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Investigating Energy Release during Solar Eruptive Events with RHESSI, STEREO, and SDO

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Motivation

- Understand the relationships among magnetic reconnection, flare energy release, and initiation/acceleration of coronal mass ejections (CMEs) for solar eruptive events
  - When do reconnection and flare energy release occur relative to CME acceleration?

Data & event selection

- Zhu et al. (2020) studied the relative timing of CME evolution and the reconnection rate for 60 CME-flare events
- **CME kinematics:** STEREO/SECCHI (EUVI, COR1, COR2)
  - Viewing angle: off-limb (within 30 degrees of the limb)
  - Cadence: 75 sec, 5 min
- **Reconnection rate**: SDO (AIA, HMI)
  - Measured by summing photospheric magnetic fluxes in regions with brightening flare ribbons and taking the time derivative (Qiu et al. 2002, 2004, 2007)
  - Viewing angle: on-disk (<45 degrees from disk center)
  - Cadence: 24 sec (uncertainties up to ~2 min)

We expand on this analysis by studying **flare energy release** with RHESSI HXR observations.

HXR data & analysis

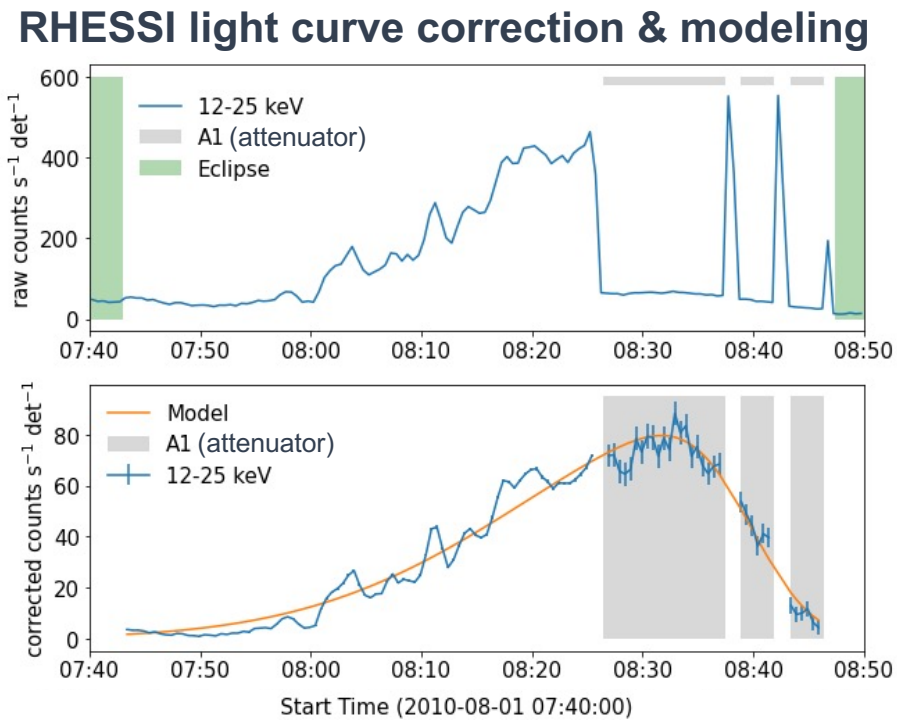
- Using the RHESSI flare image archive, we find that **12/60 events** from Zhu et al. (2020) have corresponding RHESSI data at the time of the CME acceleration peak (same location, high enough statistics for imaging)

Objective: Examine the temporal relationship between HXRs, CME acceleration, and reconnection rate

Analysis: HXR peak times

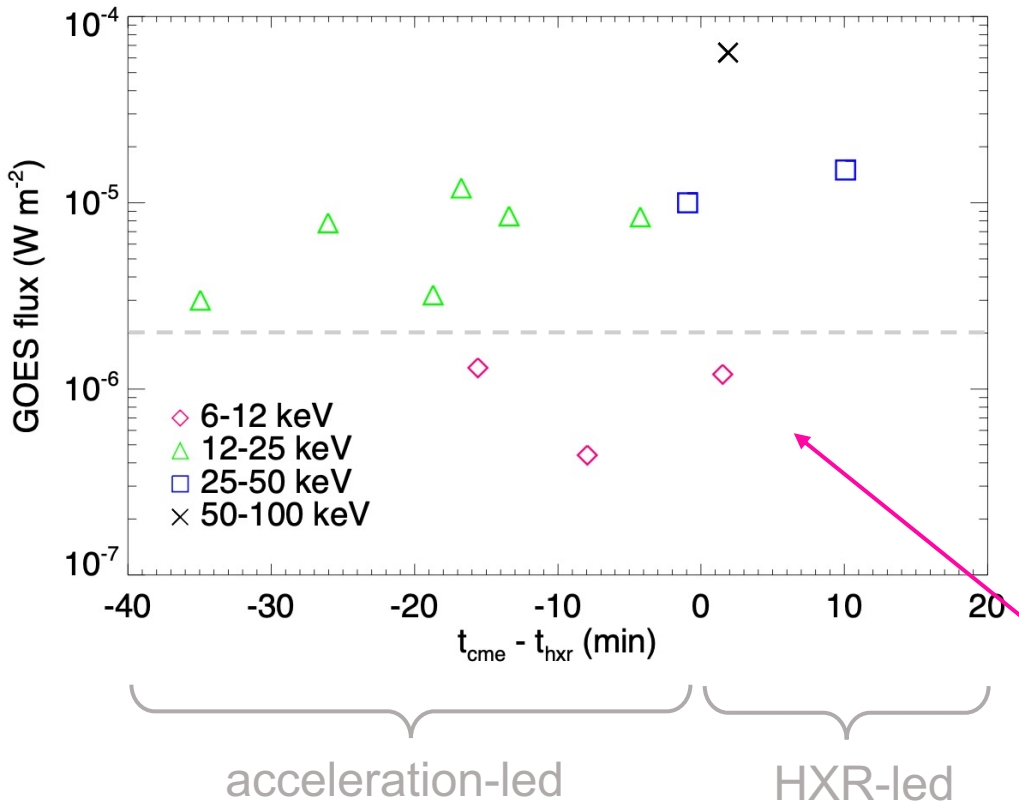
- Prepare RHESSI time profiles (multiple energy bands)
  - Background subtraction, correction for attenuators, etc.
- Model light curve as a skewed Gaussian
  - Use highest-energy band with significant emission
  - Measure peak time of model
  - Compare to CME acceleration peak time

3-6 keV
6-12 keV
12-25 keV
25-50 keV
50-100 keV



Results: HXR peak times

Time difference between CME acceleration peak and peak of maximum HXR energy band

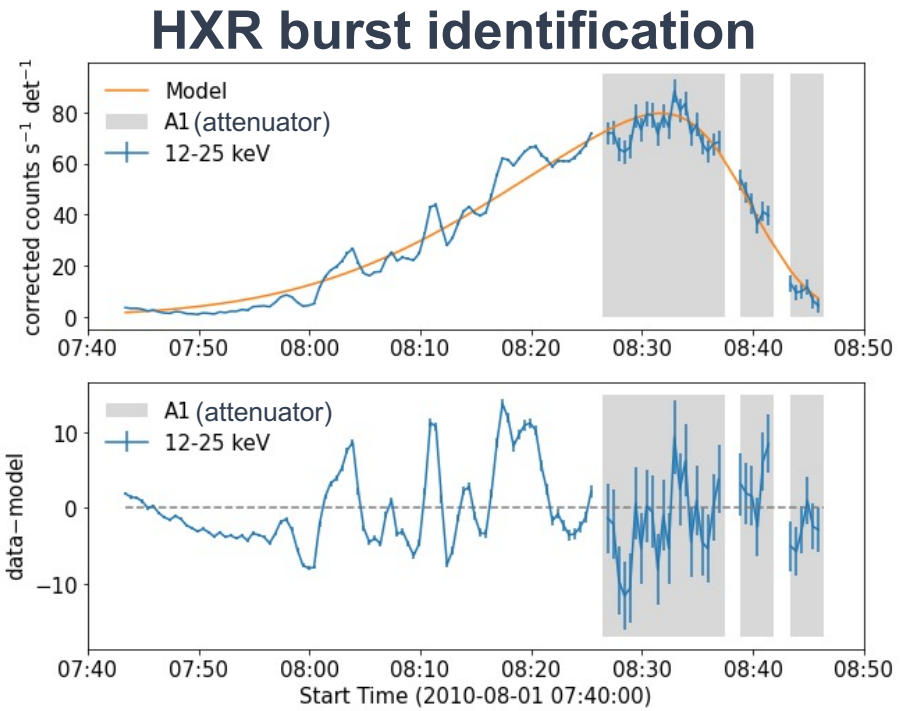


- Larger magnitude events with higher-energy emission tend to be more closely synchronized with CME acceleration
- 6-12 keV and 12-25 keV bands may include a combination of thermal and nonthermal emission
  - We subtract the slowly-varying component (model) to examine HXR bursts for these events.

Dominated by thermal emission

Analysis: Time lag correlation

- Isolate HXR bursts
  - Subtract model (slowly varying) from data
- Perform time lag correlation analysis
  - HXR bursts & reconnection rate
  - HXR bursts & CME acceleration
- For the events studied:
  - HXRs lag the reconnection rate by 1.8 ± 0.7 min (average & standard deviation)
  - HXRs lag CME acceleration by 2.9 ± 6.8 min (average & standard deviation)



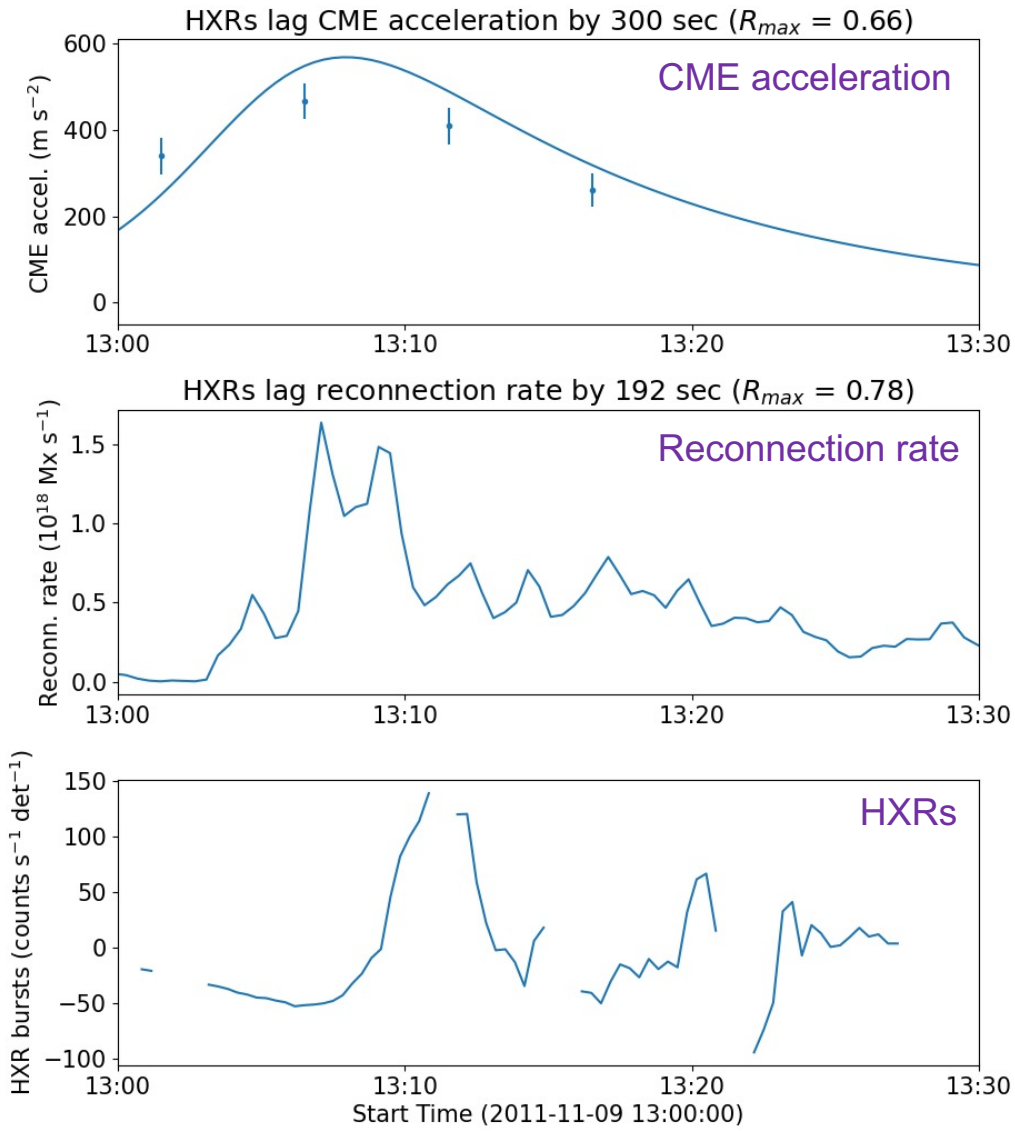
Two types of events observed (qualitatively):

- Events with a strong impulsive HXR burst (dominated by one peak)
- Events with train of several HXR bursts

Example: strong impulsive burst

Strong correlation between reconnection rate and HXRs, with **HXRs lagging reconnection rate** by ~3 minutes

Reasonably good correlation between CME acceleration and HXRs, with **HXRs lagging CME acceleration** by ~5 minutes



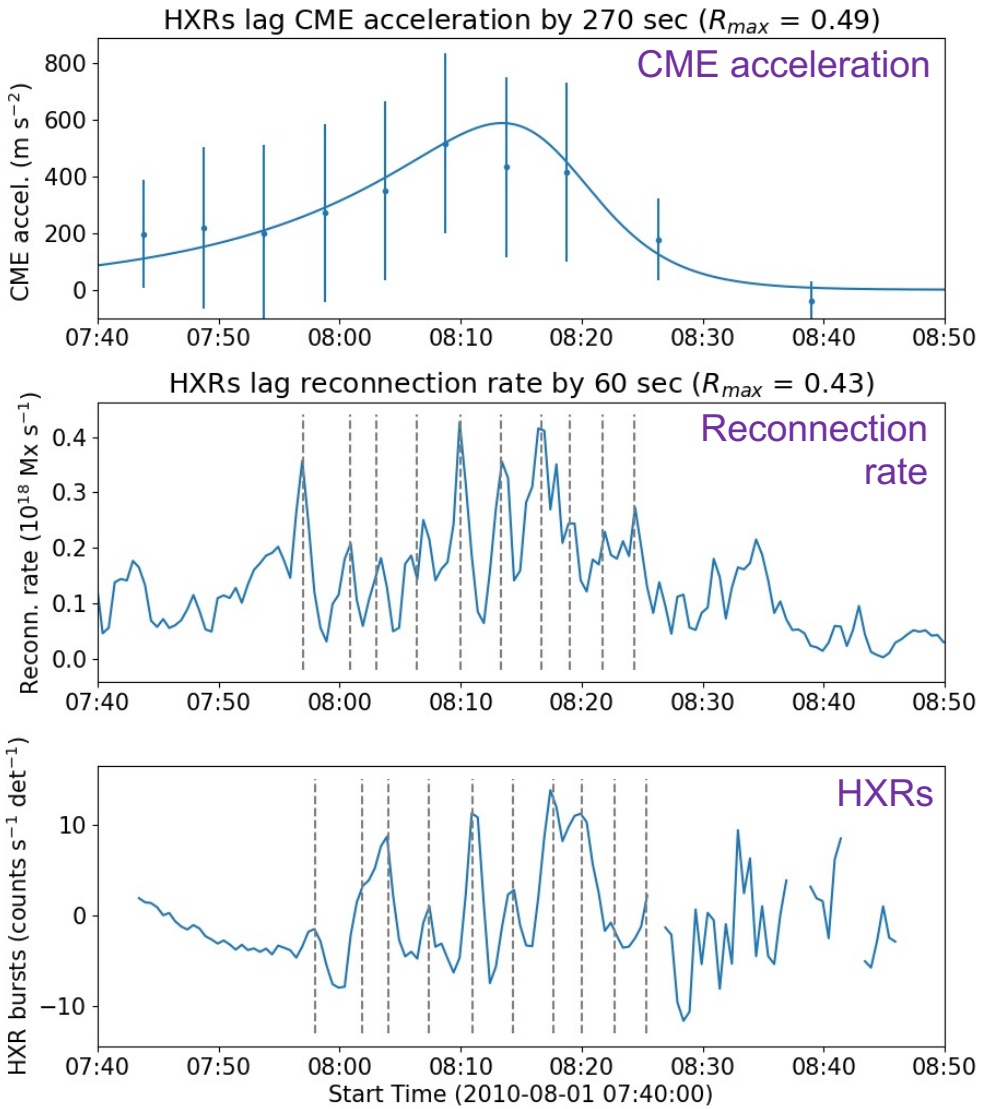
Example: bursty HXR emission

One-to-one correspondence of HXR and reconnection rate bursts during the main CME acceleration phase (shown by dashed lines)

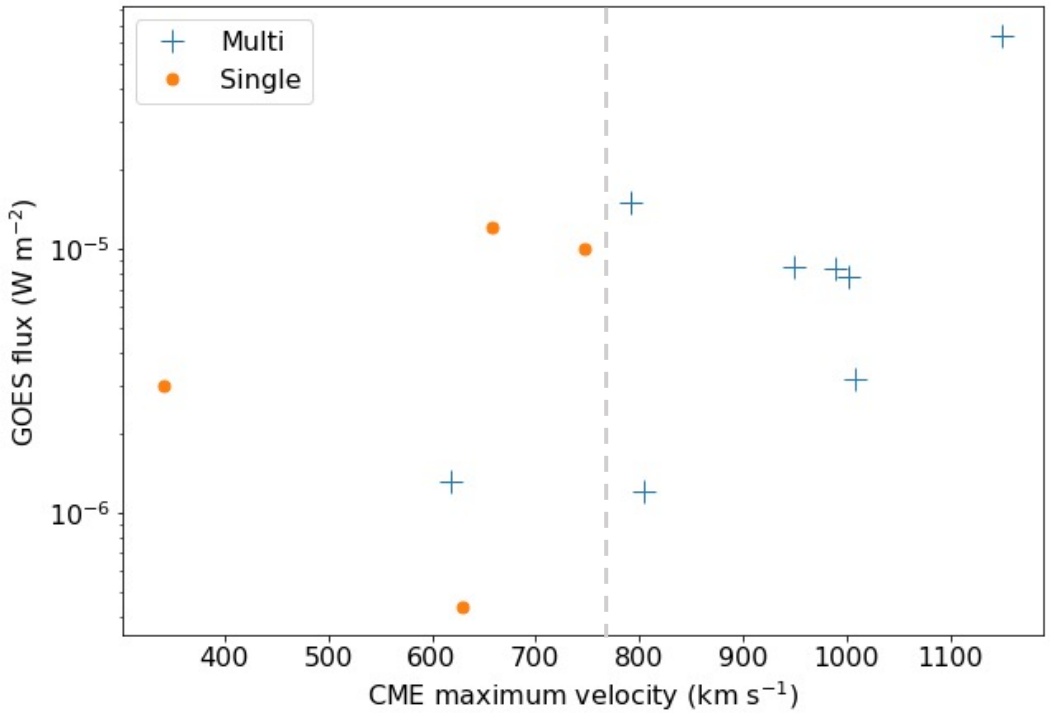
HXR bursts lag reconnection rate by ~1 minute

HXR bursts lag CME acceleration by ~4 minutes

How does the presence/absence of HXR bursts during the CME acceleration phase relate to CME evolution?



Results: HXR bursts & CME velocity



Faster CMEs

- **Multi:** HXR emission & reconnection rate characterized by multiple bursts
- **Single:** HXR emission & reconnection rate characterized by single large peak

The 7 fastest CMEs (of our sample of 12) are all associated with bursty HXR emission.

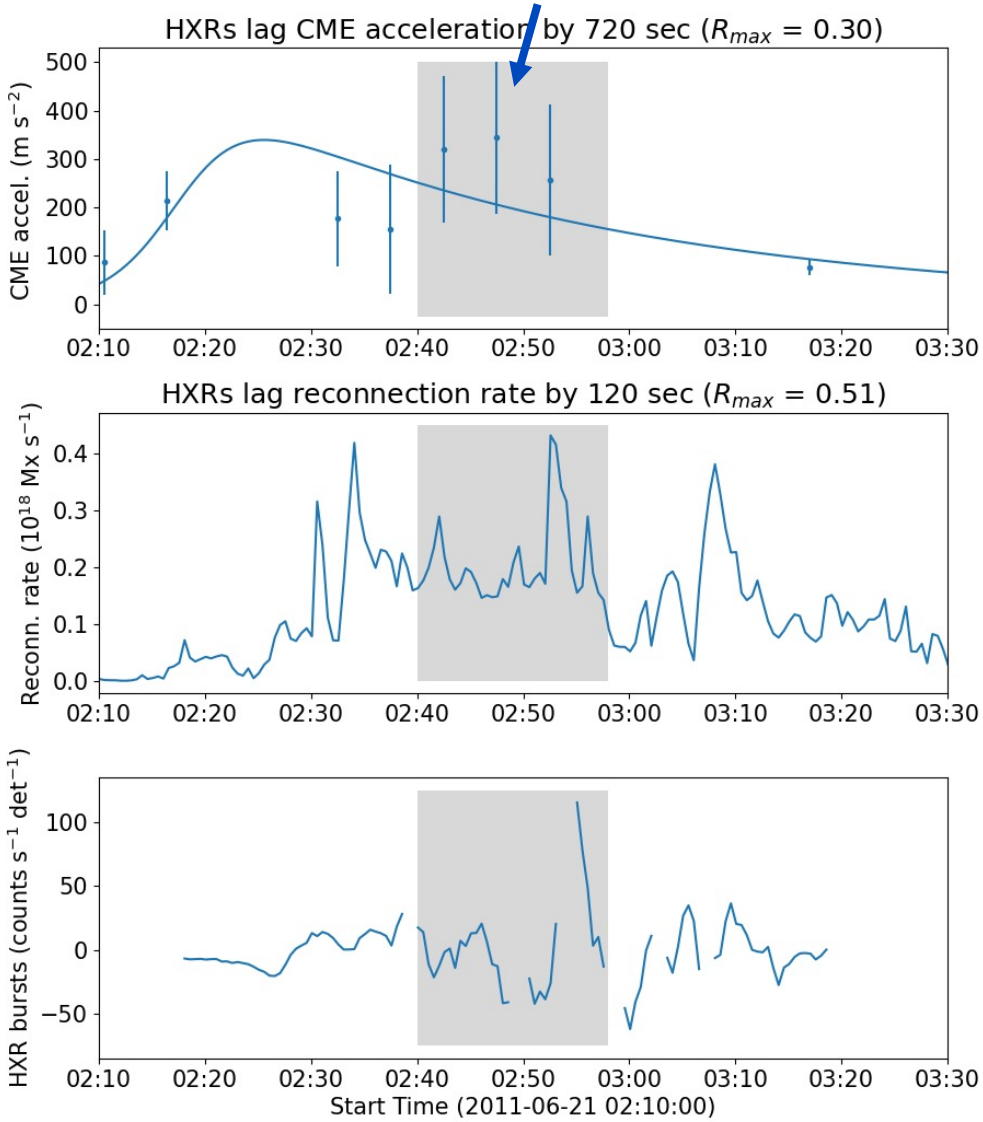
Discussion

- How does the presence/absence of HXR bursts relate to CME evolution?
- Why do bursty events correspond with faster CMEs?
- What can HXR bursts tell us about reconnection and particle acceleration?
  - Intermittent energy release
  - Contracting magnetic islands? (Drake et al. 2006a,b; Clarke et al. 2021)

Continued analysis

- Identification of **CME acceleration "bursts"**
- Investigation of **HXR flares occurring outside of active regions** (ARs)
  - Two such events have already been identified
- Examination of **flare morphology** for events with and without bursty emission
- **Spectral analysis of HXR bursts** (e.g., soft-hard-harder trend & associated with SEPs; Grigis & Benz 2008)

Second acceleration peak is missed by the two-phase exponential function



Second CME acceleration peak coincides with large bursts in the reconnection rate and HXR emission

Summary

- We study the relative timing between the HXR, CME acceleration, and reconnection rate profiles and examine fast-varying features for 12 CME-flares using data from RHESSI, STEREO, and SDO.
- We find that HXR bursts occur throughout the main CME acceleration phase for most events, with the acceleration leading the HXR bursts by an average of 2.9 ± 6.8 minutes, indicating a close relationship between flare energy release and CME acceleration.
- A close correspondence is observed between bursts in the reconnection rate and HXR emission, with HXRs lagging the reconnection rate by 1.8 ± 0.7 minutes, on average.
- Qualitatively, the studied events fall into two categories: events with a single dominant HXR burst and events with a train of multiple HXR bursts.
- Events with multiple HXR bursts, likely a signature of intermittent reconnection and/or particle acceleration processes, are found to be associated with faster CMEs.
- Future studies will examine CME acceleration “bursts”, non-AR HXR flares, flare morphology, and HXR spectra.