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What can we learn about coronal mass ejections from their associated coronal dimmings?

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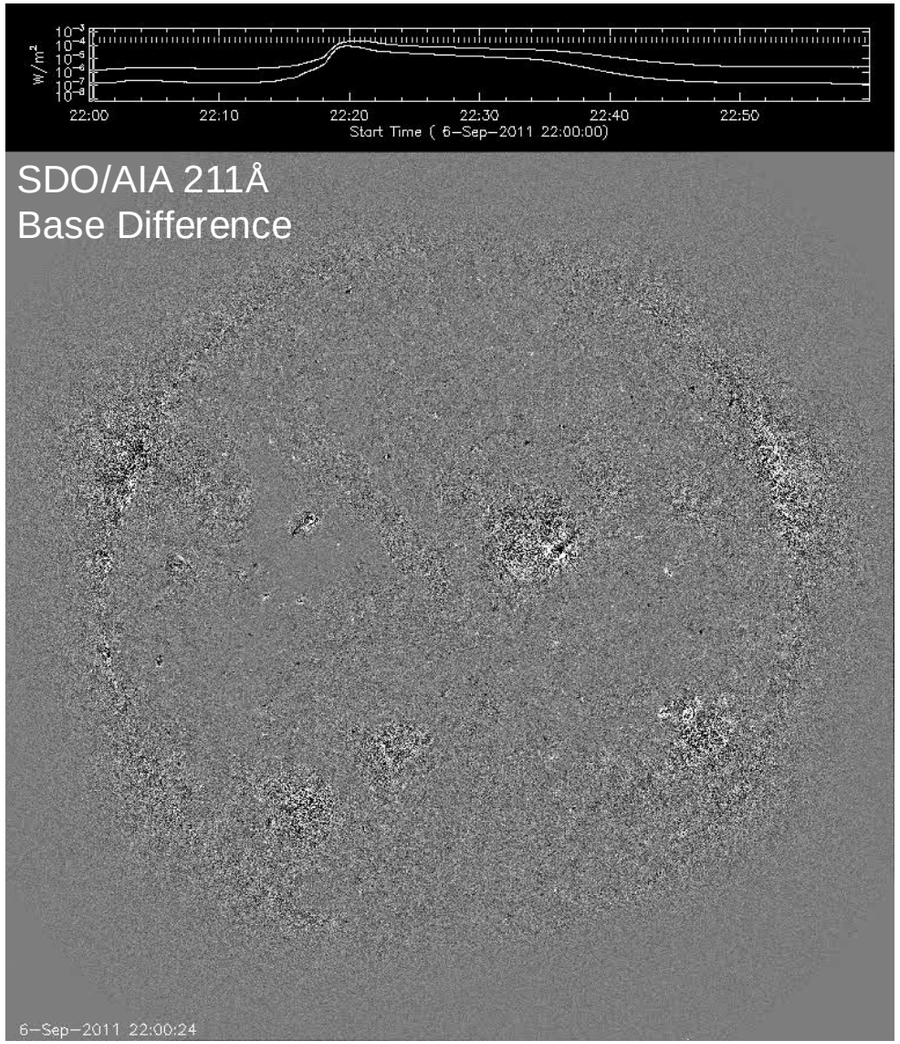
Coronal Dimmings

- Transient decrease in EUV and SXR emission during early CME evolution
- Interpretation: expansion and mass depletion by CME eruption

  (Hudson & Webb 1996, Sterling & Hudson 1997, Thompson+1998, Zarro+1999, Harrison & Lyon 2000, Zhukov & Auchere 2004, Dissauer+2018, 2019)
- Confirmed by plasma outflows in spectroscopic observations

  (Harra & Sterling 2001, Jin+2009, Tian+2012, Veronig+2019)

→ Dimmings are an (indirect) signature of CMEs from the Sun

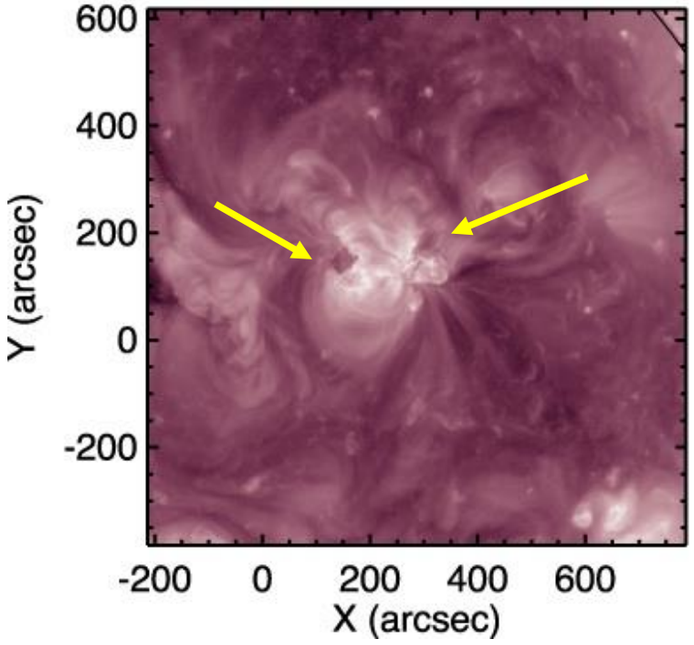


6 Sep 2011 X2.1 flare/CME (v=990 km/s)
http://www.lmsal.com/nitta/movies/AIA_Waves/oindex.html

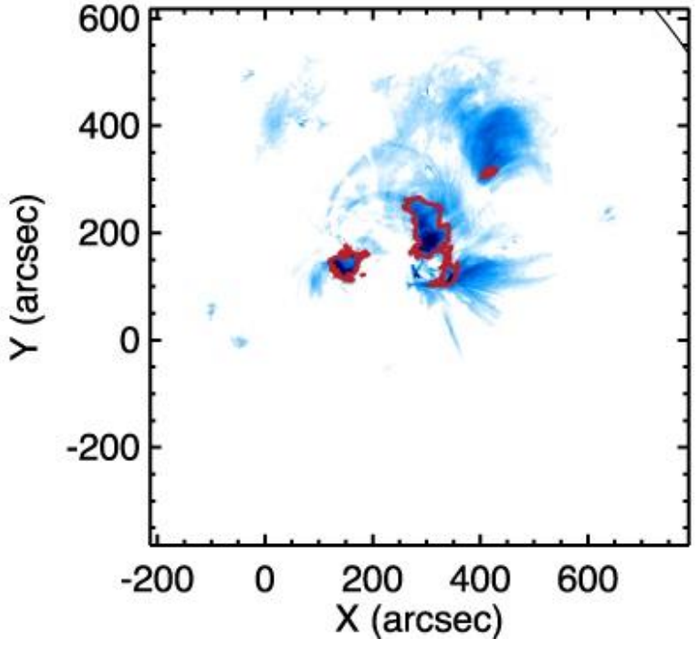
Coronal Dimmings

- Detections of dimming regions and underlying LOS magnetic field
- *Core dimmings* (bipolar) may relate to the anchor points of erupting flux rope
  (Sterling and Hudson 1997, Webb et al. 2000, Mandrini et al. 2007)

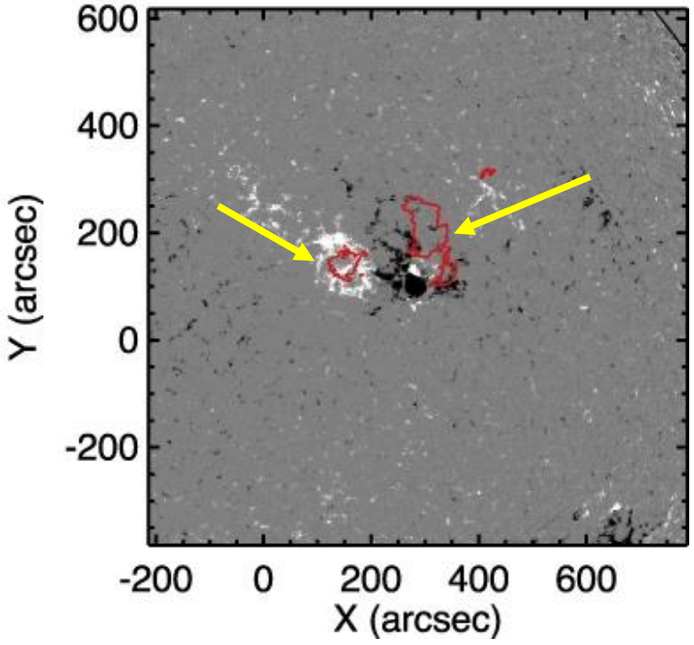
SDO/AIA 211Å



AIA 211Å Diff. image



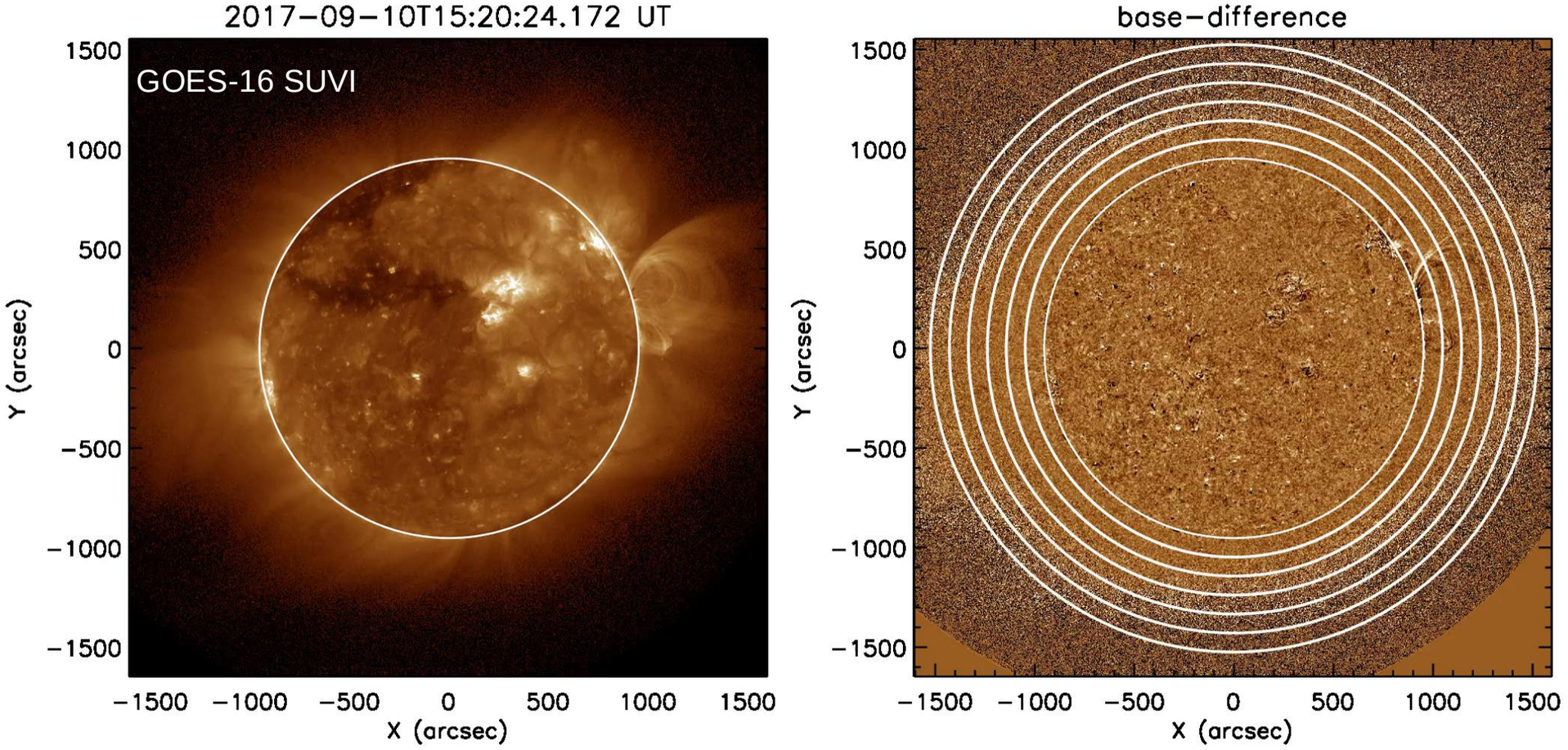
HMI LOS magn. field



Dissauer et al. (2018a)

Coronal Dimmings

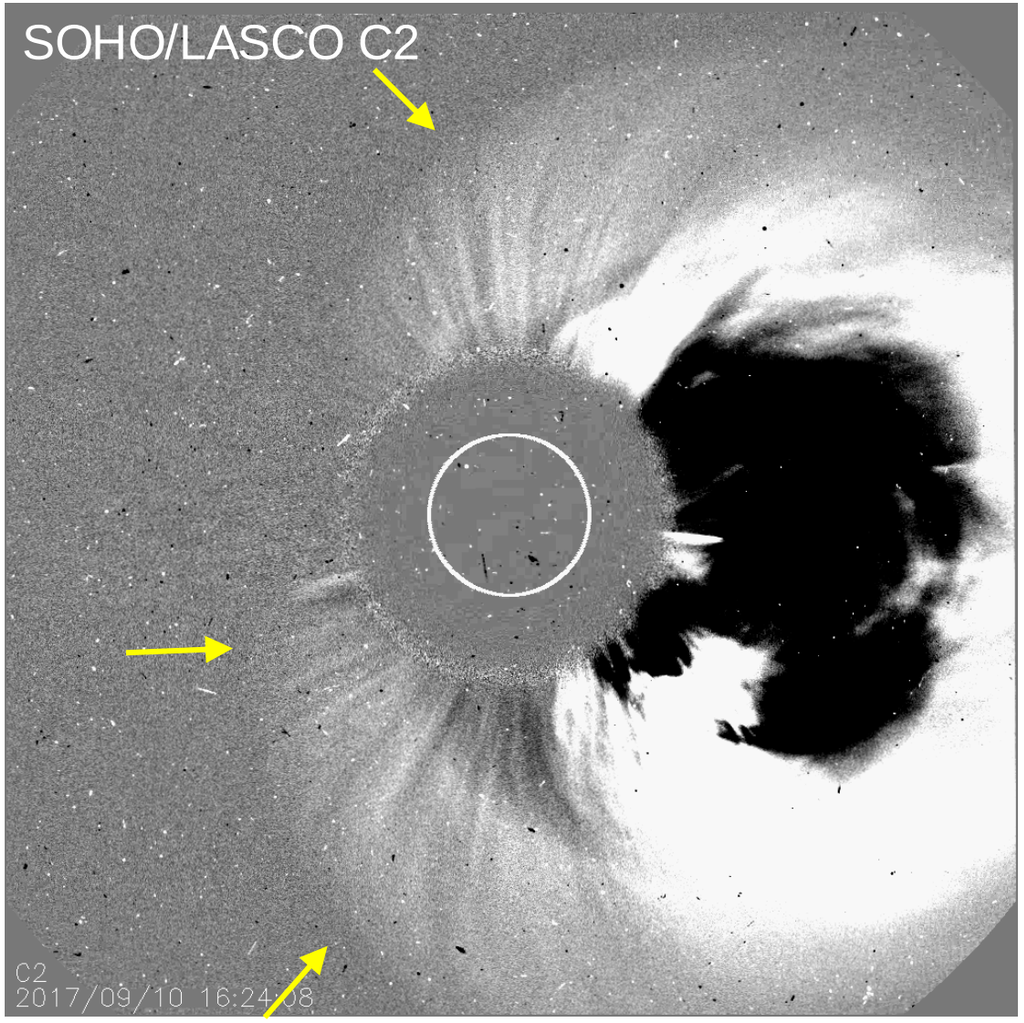
Dimming observed off-limb, associated with X8.2 flare, fast CME and global EUV wave on 10 September 2017. Considerable part of corona is blown away.

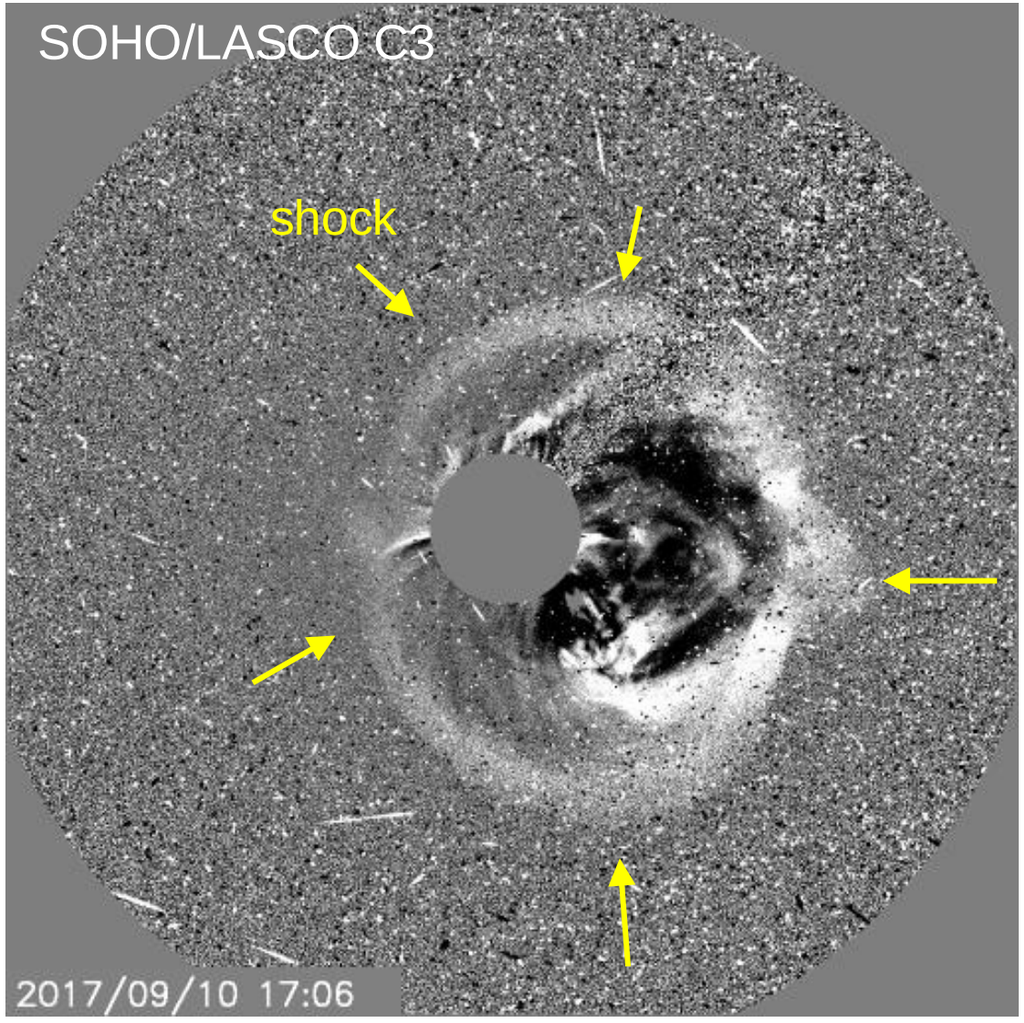


Veronig et al. (2018)

Coronal Dimmings

Associated fast halo CME (v > 3000 km/s)

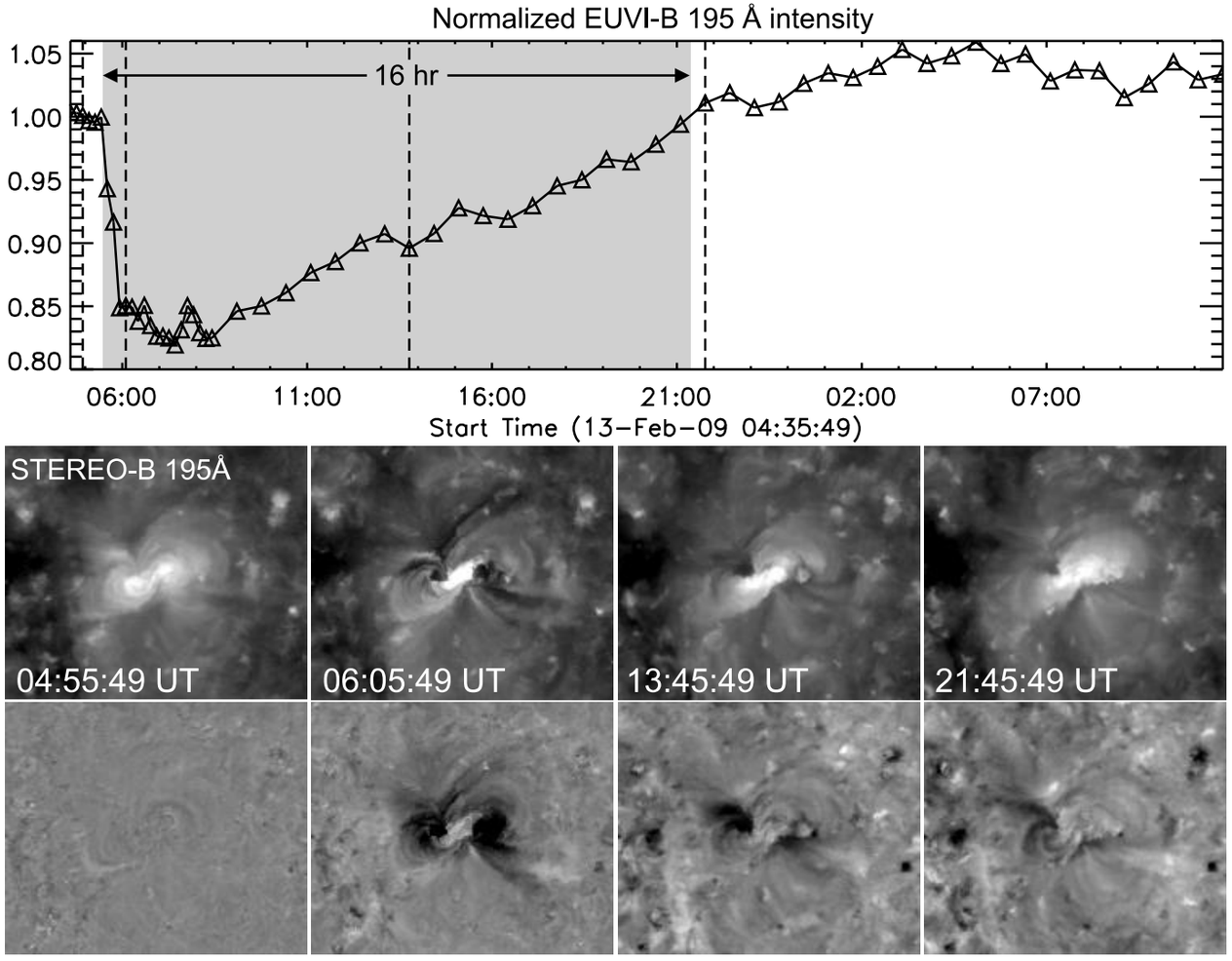




Veronig et al. (2018)

Coronal Dimmings

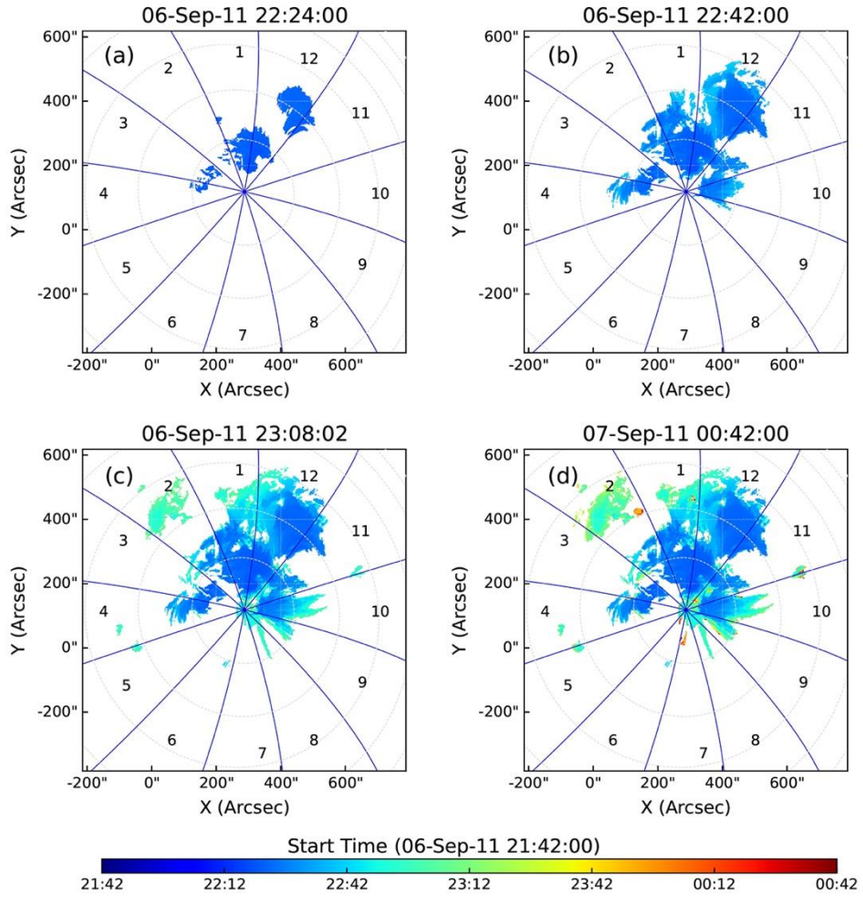
Evolution: decrease is impulsive (<1 hr), followed by a gradual recovery which may take many hours to days (Reinard & Biesecker 2008, Attrill+2008, Kahler & Hudson 2000, Dissauer+2018b)

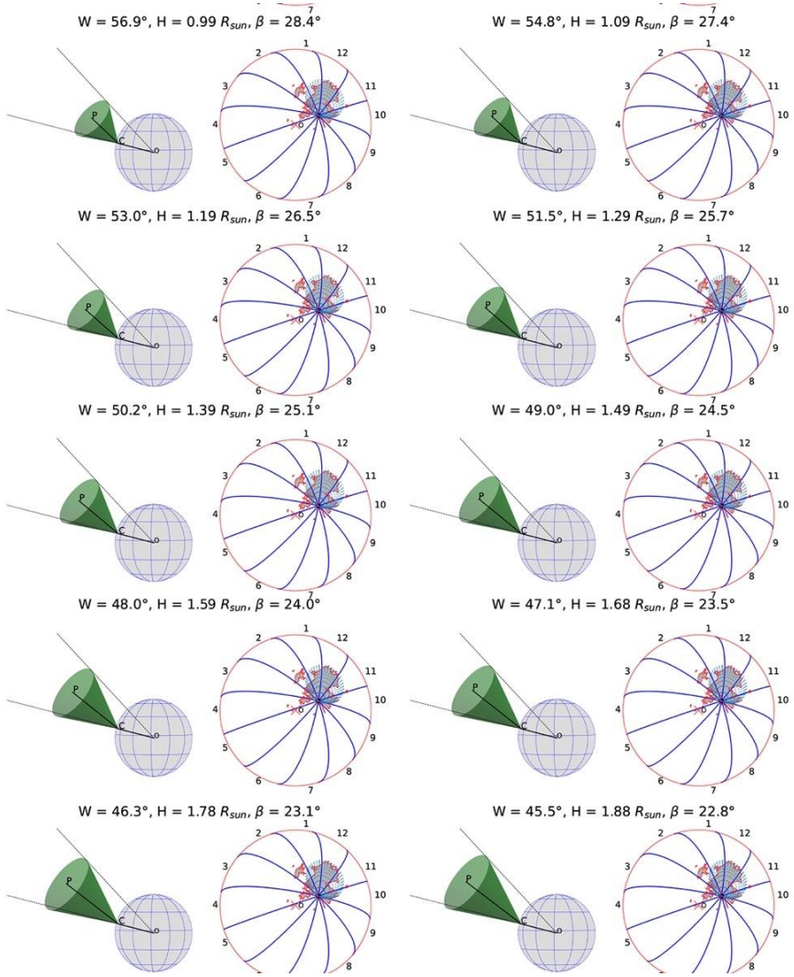


Miklenic et al. (2011)

Coronal Dimmings: CME direction

Comparison of dimming area expansion and forward modeling of CME cone gives insight into the CME direction/ deflections from radial motions (Jain et al. 2024)



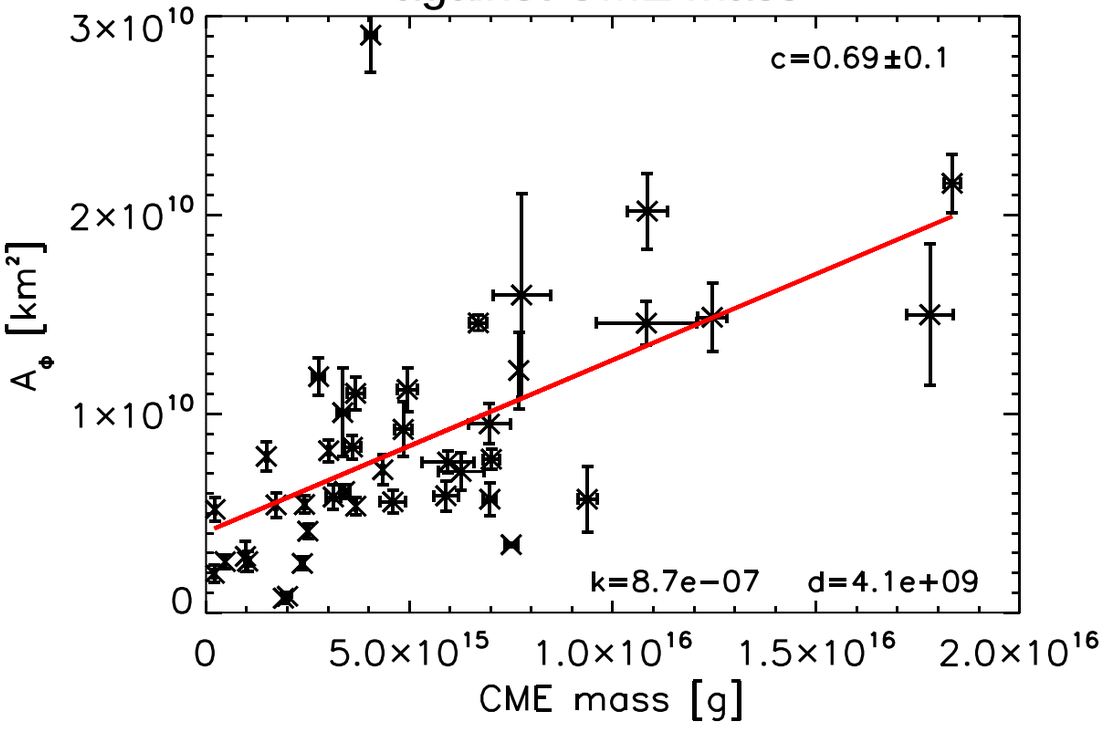


Jain et al. (2024)
& ESPM-17 Poster

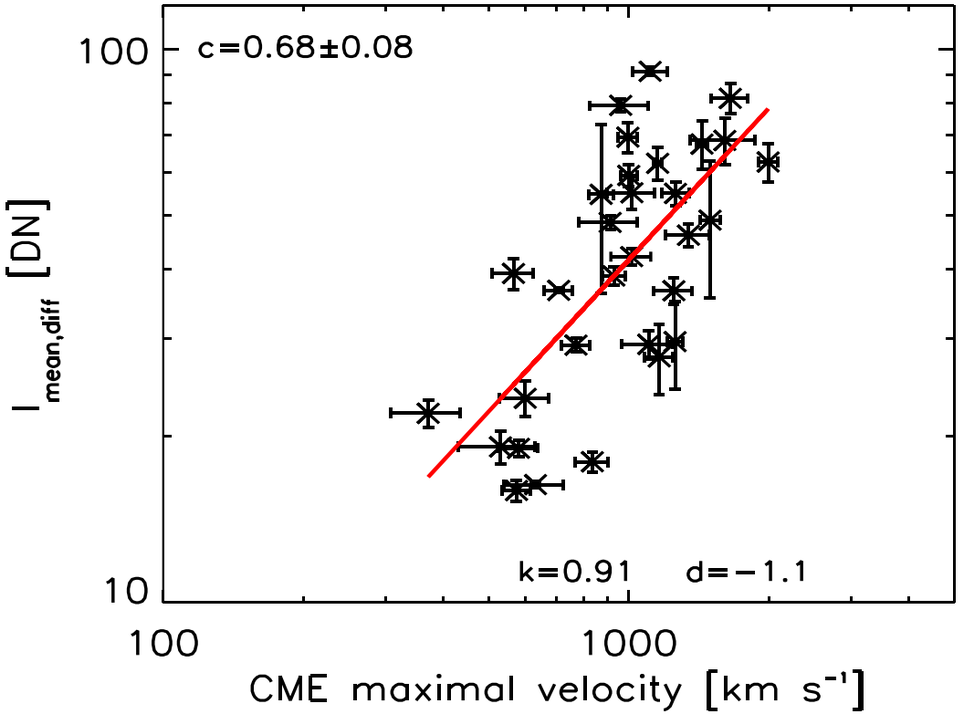
Coronal Dimmings - CME mass & speed

OBSERVATIONS: dimmings observed ON-DISK

Dimming area
against CME mass



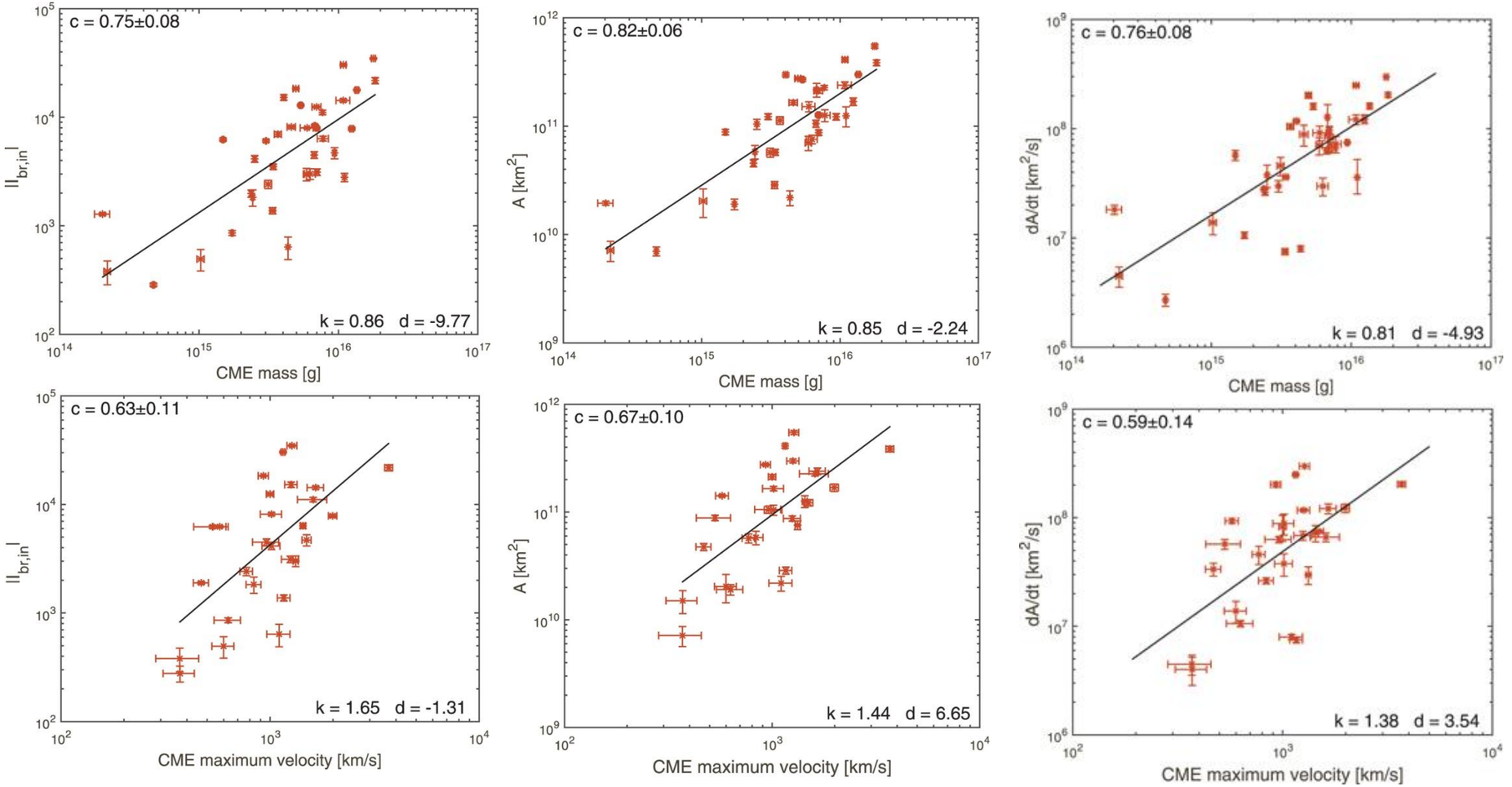
Dimming emission drop
against CME speed



Dissauer et al. (2019)

Coronal Dimmings - CME mass & speed

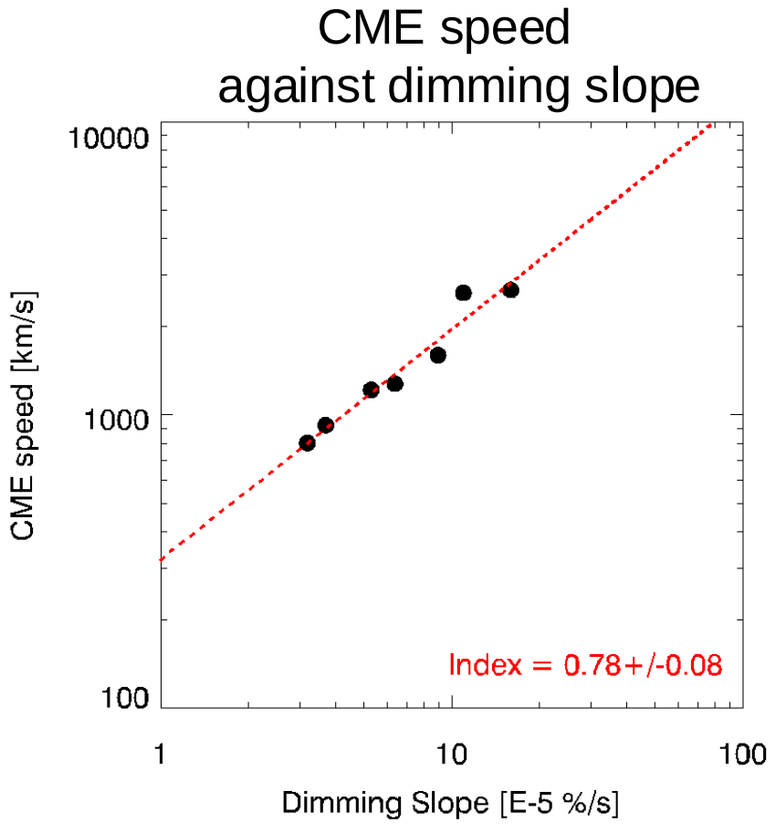
OBSERVATIONS: dimmings observed on the LIMB

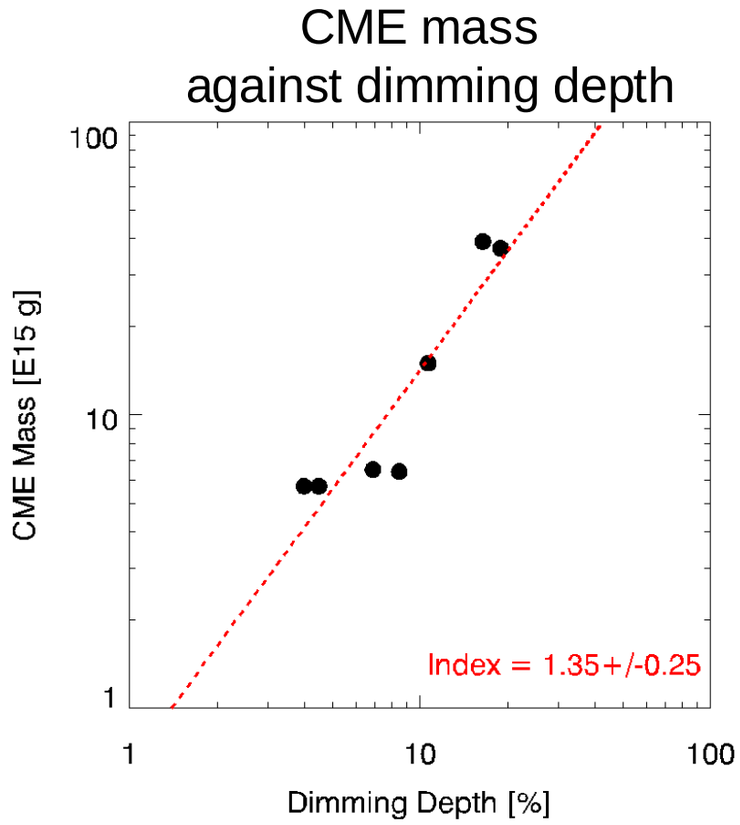


Chikunova et al. (2021)

Coronal Dimmings - CME mass & speed

MHD SIMULATIONS

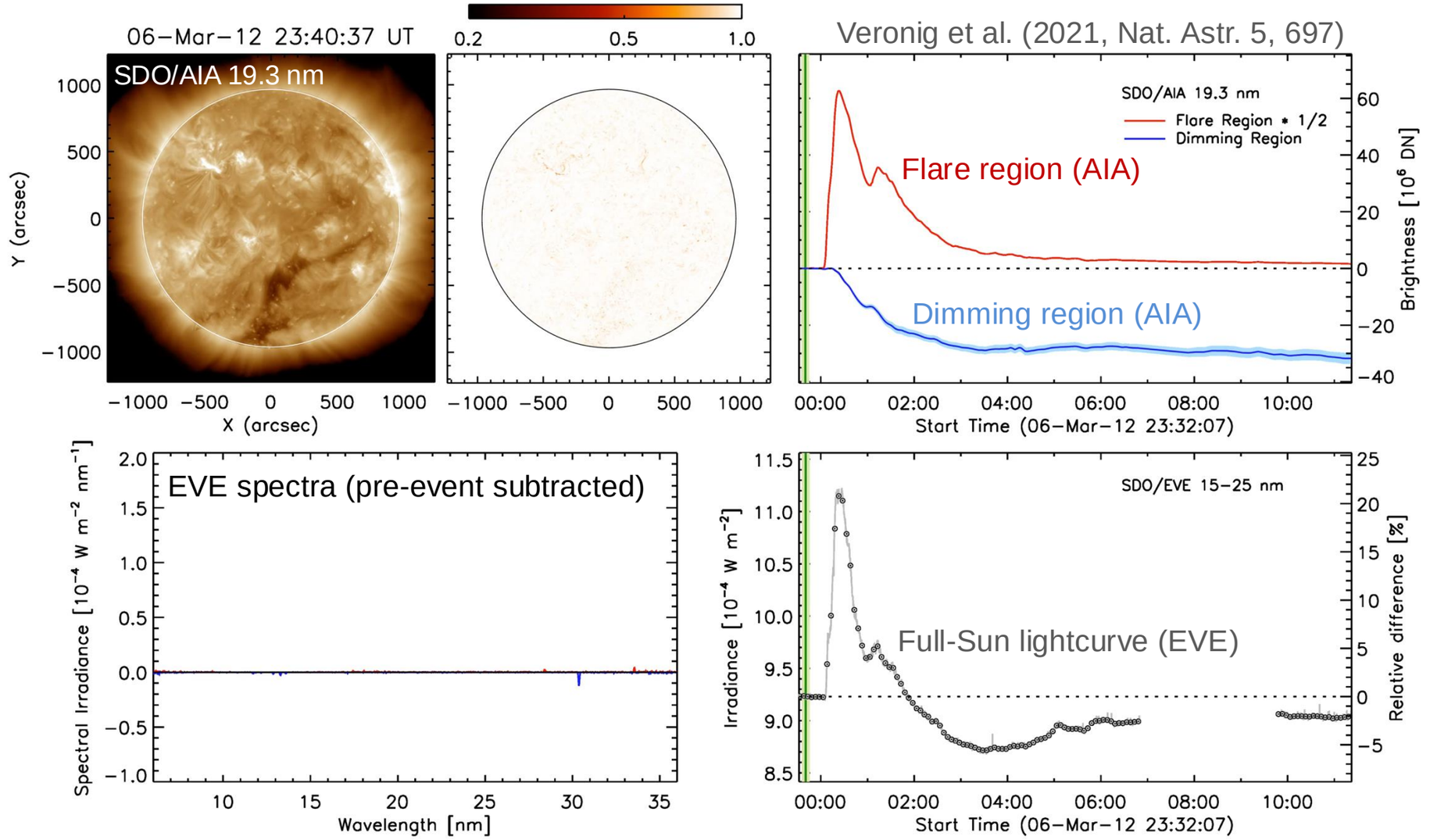




Meng Jin et al. (2022)

Sun-as-a-star observations: SDO/EVE

Solar dimmings can be detected in full-Sun EUV spectra and light curves
(Mason et al. 2014, 2016, Harra et al. 2016, Veronig et al. 2021)



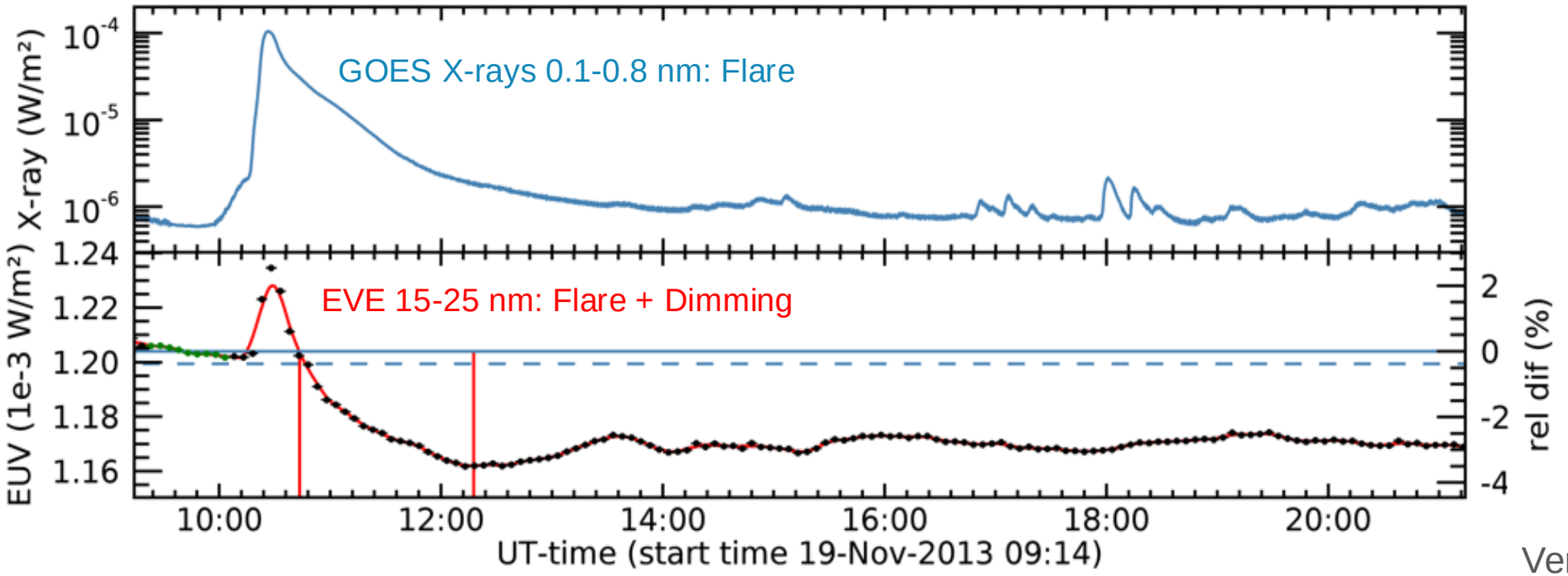
Can we use dimmings for stellar CME detection?

Step 1: Establish dimmings as proxy for solar CMEs

- Use SDO/EVE 15-25 nm Sun-as-a-star observations of large flares to test:
  a) How often coronal dimmings caused by CMEs can be identified in full-Sun EUV light-curves?
  b) How often do we observe false positives, i.e. we detect a dimming although there was no CME associated with the flare?
- Studied 44 large flares (> GOES M5) that were observed by SDO/EVE MEGS-A (2011 - 2015):
  38 with CME, 6 without CME.

Solar dimmings in full-Sun EUV lightcurves

Example of flare/dimming light curves for flare with CME (=eruptive).



Veronig et al. (2021)

Solar dimmings in full-Sun EUV lightcurves

Examples of flare/dimming
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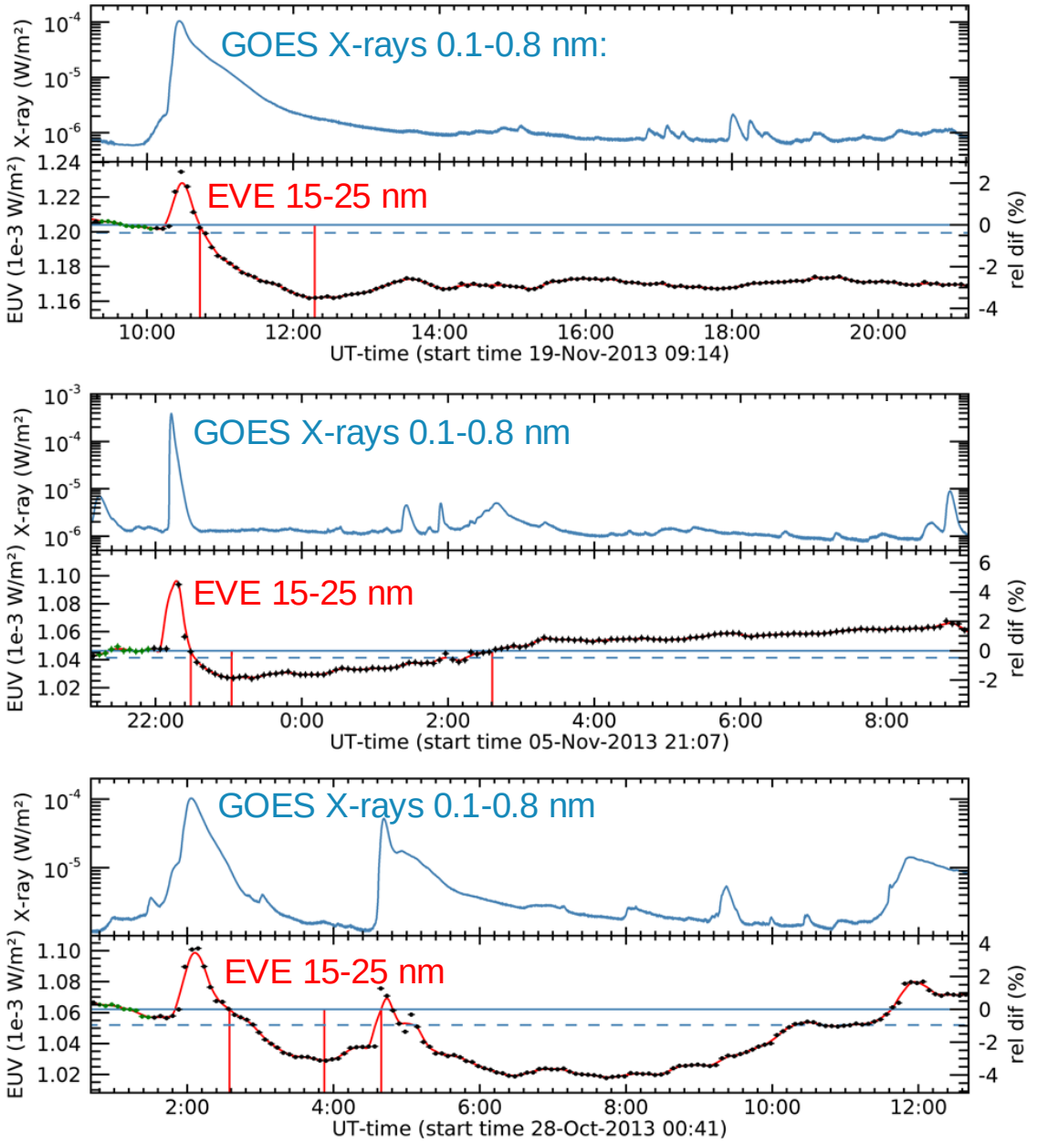
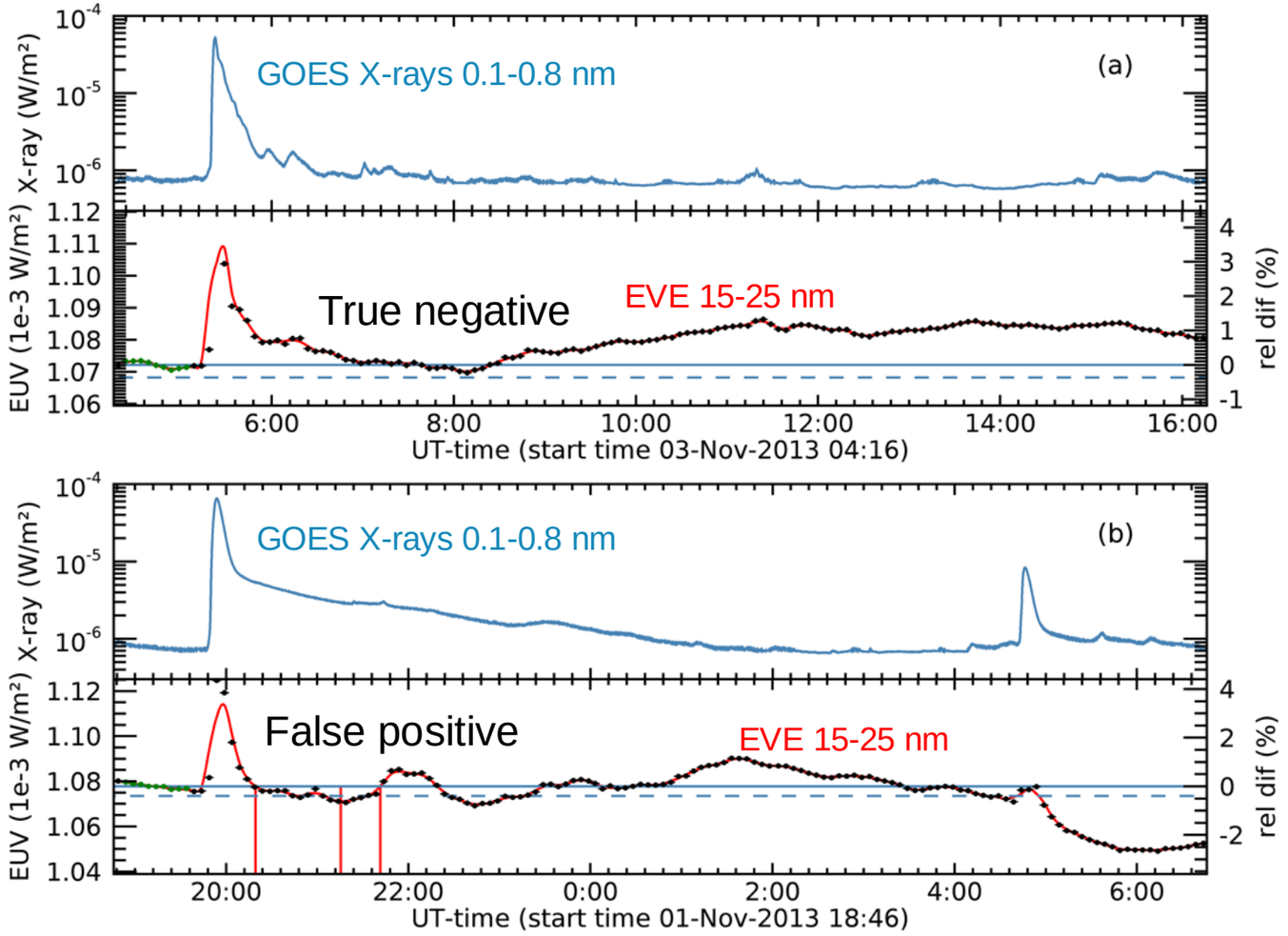


Veronig et al. (2021)

Solar dimmings in full-Sun EUV lightcurves

Examples of flare/dimming light curves for flares without CMEs (=confined).



Veronig et al. (2021)

Solar dimmings & CME ocurrence

Overall statistics:

- 84% of CMEs show dimming in full-Sun EUV light curves.
- 17% false alerts.
- 96% conditional probability that a CME has occurred given that a dimming was detected in the aftermath of a large flare.

Table 1 | The occurrence of CMEs and coronal dimmings in association with large flares, as derived from SDO-EVE 15–25 nm broadband light curves and full-disk integrated SDO-AIA 19.3 nm light curves

		!Dimming	Dimming
EVE			
	!CME	5	1
	CME	6	32
AIA			
	!CME	14	2
	CME	13	39

⇒ **Post-flare coronal dimmings** are a strong indicator for CME occurrence.

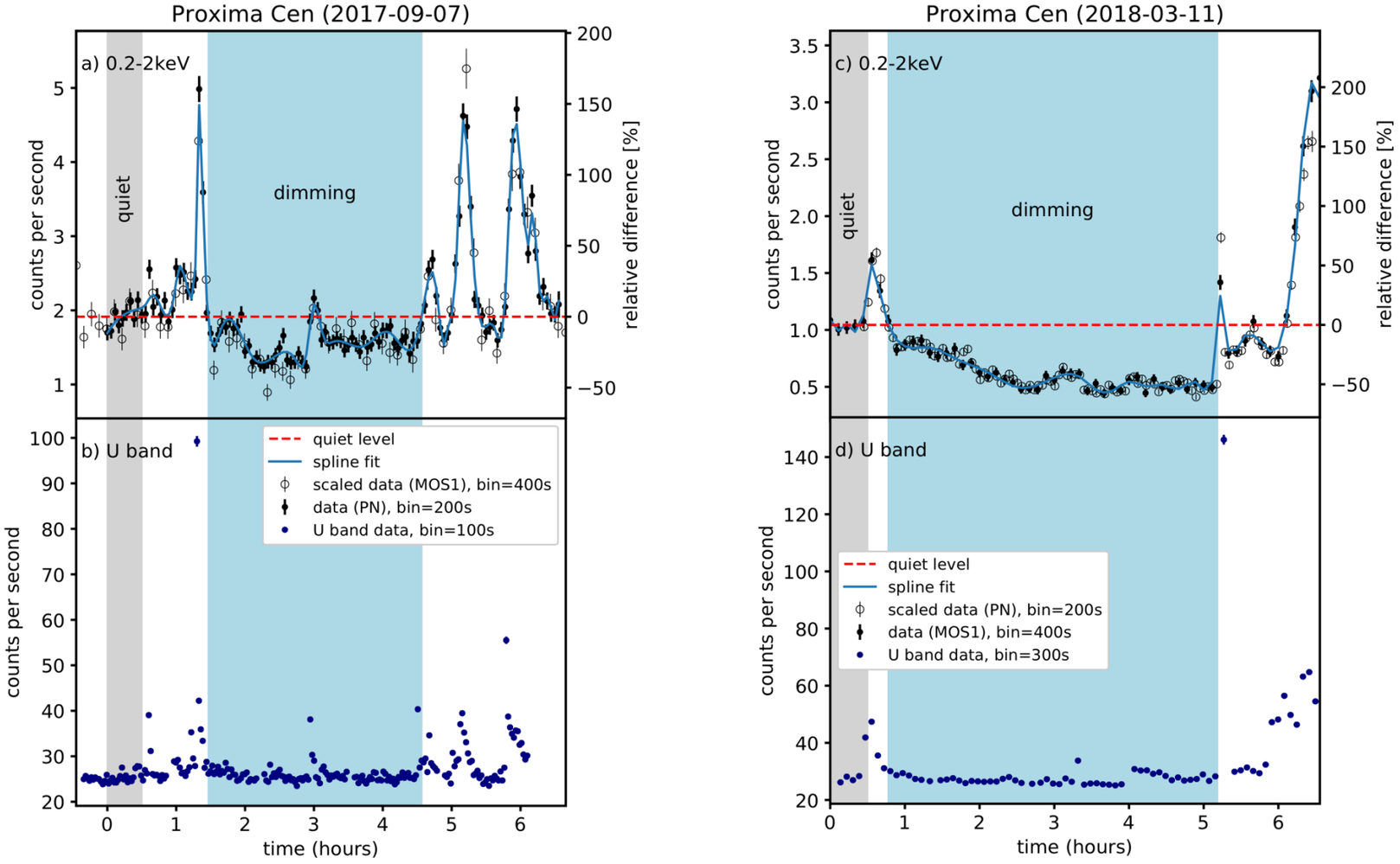
Can we use dimmings for stellar CME detection?

Step 2: Use the solar knowledge and same methods to search for post-flare coronal dimmings in stellar lightcurves.

- Search through archives of X-ray and EUV observations from stars: Chandra, XMM Newton, EUVE
- Suitable observations from 201 solar-like and late-type stars
- Detected 21 dimmings on 17 different stars (1 EUVE, 3 Chandra, 17 XMM)
- Half of the events were found on three stars: the young and rapidly rotating K0V star AB Dor (5), the young M0Ve star AU Mic (3) and the nearby M5.5Ve star Proxima Centauri (2)

Stellar CME detection via dimmings

Dimmings detected on Proxima Centauri (XMM Newton observations)

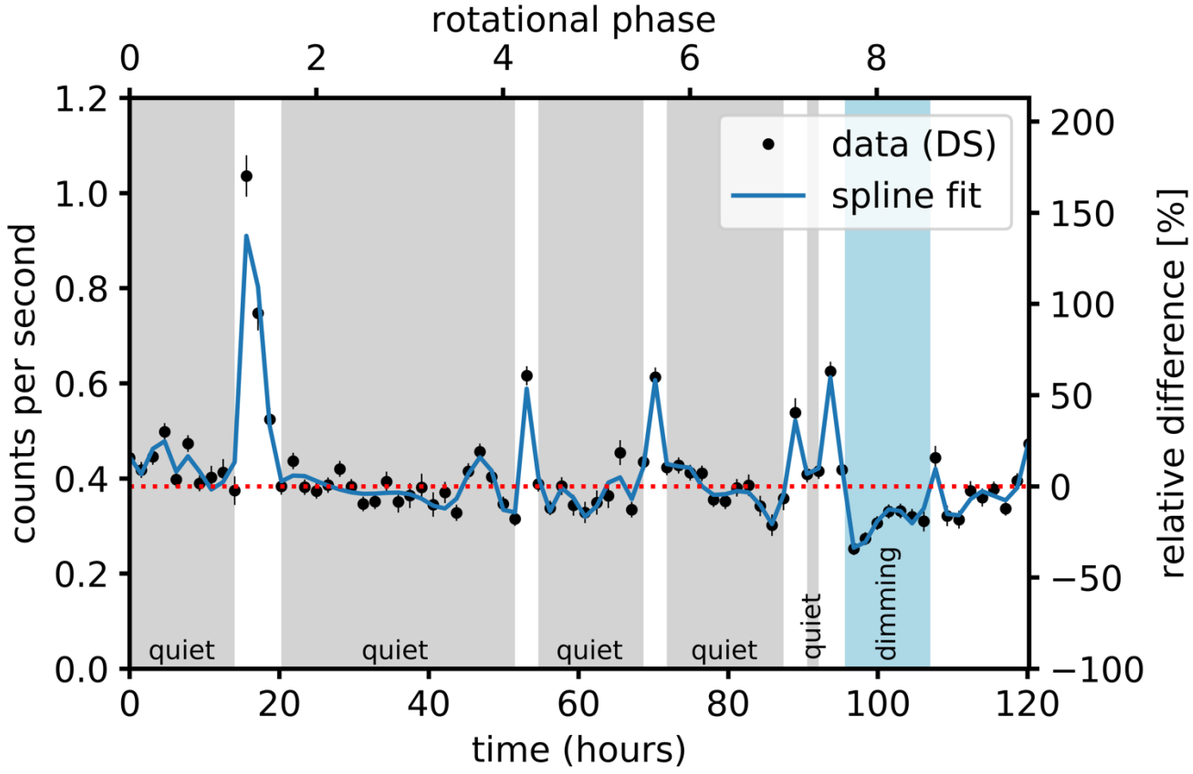


Veronig et al. (2021, Nat. Astr. 5, 697)

Stellar CME detection via dimmings

Dimming detected on AB Dor (EUVE observations, 8-18 nm)

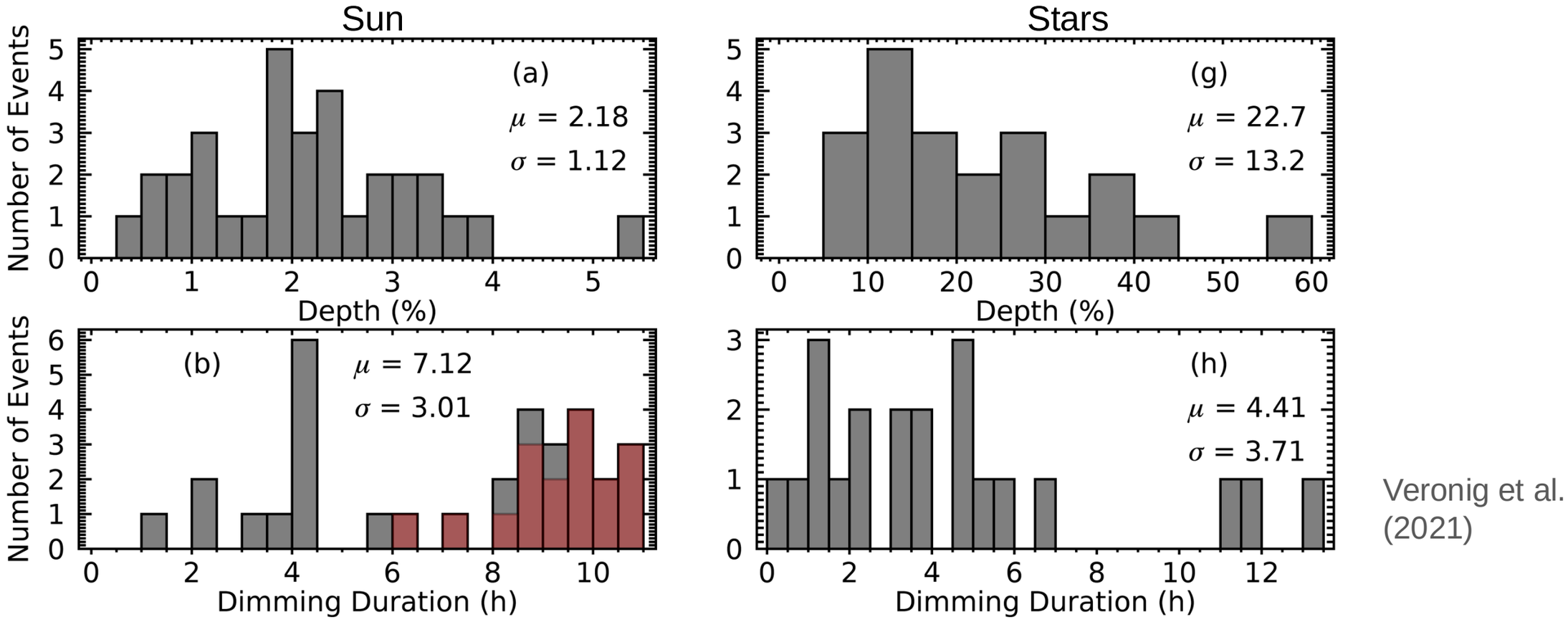
- Data show 9 rotations of AB Dor, no obvious modulation
- Dimming duration > P_rot
- AB Dor: inclination i = 60°
- AB Dor has polar starspots (Doppler Imaging, Donati et al. 1999)



⇒ Suggests that the dimming arises from a CME that originated from a polar starspot.

Veronig et al. (2021)

Stellar CME detection via dimmings



Veronig et al. (2021)

- Dimming depths are about an order of magnitude larger for stellar CMEs than for solar CMEs
- Dimming durations are similar in both cases (and often underestimated)

Conclusions

Sun:

- Dimmings are robust proxies for CME.
- They can provide estimates of CME mass, speed and direction.
- They give also insight into the magnetic topology of the eruption.

Stars:

- Post-flare dimmings are a promising candidate for stellar CME detections.
- Emission drops in stellar dimmings up to 50%, indicating that a large part of the corona is blown away with the CME. (In solar case it is a few %.)
- Can potentially then also be used to provide estimates of CME occurrence rates, masses and speed.
- Next steps to make full use of this method: more sensitive stellar EUV missions (e.g. NASA ESCAPE mission concept)