Dimmings and SEPs

Hugh Hudson, SSL and U of Glasgow

What is a dimming?

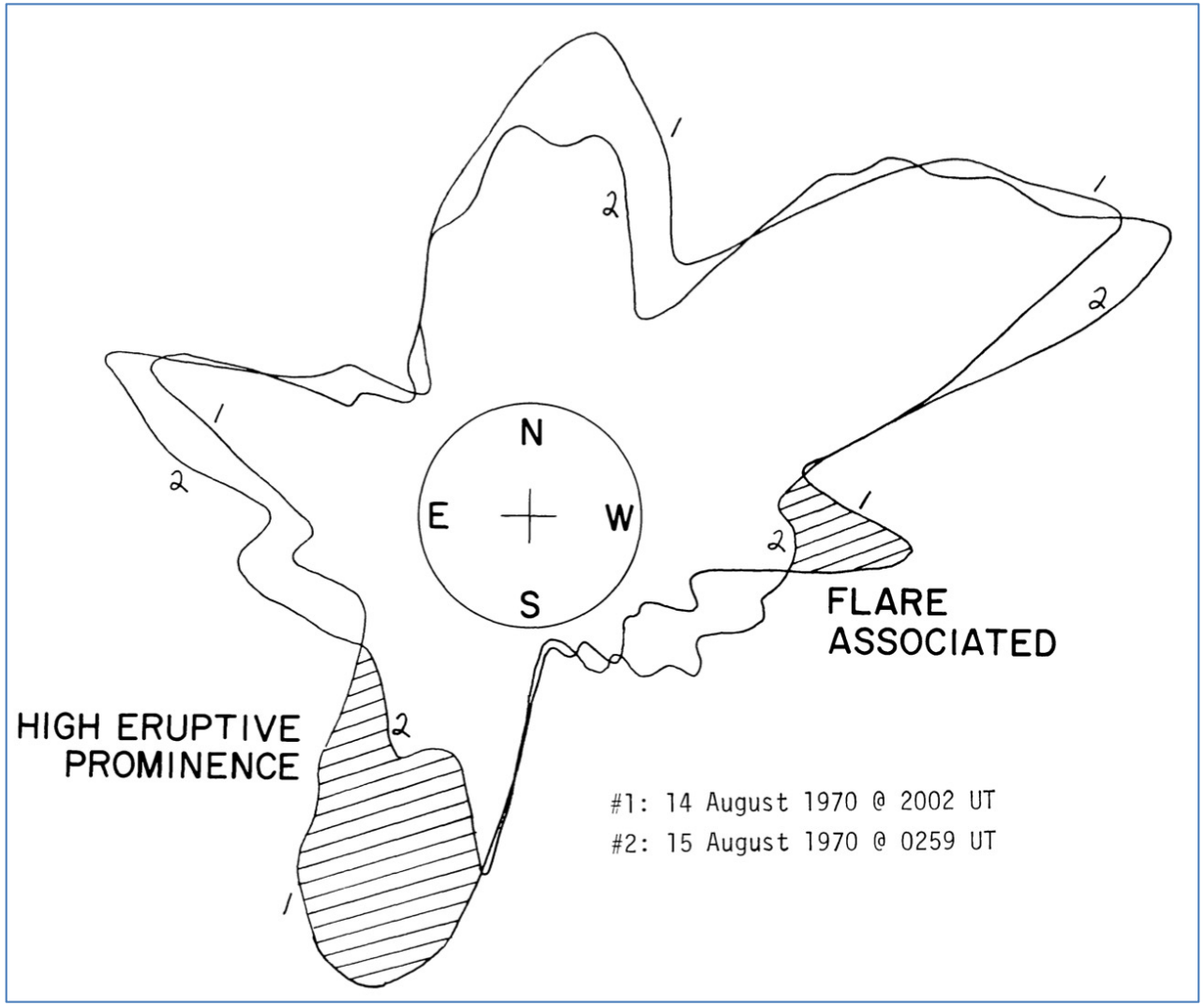
CME-related:

- Green-line depletions (K-coronameter)
- EUV global dimmings (EVE)

Flare development:

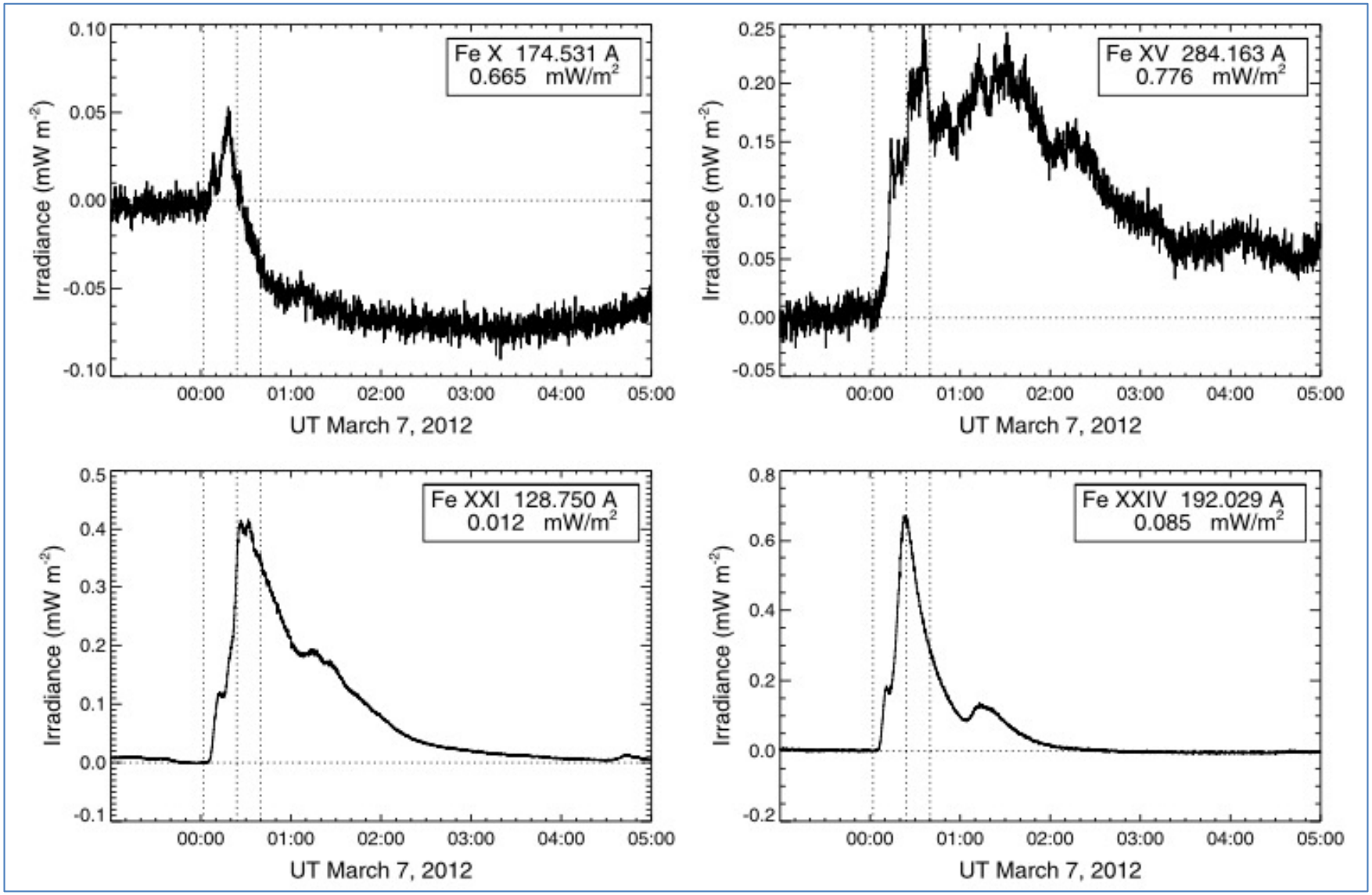
- X-ray “transient coronal holes” (Skylab)
- Yohkoh/SXT (eg, Kahler & Hudson 2001)

Coronal Depletions -1974



Hansen et al. 1974

Coronal Depletions -2012

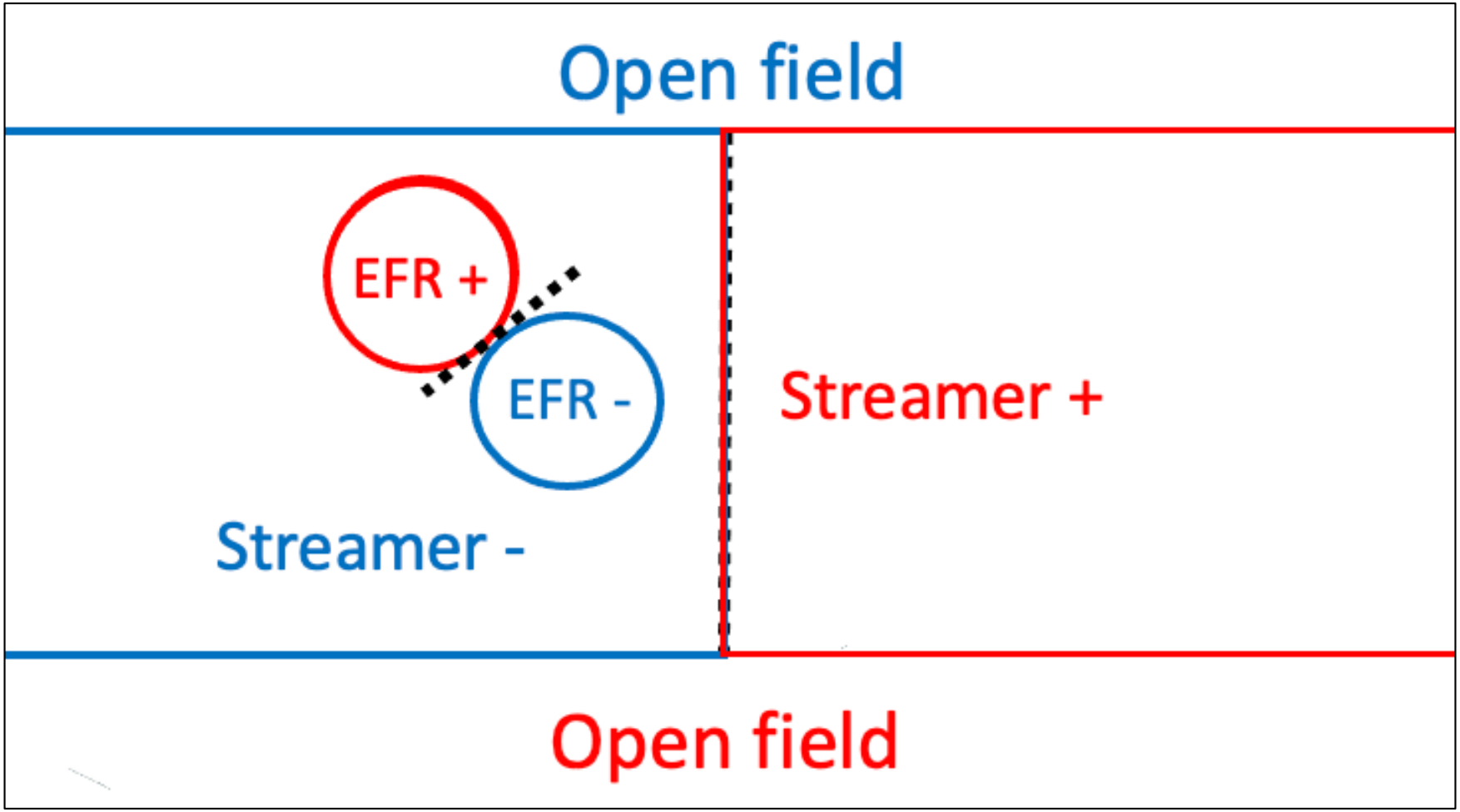


Harra et al. 2016

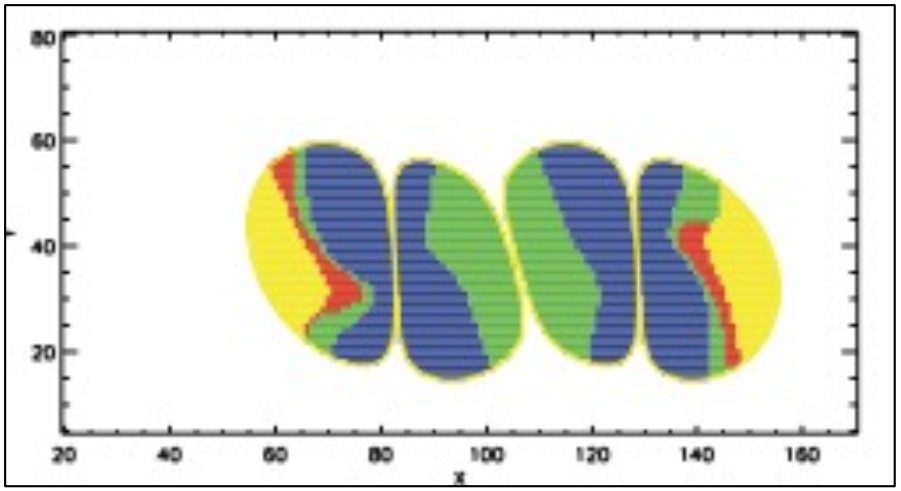
A complex magnetic domain structure

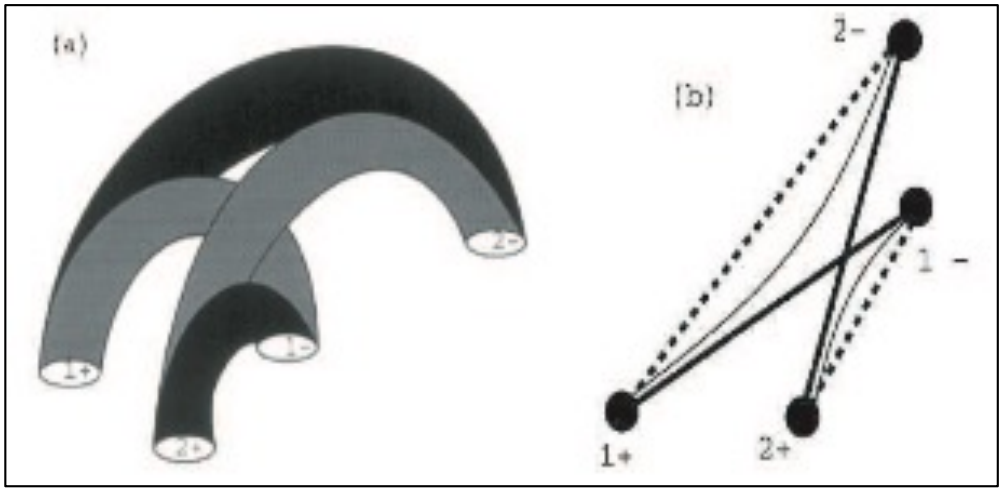
- The simplistic Sun-as-a-star view of flare/CME dimming can capture its mass distribution
- The coronal structure and evolution during the eruption can be (arbitrarily) complex in terms of its domain structures with flux transfers among them (Mackay – van Ballegooijen 2006).
  - Core field
  - Flux rope
  - Strapping field (multiple domains?)
  - Open field

Generalized polarity map



Two approaches to global modeling

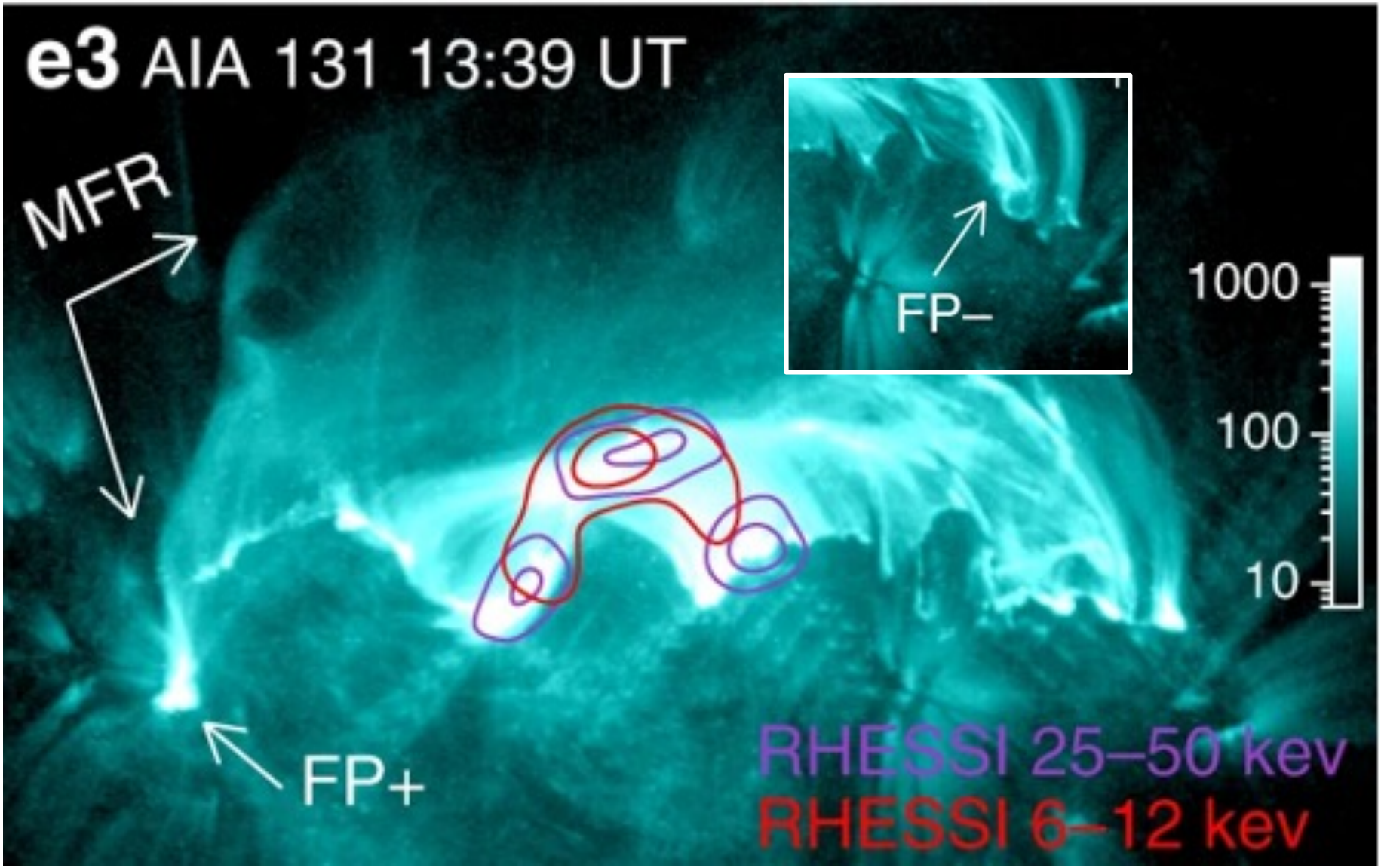




1. Two bipolar magnetic fields interact (Mackay - van Balle-gooijen, 2006).

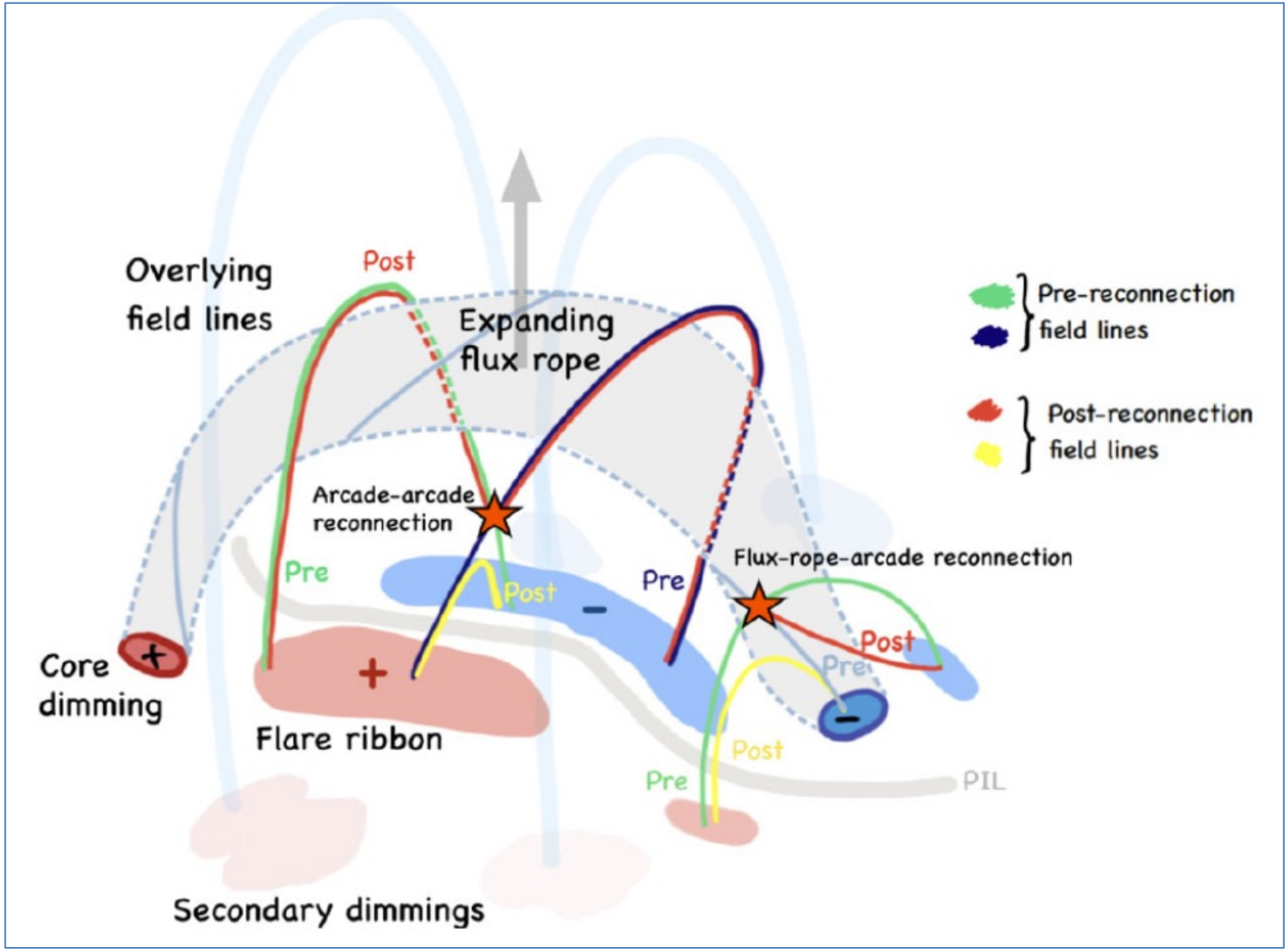
2. Two current flows interact (Melrose 1997) – more intuitive for energetics.

The complexity of a solar eruption



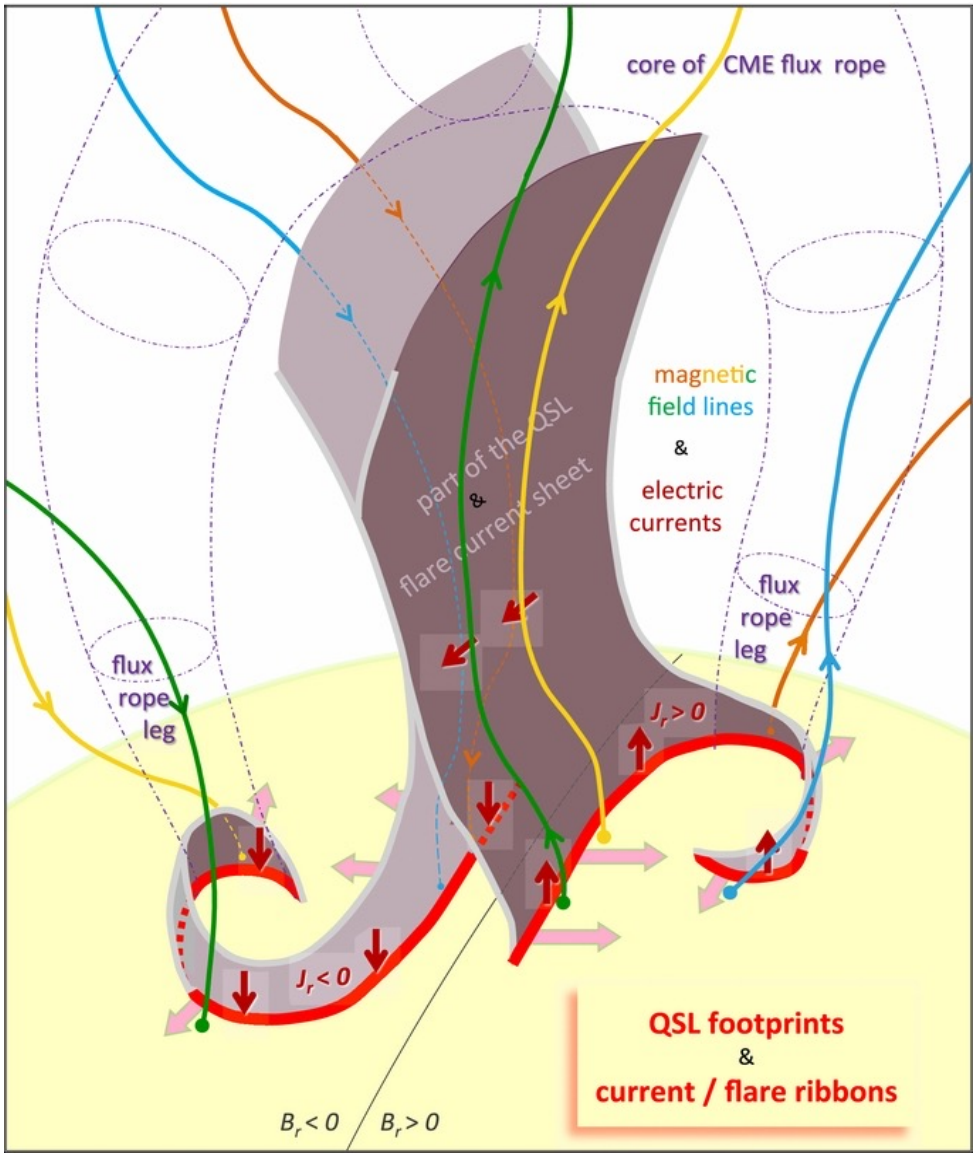
Wang et al. 2017, SOL2015-11-04

The complexity of a solar eruption

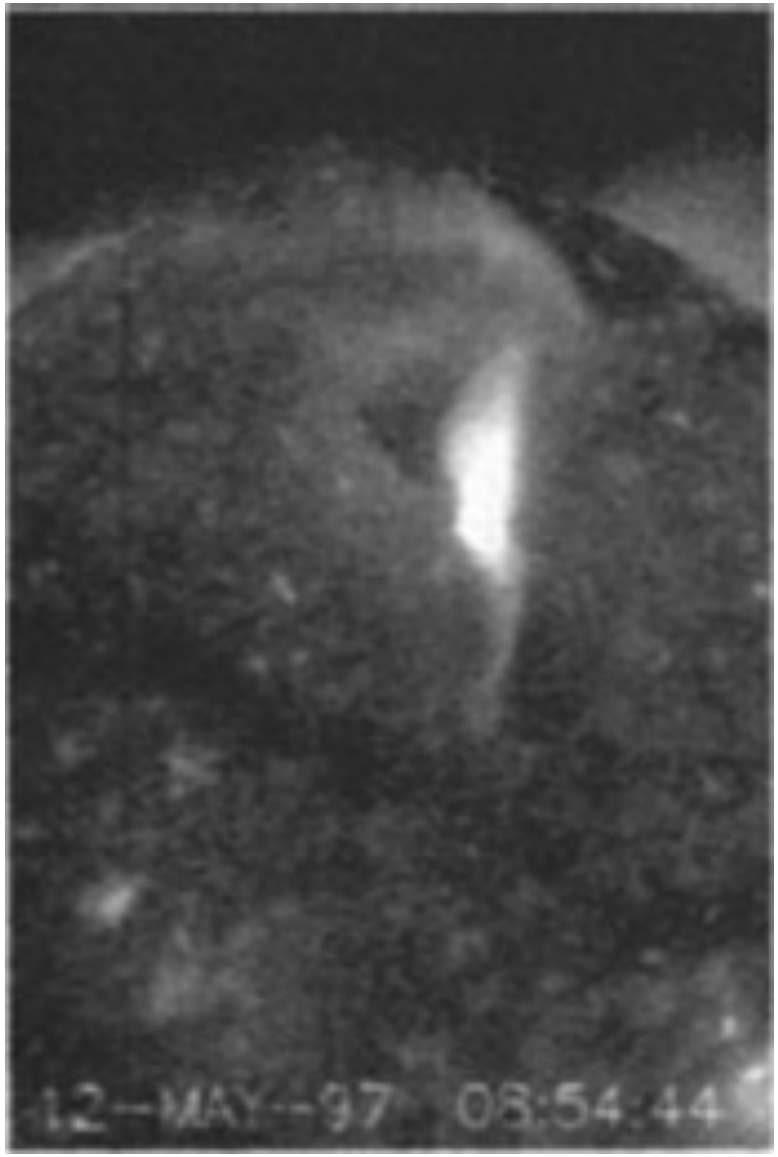


Kazachenko et al. 2022

Janvier cartoon / Real World



Janvier *et al.* 2014



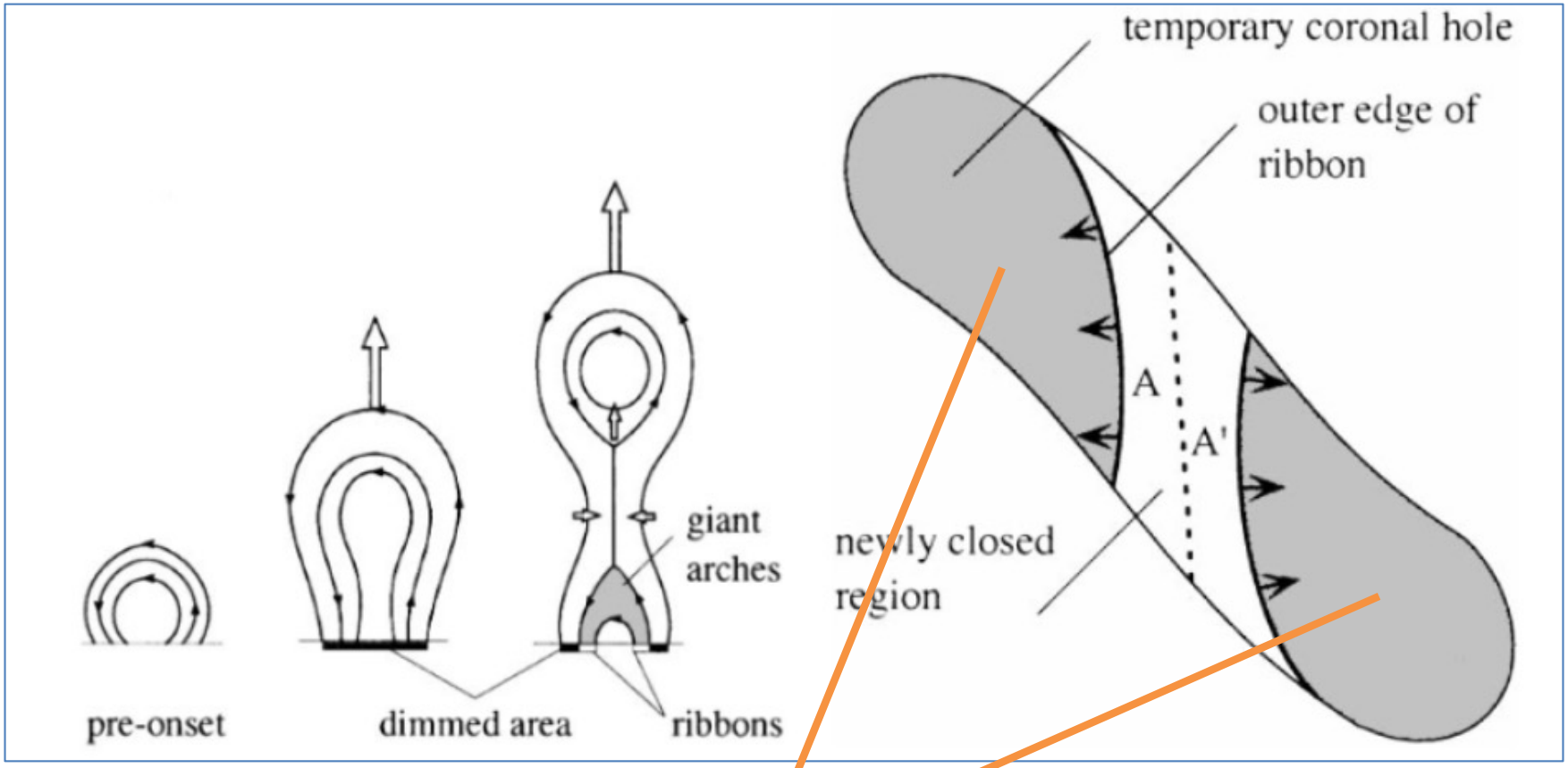
Kahler & Hudson 2001
(SOL1997-05-12)

The Dimming-SEPs relationship

- Flares involve high-energy particles
- We can observe flare emissions and SEPs
- How are these populations connected?

- Dimming shows connectivity changes
- Only charged particles can actually define connectivity in a moving plasma

Fundamental cartoon of dimming



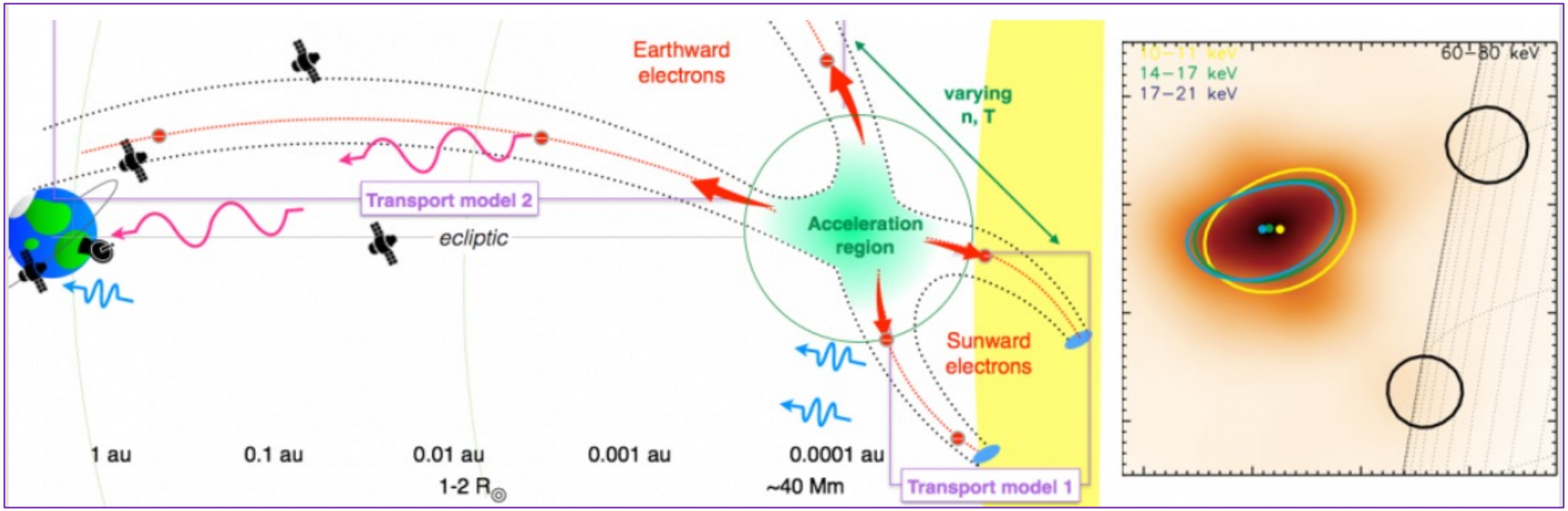
Forbes & Lin 2000

Gray areas show ”opened” strapping field

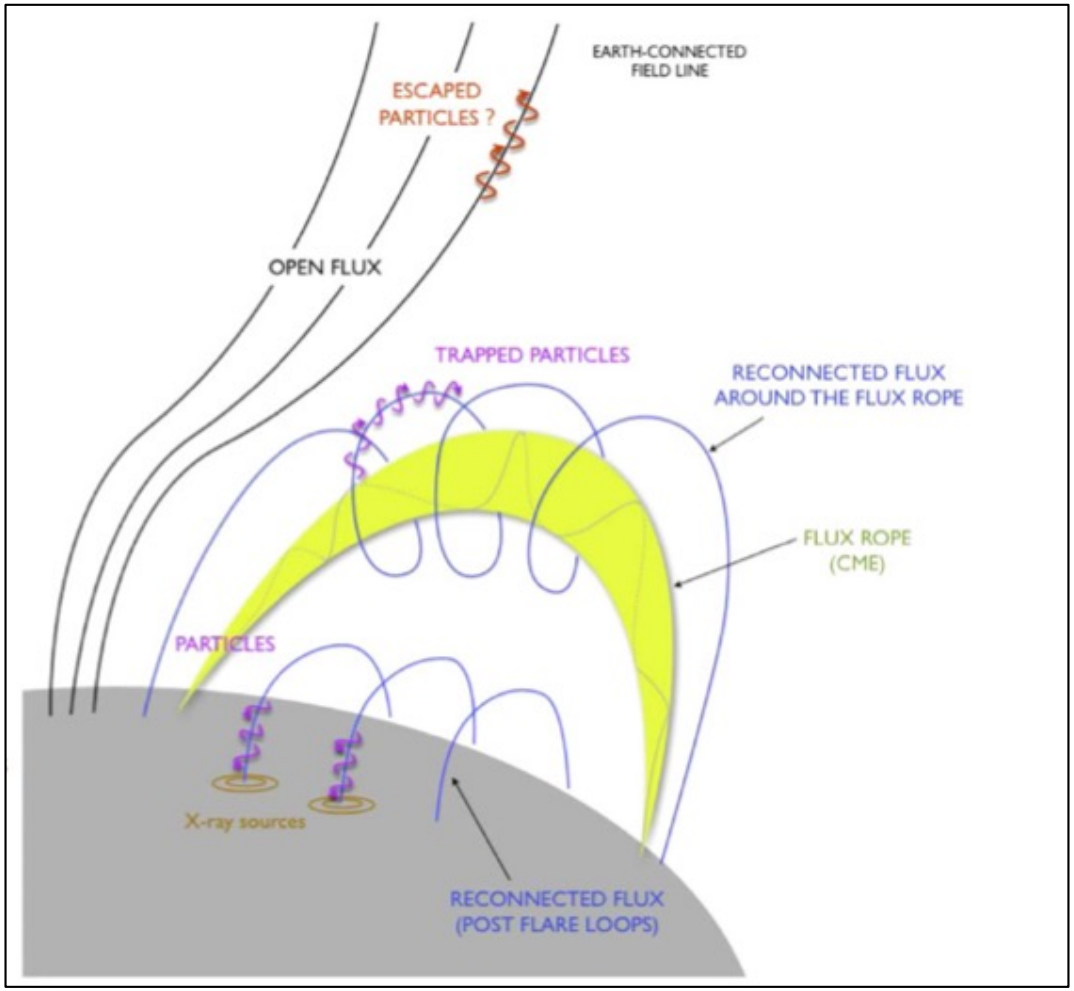
Where do particles fit in?

- First problem: How do flare particles get out?
  - Vilmer presentation
  - Masson presentation
  - General problem of connectivity
- Second problem: How do SEPs get in?
  - Fermi/LAT discussion

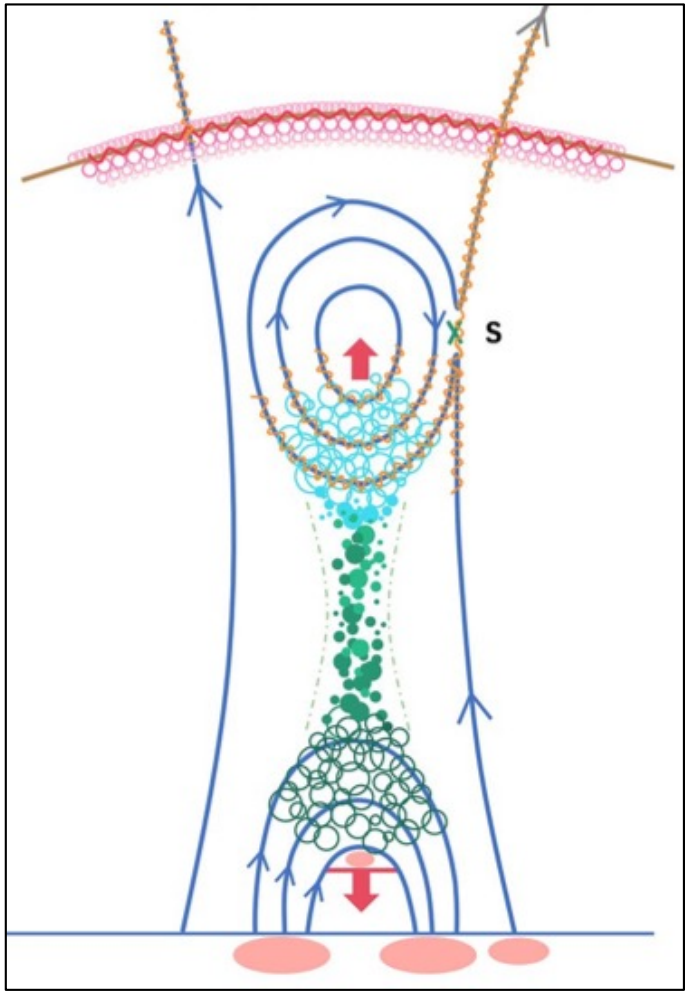
Jeffrey-Effenberger



More reconnection is needed!

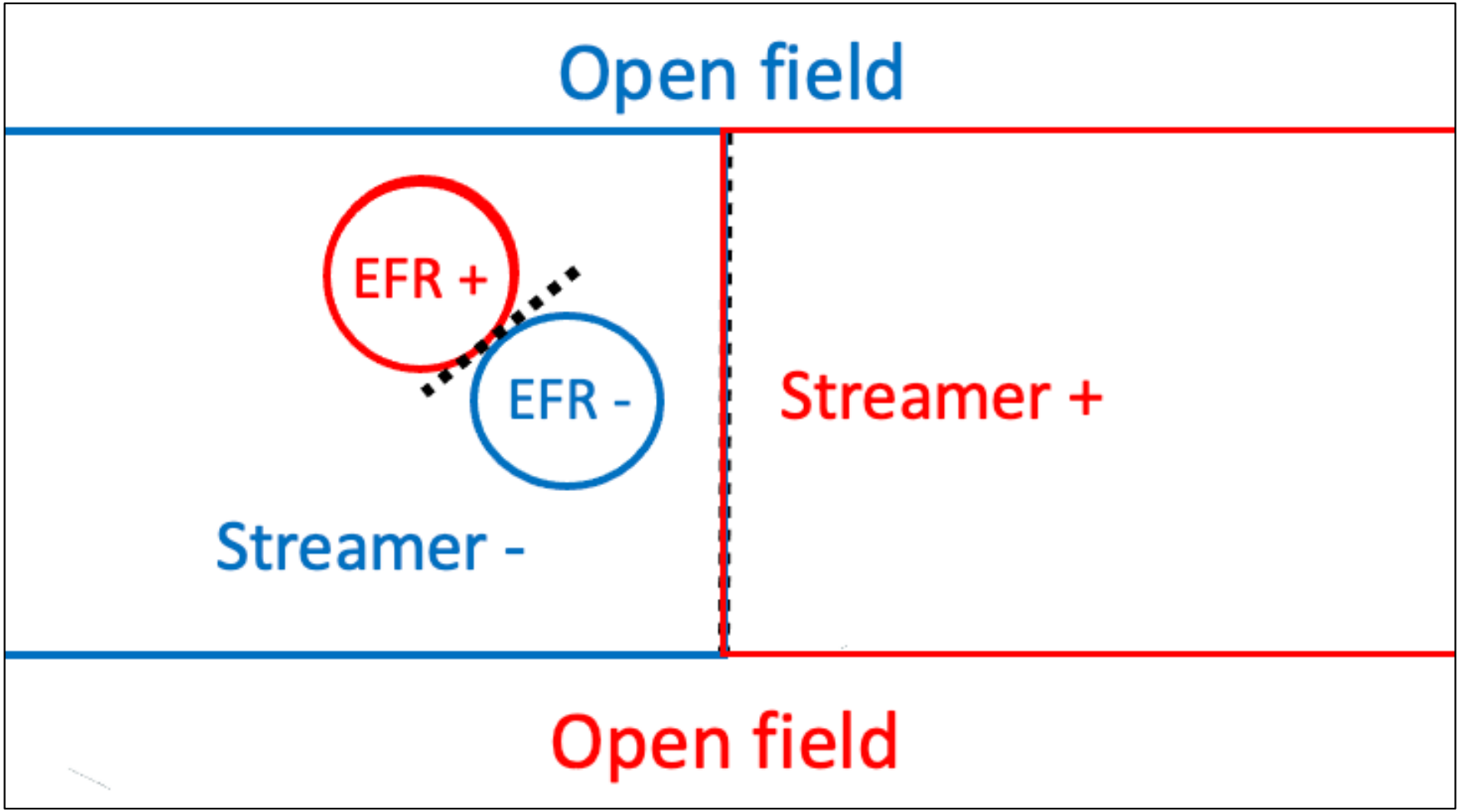


Masson *et al.*, 2013

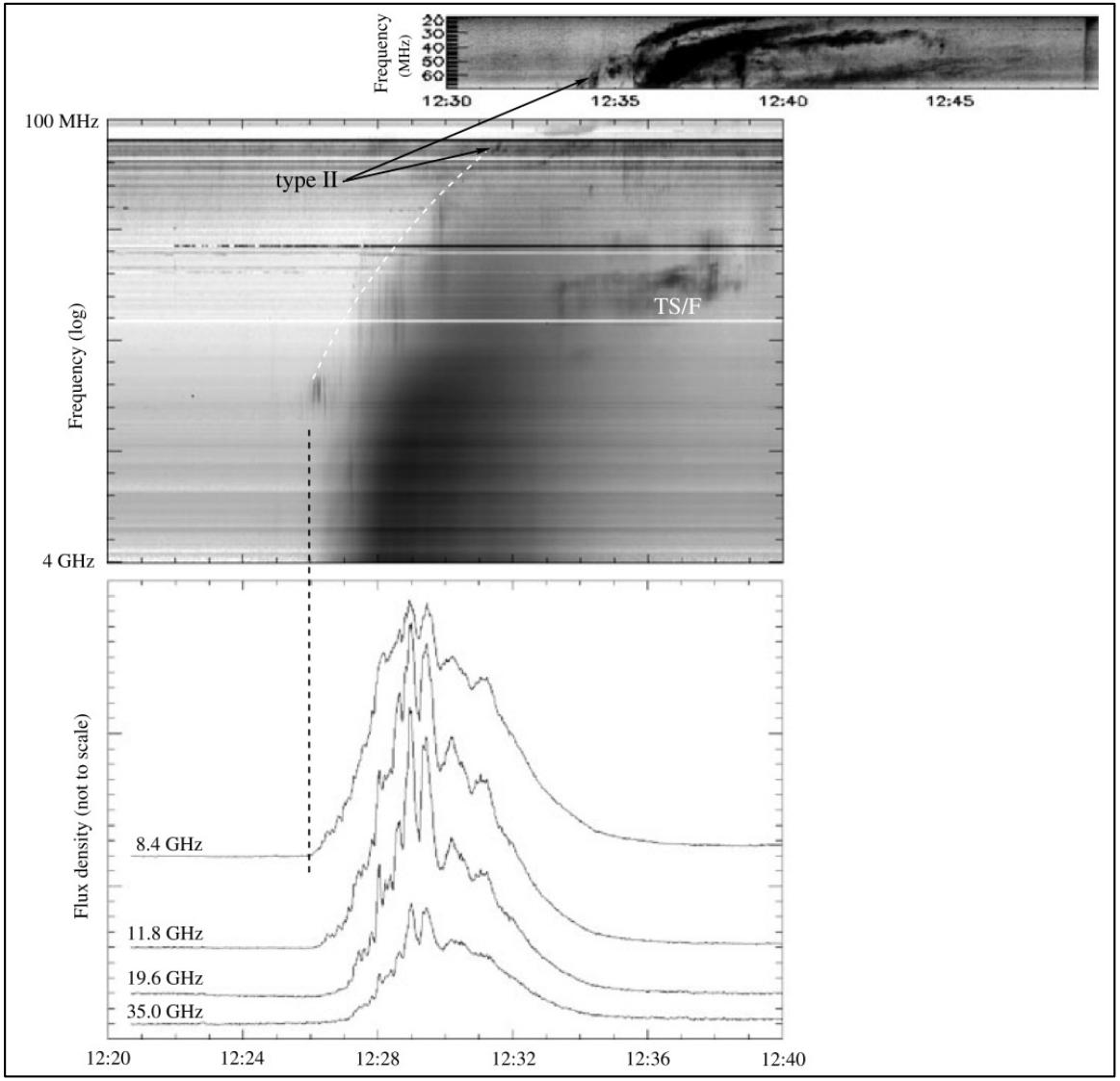


Li *et al.*, 2021

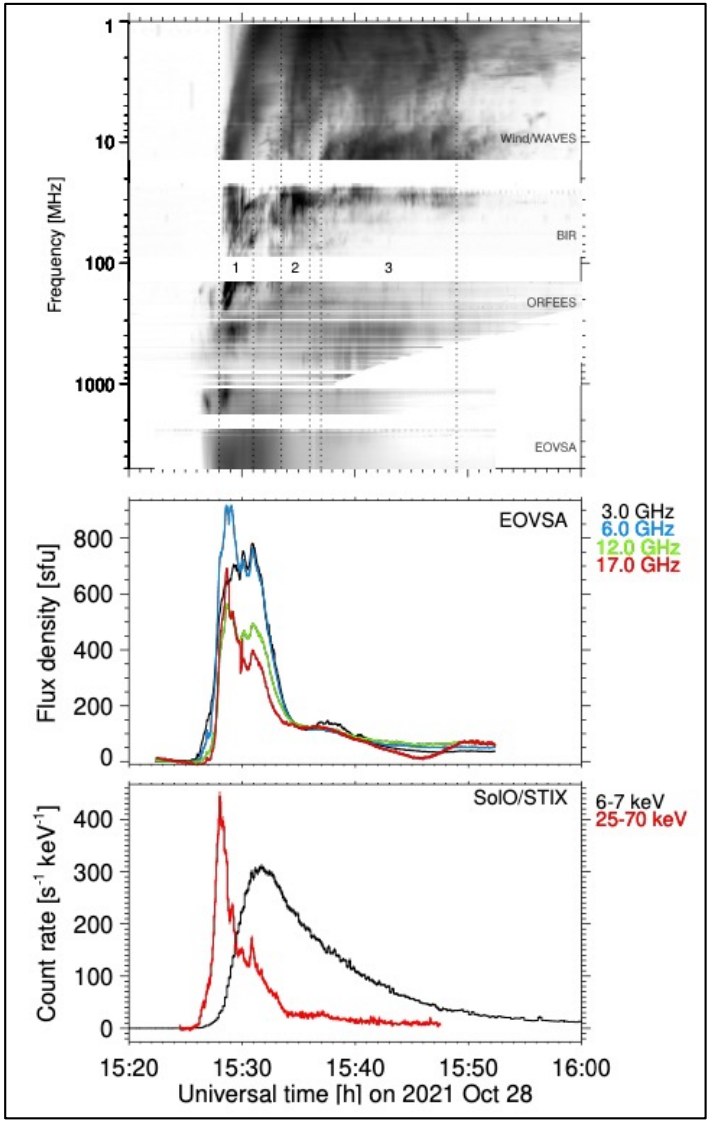
Generalized polarity map



Open fields at flare onset



Kallunki-Pohjolainen 2012

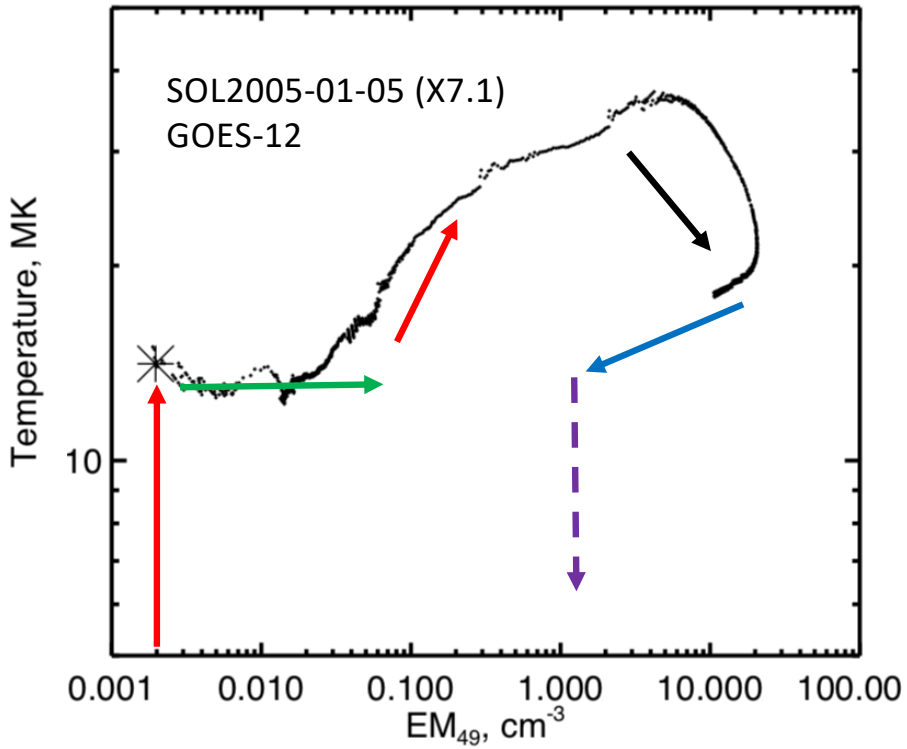


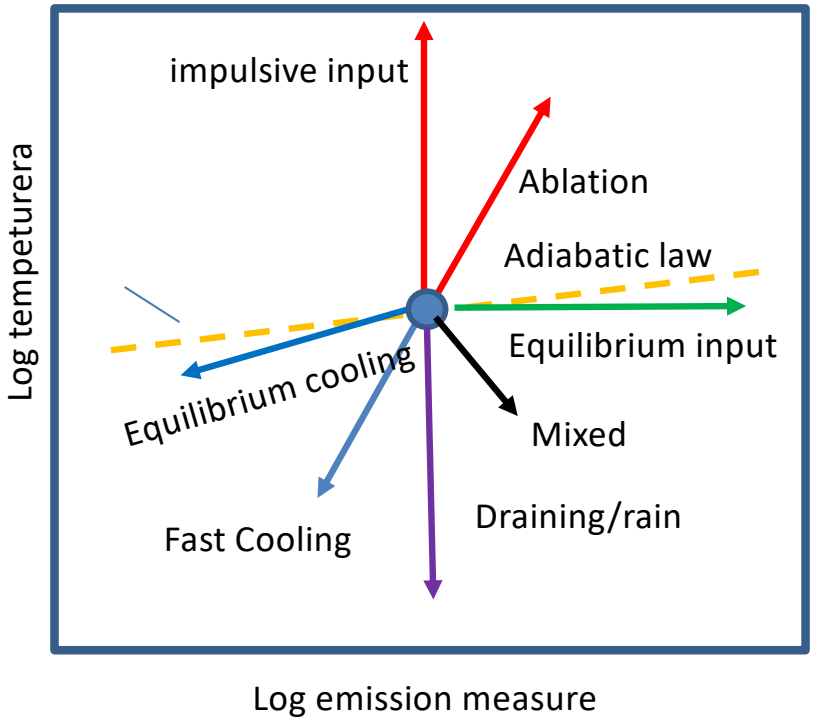
Klein *et al.* 2022

Hot Onset Precursor Events

- All solar flares begin at high temperature; there is no “heating” phase.
- “Hot Onset Precursor Event” = HOPE.
- This is a strong candidate to be the “flare trigger” itself.
- Does flare dynamics in this phase help to trace connectivity?

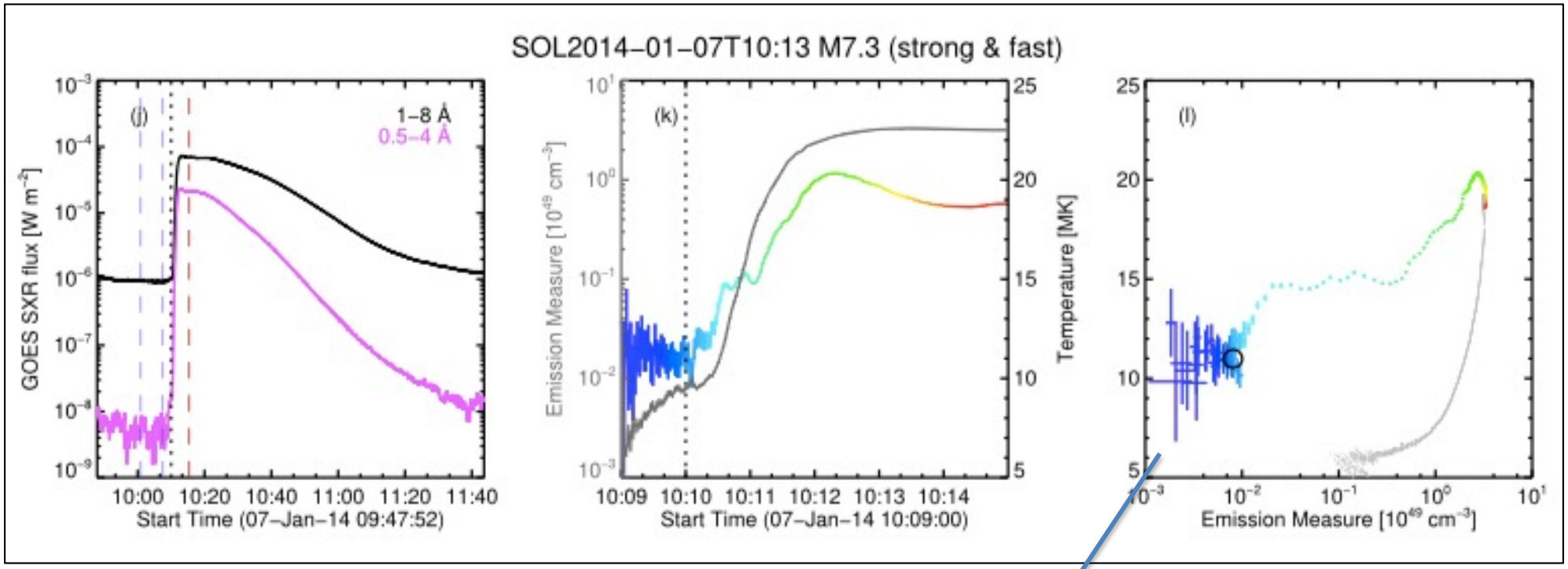
HOPE behavior patterns





- Diagnostic diagram [T, EM] after B. Sylwester, 1974
- Neupert effect (no HOPE) is *diagonally up*
- HOPE is *horizontal*
- (Coronal) rain is *purple*

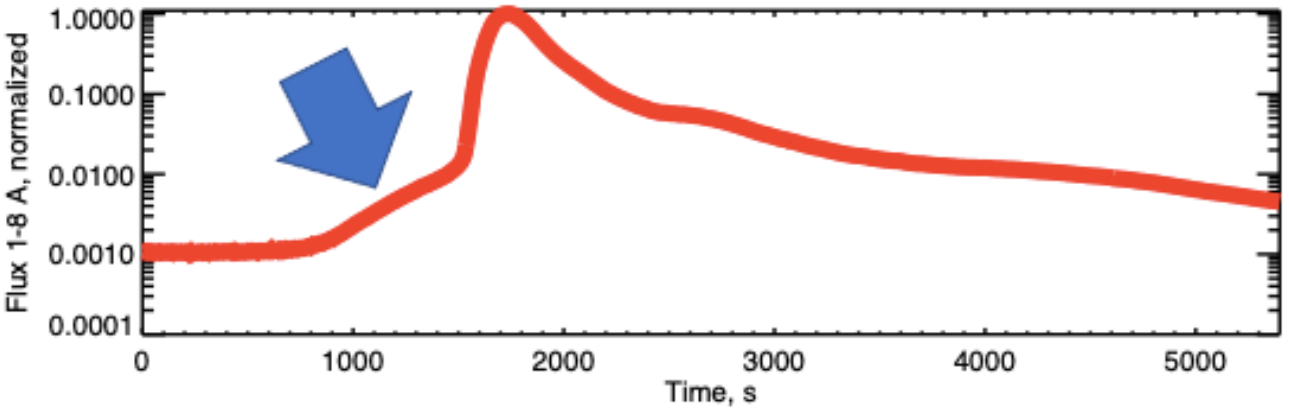
Early HOPE example

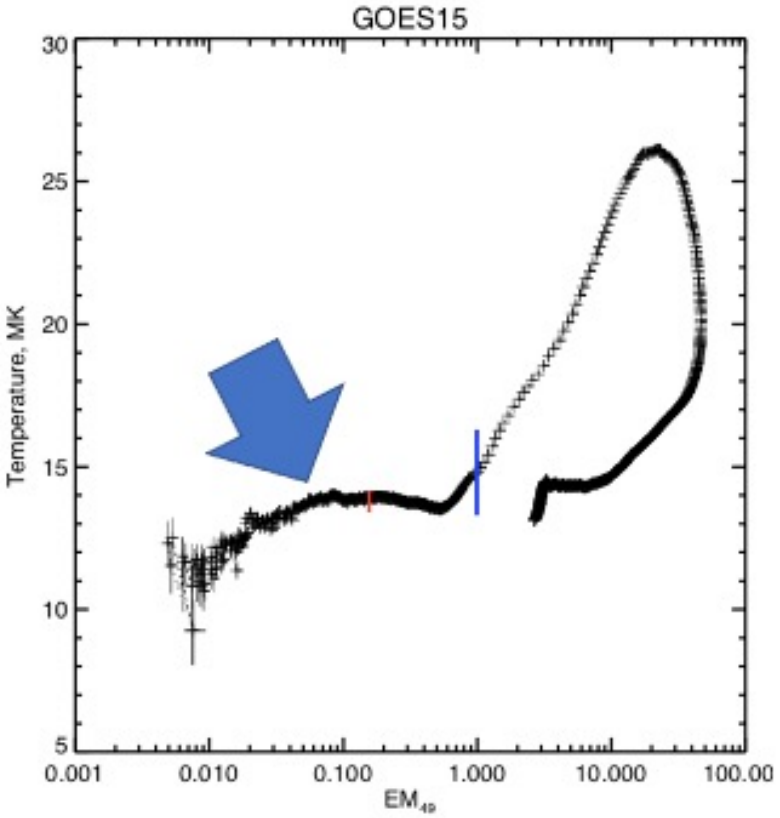


Fluxes [T, EM] ”Loopdeloop”

- Hot Onset Precursor Event (HOPE; Hudson *et al.* 2021)
- The key finding is that there is a horizontal branch in the [T, EM] diagram. T remains roughly constant, while EM increases steadily.

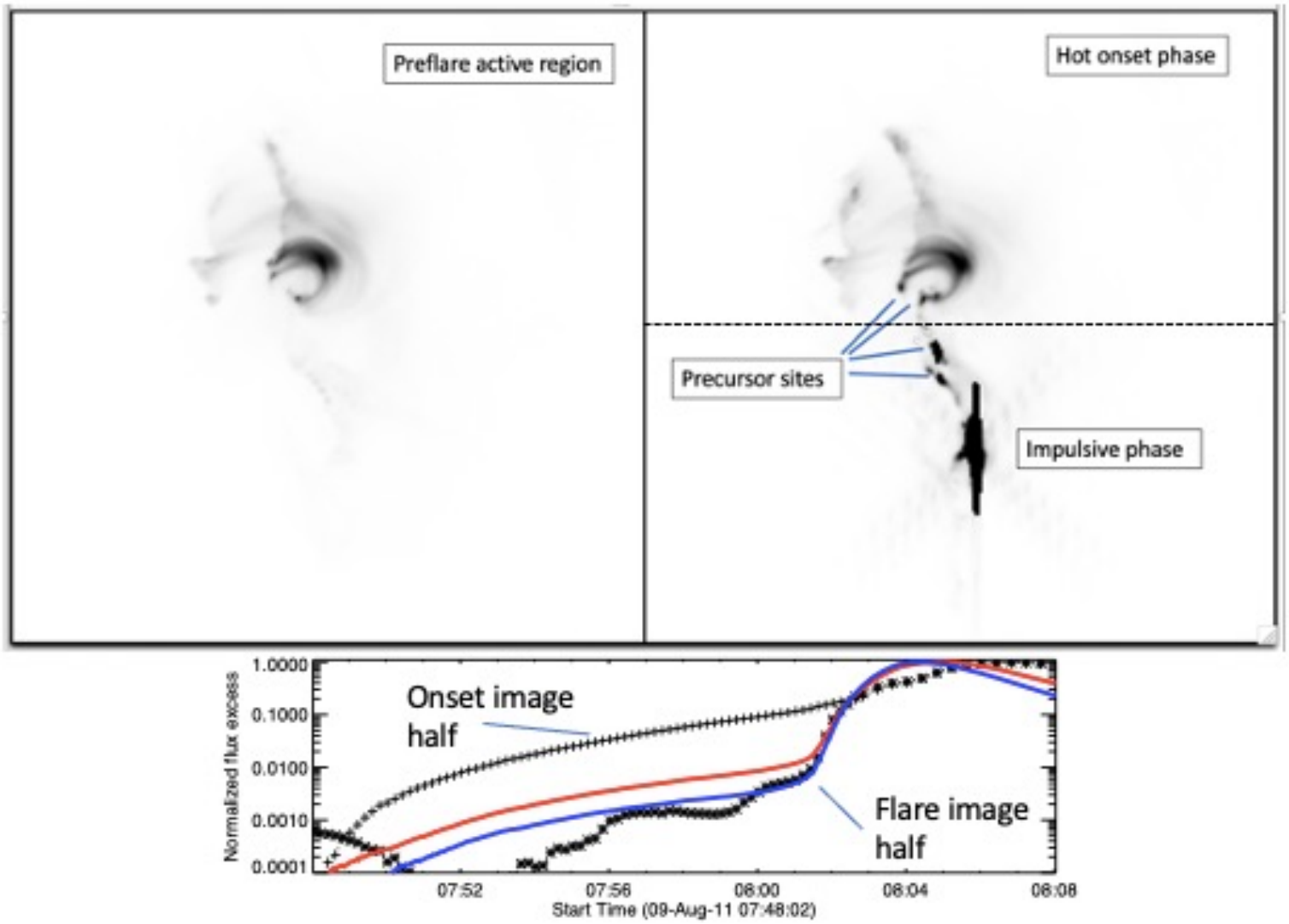
A “Slow HOPE”



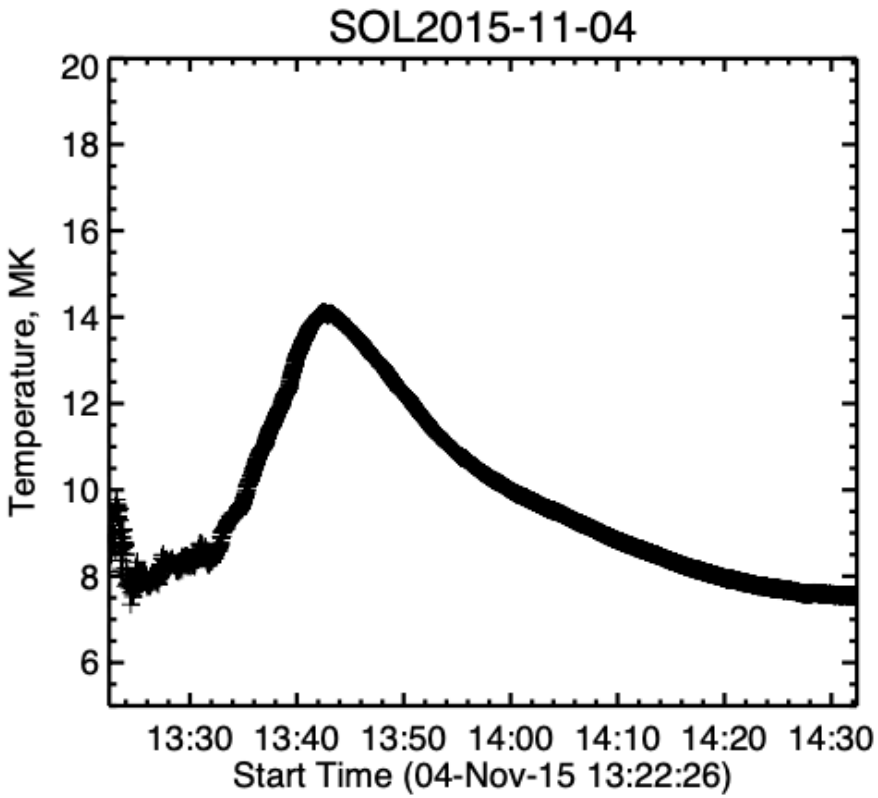


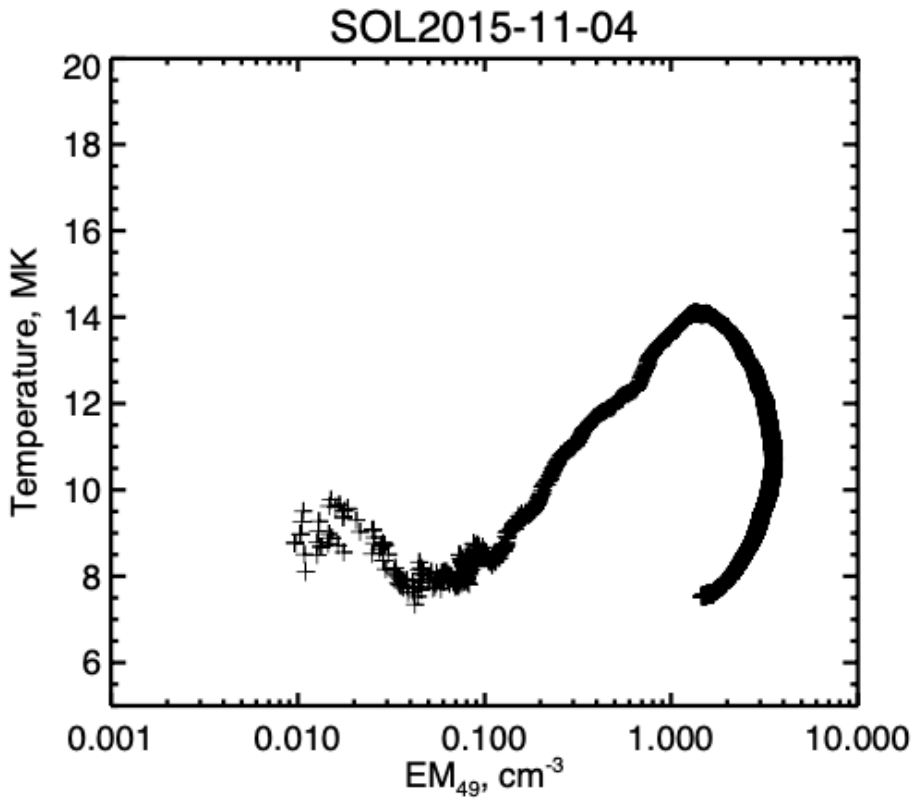
- SOL2011-08-09 (X6.9) has a HOPE lasting for minutes
- The GOES T vs. GOES EM “loopdeloop” plot has an apparently smooth horizontal branch.

What does AIA say?



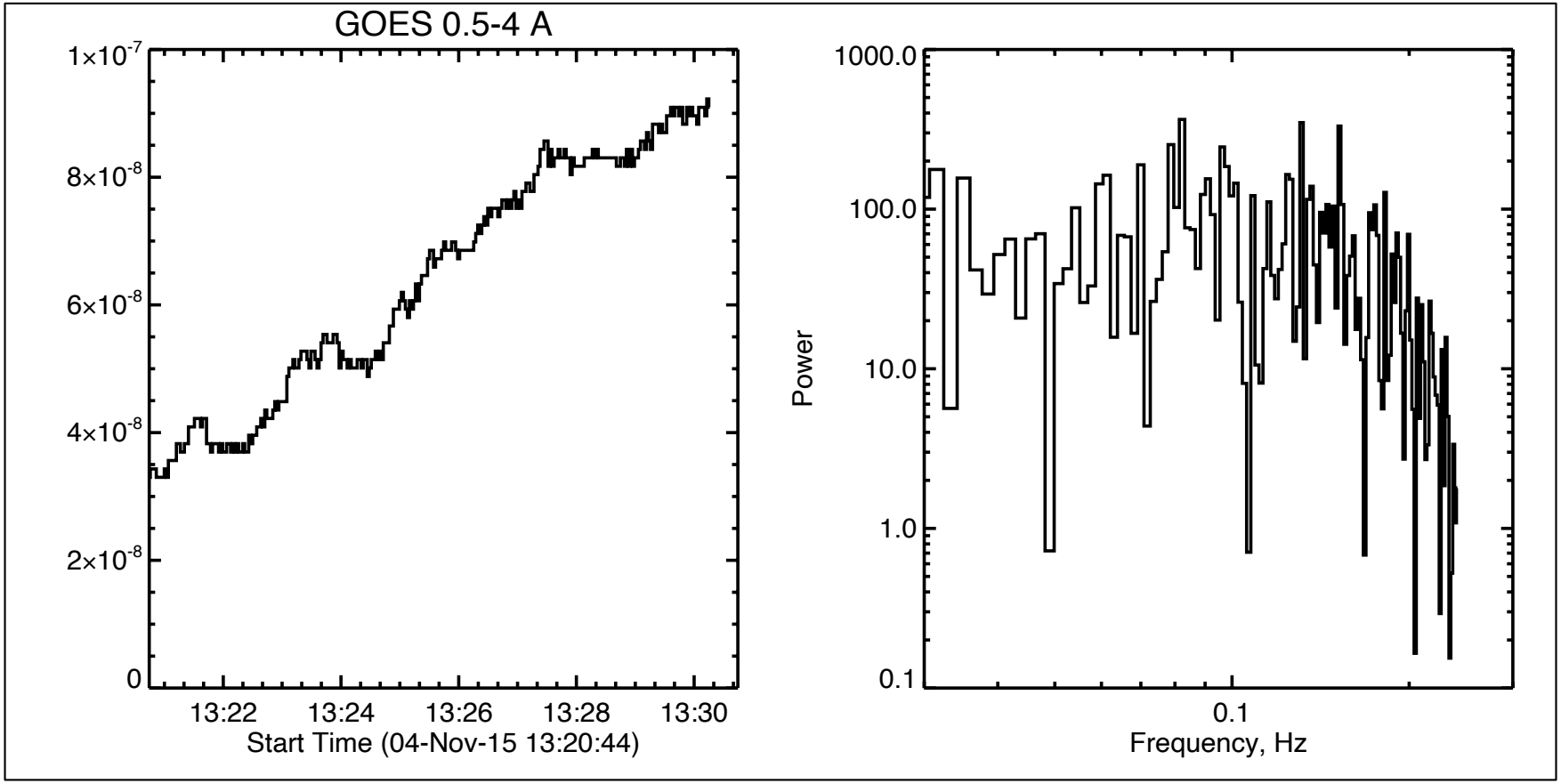
SOL2015-11-04 (Wang et al. 2013) is also a “slow HOPE”





- Is the HOPE phase describable as tether-cutting?
- Is it punctuated by episodic heating?

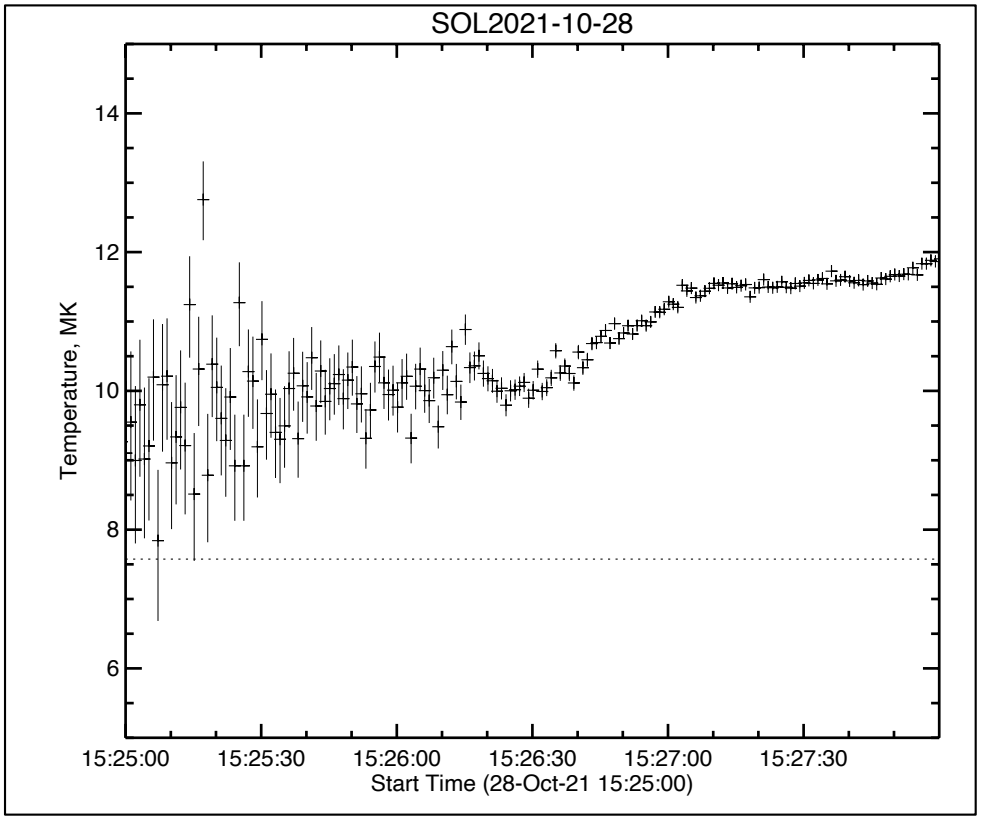
SOL2015-11-04 HOPE timeseries



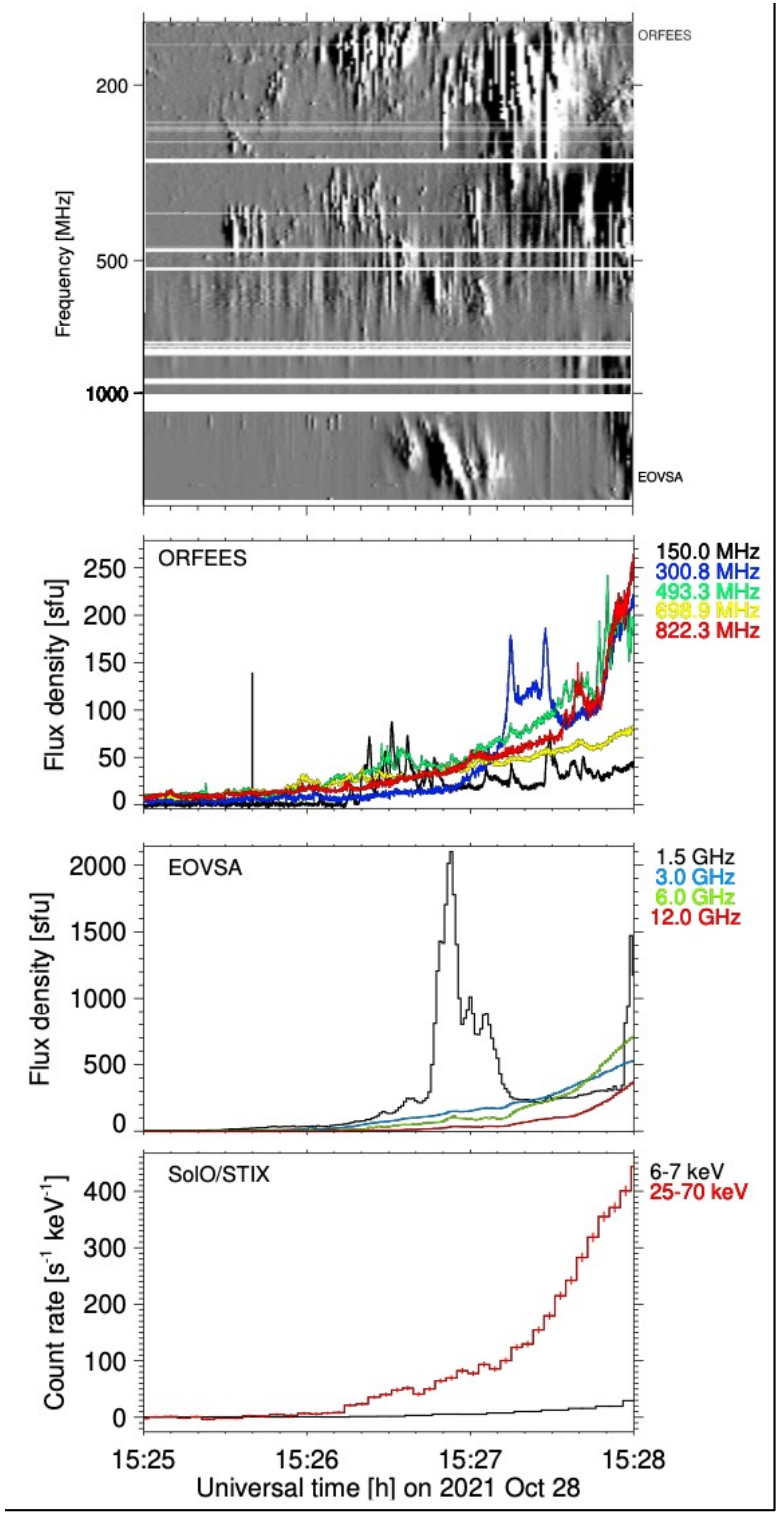
- This slow HOPE has a structured GOES timeseries
- Does this result from “tether-cutting”?
- If so, its shot-noise timescale is about 5 s

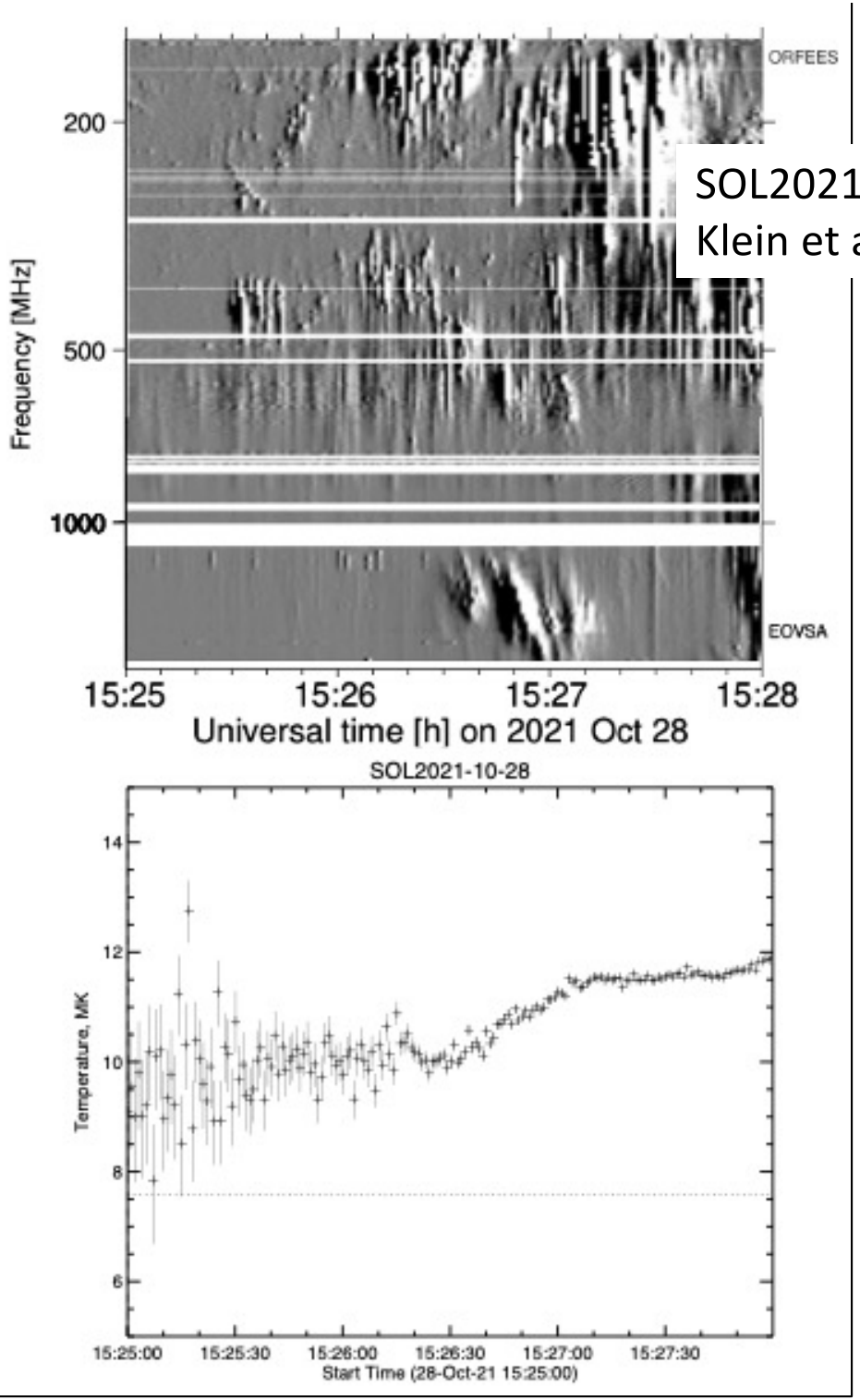
”Tether-cutting reconnection”

- First problem: Is this real?
  - It’s a bad example of tendentious neologism!
- Do type III bursts guide us to it?
- SOL2021-10-28 (= GLE73, another slow HOPE): Klein *et al*. 2022



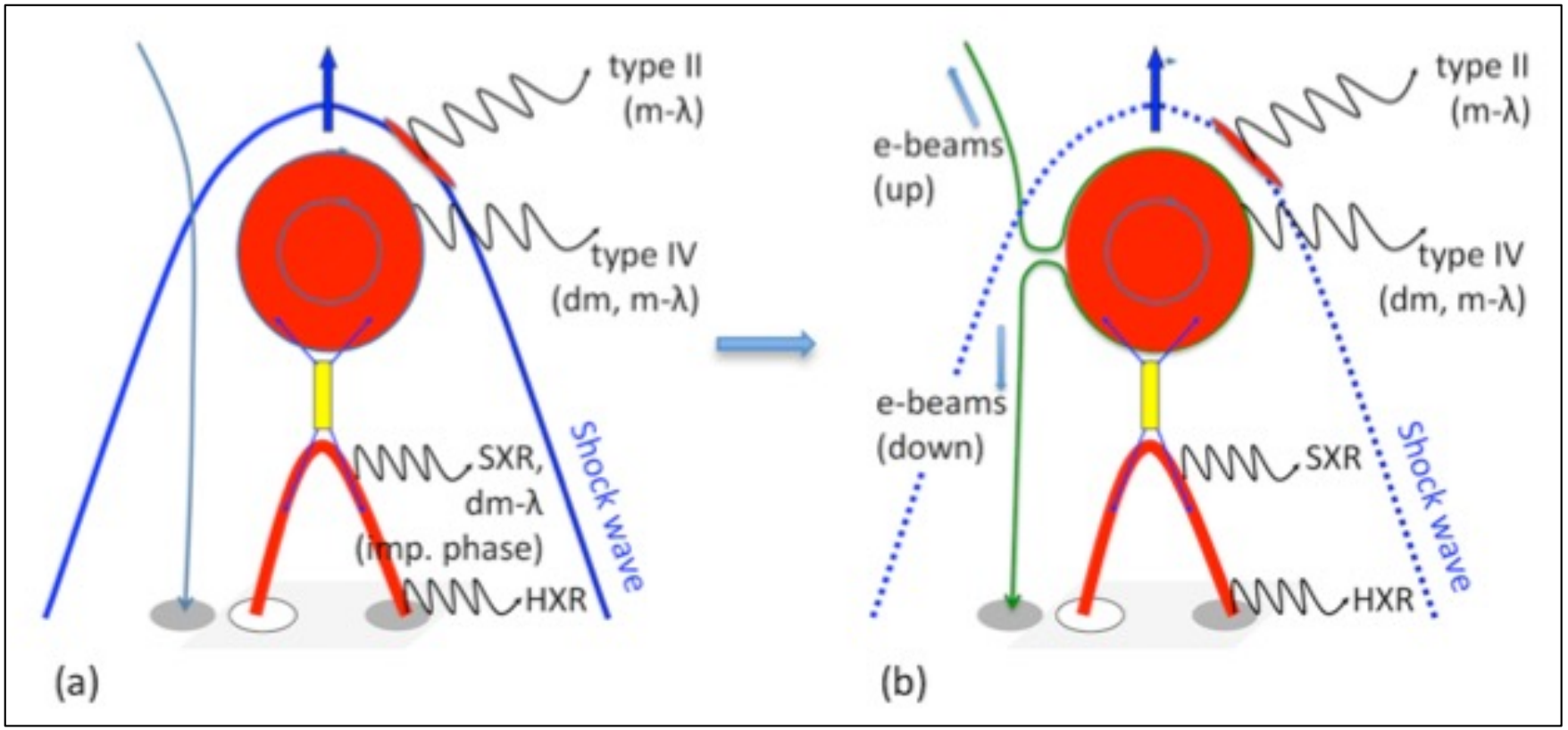
GOES isothermal-fit temperatures for the flare excess. For modern GOES-R data, the (non-solar) background fit is at the dotted line.





SOL2021-10-28
Klein et al. 2022

”Release reconnection”



Klein *et al.* 2022

- Again, the Masson *et al.* (2013) cartoon
- Does the reconnection have any role in the particle acceleration itself?

Conclusions about connectivity

- Dimming shows us much more than justthe footprints of the flux rope (Mandrini et al. 2007).
- Other domains include the strapping fields and the open fields, but we don’t understand the reconnection geometry
- Energetic particles definitively track magnetic domains.
- The X-ray and γ-ray data lack sensitivity and angular resolution; the radio data lack angular resolution: what to do?

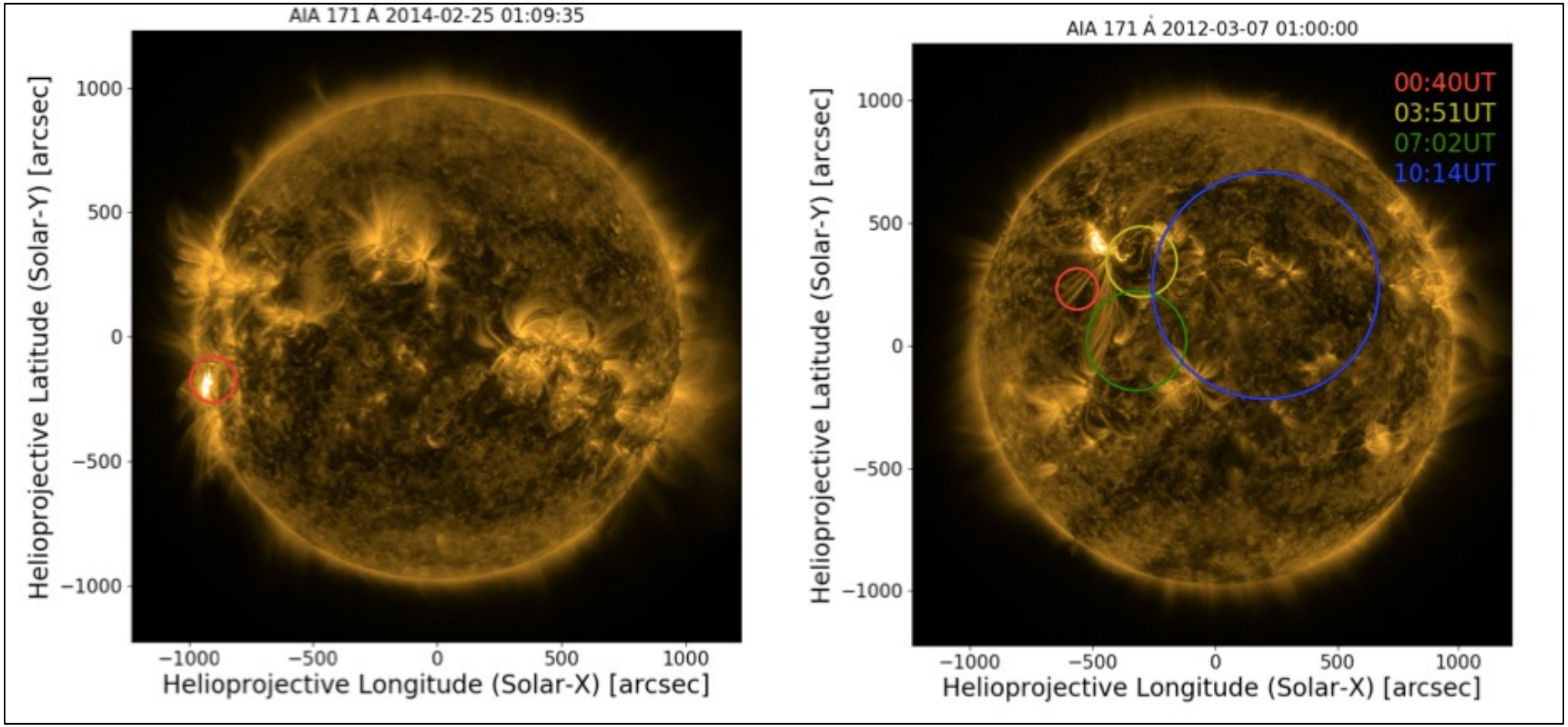
Remarks about “tether-cutting”

- Clear signatures of HOPE phase nonthermal activity may appear at dm wavelengths (Benz, Karlicky)
- Theoretically, one might imagine that “tether-cutting” would *decrease* the system’s free energy, and actually *stabilize* it.
- We do not understand HOPE, nor those cases where nonthermal activity accompanies it.

Remarks about SEPs precipitating

- Long-lasting gamma-ray emission may follow a flare/CME event, on time scales of hours. There is no known visible counterpart for these sources.
- The particle energies are similar to SEP energies.
- Can SEPs actually *return* to the Sun and “precipitate”? If so, where would they do this?
  - Polar coronal holes?
  - Active-region coronal-hole intrusions?

SEPs precipitating?



Pesce-Rollins *et al.* 2022
(Ajello *et al*. 2021)

Conclusion

- There is a good case to be made for HOPE as the flare trigger.

* But how do we proceed?