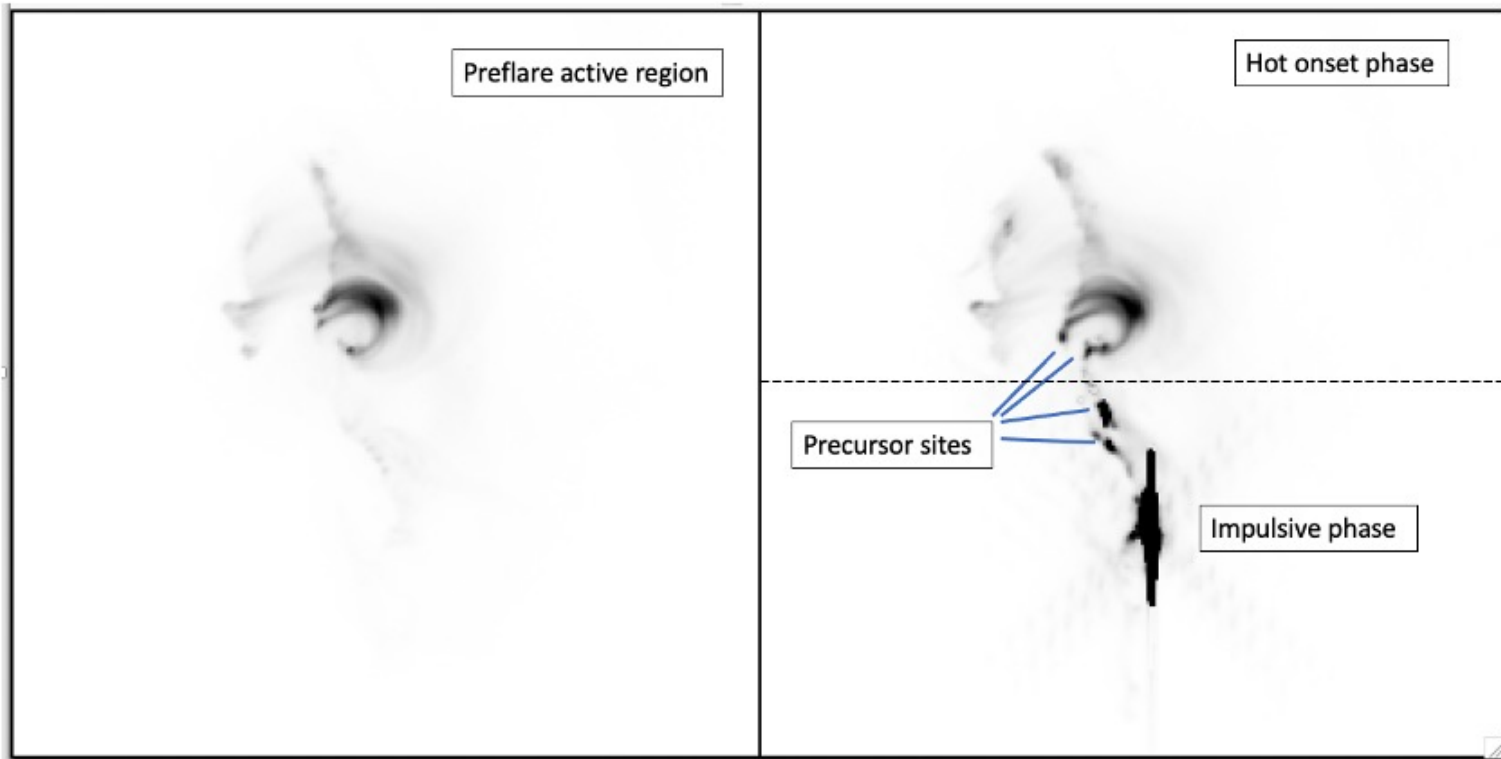
Conclusions

- What we have learned about solar flares depends a great deal on Yohkoh and upon Shibata-sensei
- I think future work needs to focus on the lower atmosphere to understand “tether-cutting” physics and to understand how HOPE leads to eruption

If there is time, the “Slow HOPE”

SOL2011-08-09T08:00





Message: The HOPE phase may be quite remote from the flare. It looks non-episodic here, but check out Fárník et al. 2003. How does this development lead to the major instability?