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What can we learn from coronal dimmings about the early evolution of Earth-directed CMEs?

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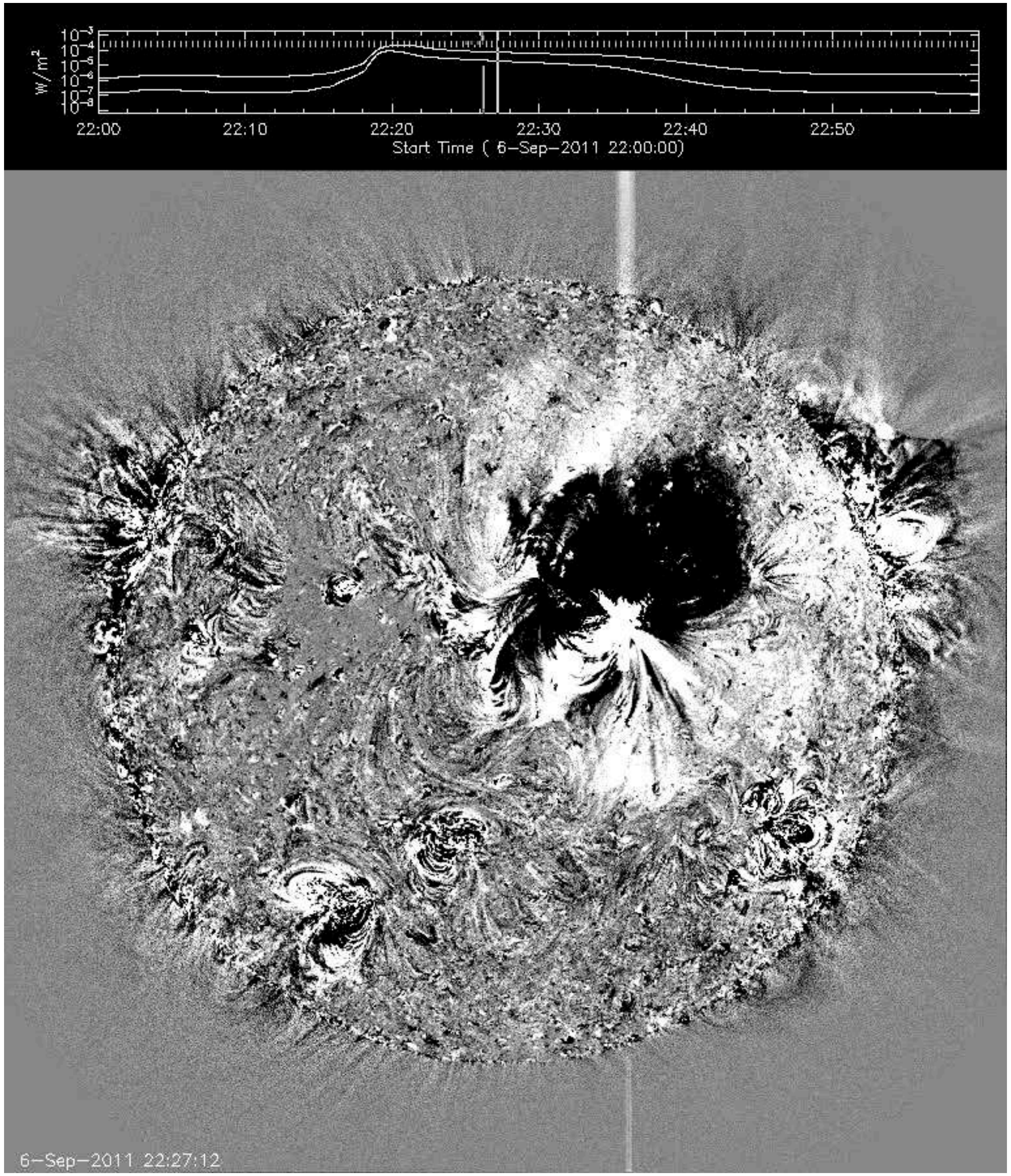
FWF Der Wissenschaftsfonds.

FFG

Coronal dimmings

- regions of reduced emission low in the corona observed in EUV and soft X-rays (Hudson et al. 1996; Sterling and Hudson 1997; Thompson et al. 1998, 2000)
- dimmings are interpreted as density depletion caused by the evacuation of plasma during the CME lift-off (Hudson et al. 1996; Thompson et al. 1998; Harrison & Lyons 2000)
- supported by simultaneous and co-spatial observations of coronal dimmings in different wavelengths (e.g. Zarro et al. 1999; Chertok & Grechnev 2003)
- spectroscopic observations → plasma outflows in dimming regions (e.g. Harra & Sterling 2001; Jin et al. 2009; Tian et al. 2012)
- plasma diagnostics (DEM analysis) → density decrease by up to 70% in dimming regions (e.g. Cheng et al. 2012, Vanninathan et al. 2018)

Coronal dimmings



Credit:Nariaki Nitta, http://www.lmsal.com/nitta/movies/AIA_Waves/

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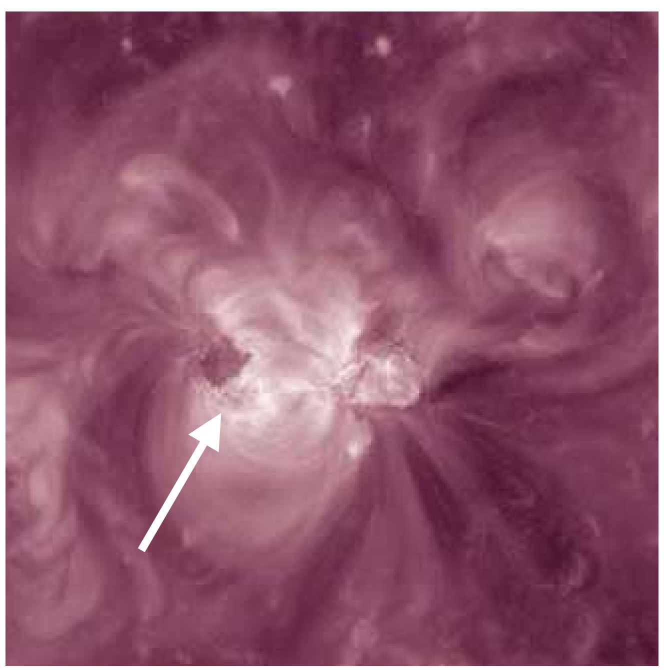
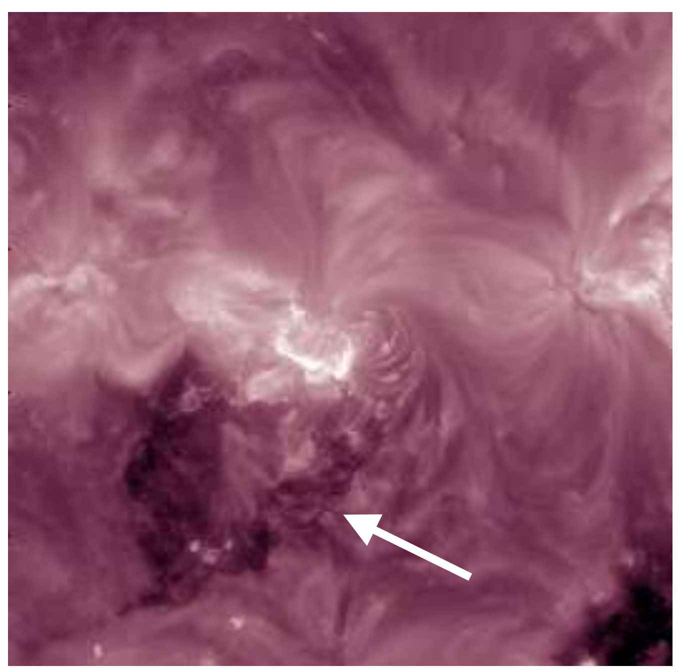
Coronal dimmings

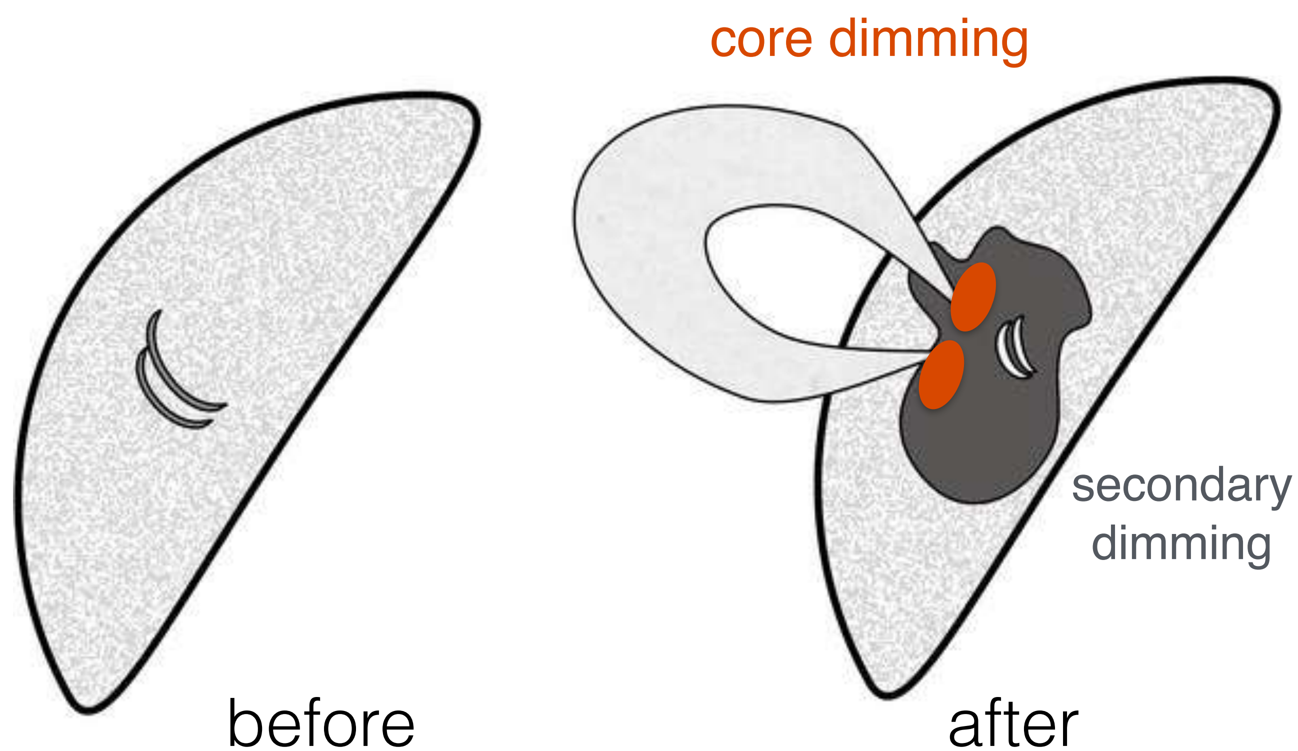
- core/twin dimmings: localized, dark regions near the eruption sight in opposite polarity regions → mark the footpoints of the ejected flux rope (e.g. Sterling & Hudson 1997; Thompson et al. 2000; Mandrini et al. 2007)
- secondary/remote dimmings: more shallow and extended regions → expansion of the overlying corona (e.g. Mandrini et al. 2007; Attrill et al. 2009)



core dimming



secondary dimming

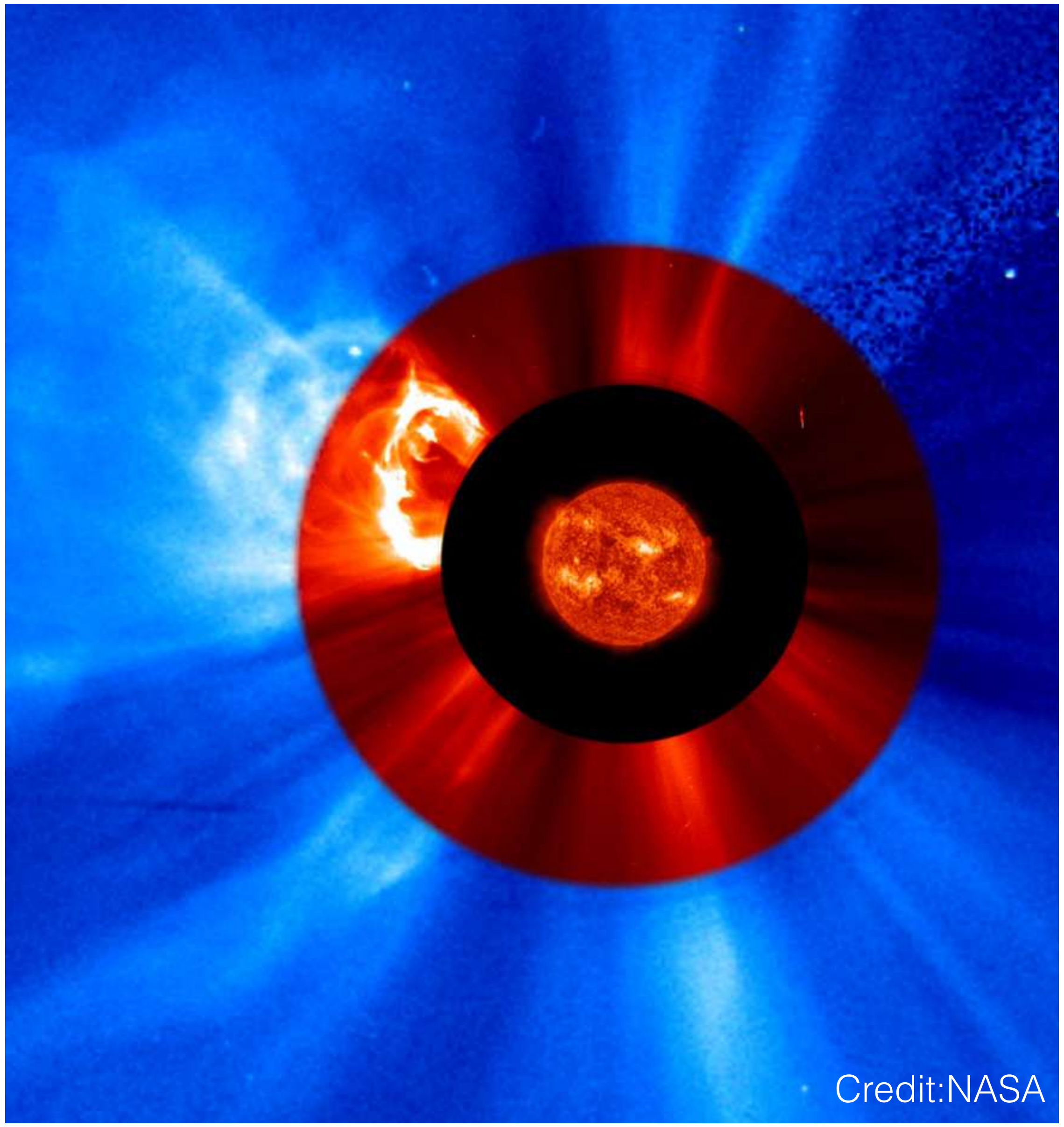


adapted from Mason et al. 2014

Why should we study coronal dimmings?

CME measurements

- use mostly coronagraphic observations
- limited due to projection effects
- Earth-directed events: obtained CME parameters have large uncertainties
- no information on the CME onset



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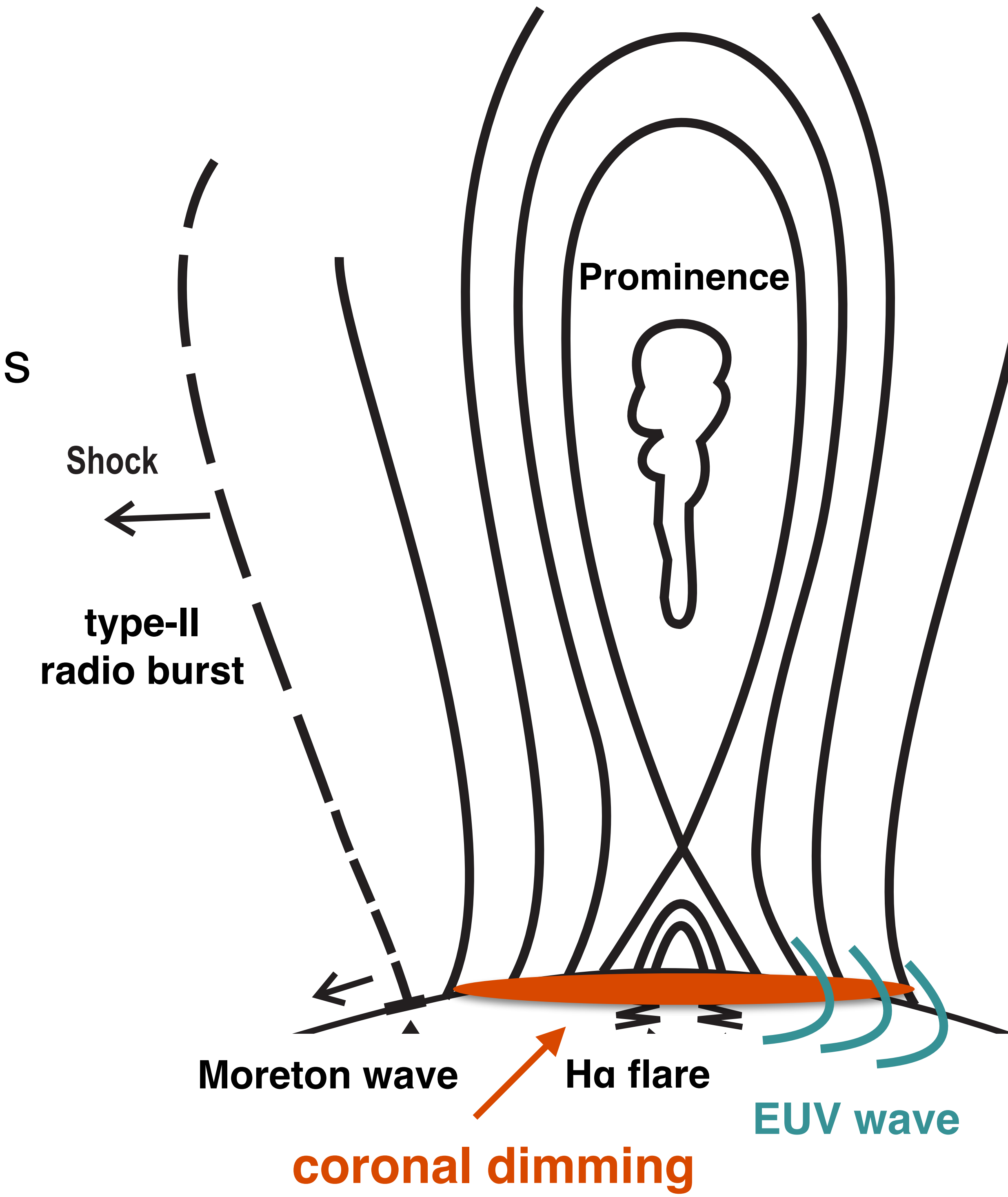
CME measurements

- use mostly coronagraphic observations
- limited due to projection effects
- Earth-directed events: obtained CME parameters have large uncertainties
- no information on the CME onset
- use associated phenomena: e.g. coronal dimmings



adapted from Balasubramaniam et al. 2010

Statistical study on dimmings - halo CMEs - flares

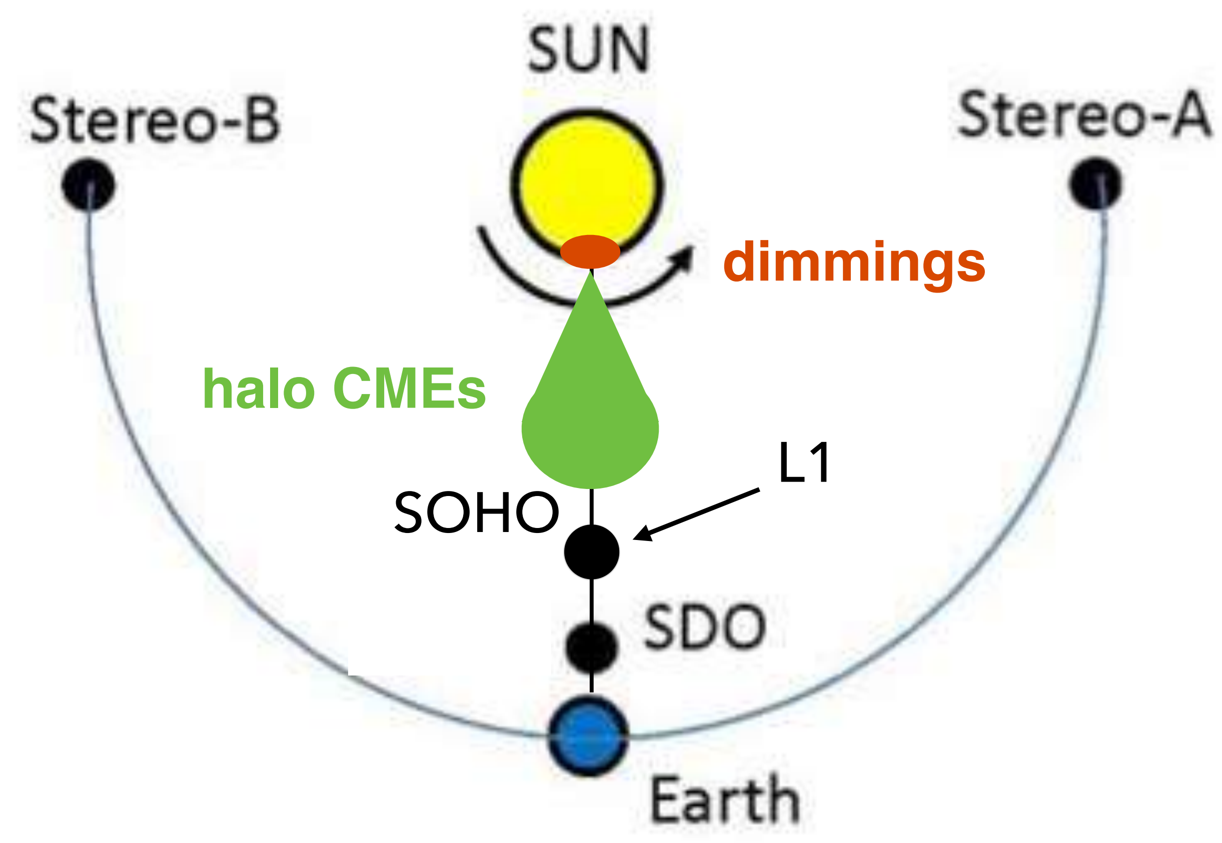
- Goal: Statistical relationship between coronal dimmings and basic flare and CME parameters

- only few statistical studies between dimming parameters and flare and CME quantities (Reinard & Biesecker 2008, Bewsher et al. 2008, Aschwanden 2016, Mason et al. 2016, Krista & Reinard 2017)

- 62 events during 2010-2012 (STEREO-SDO quasi-quadrature period)

- Earth-directed CMEs observed off-limb by STEREO → low projection effects

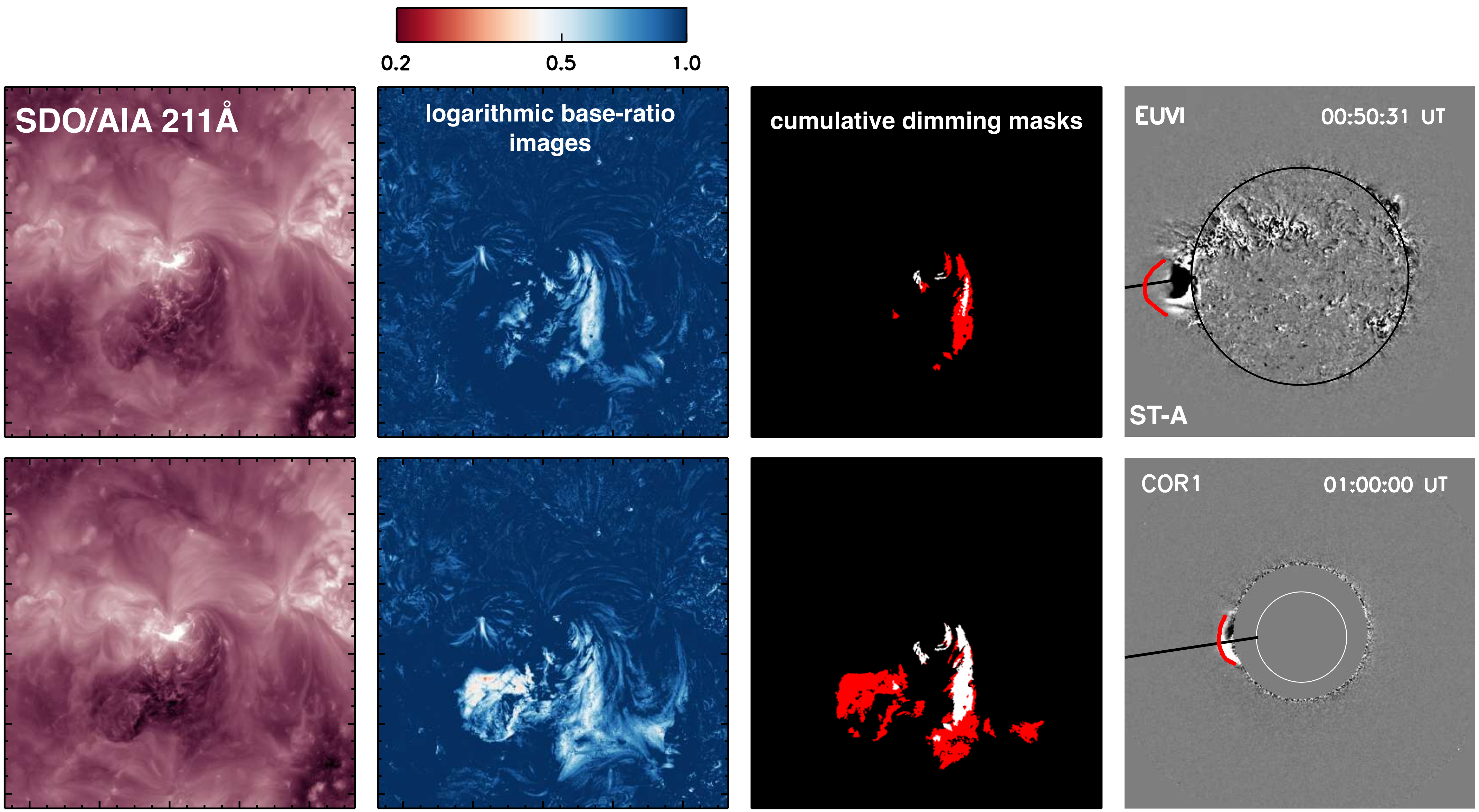
- coronal dimmings are detected on-disk from high-cadence SDO/AIA observations

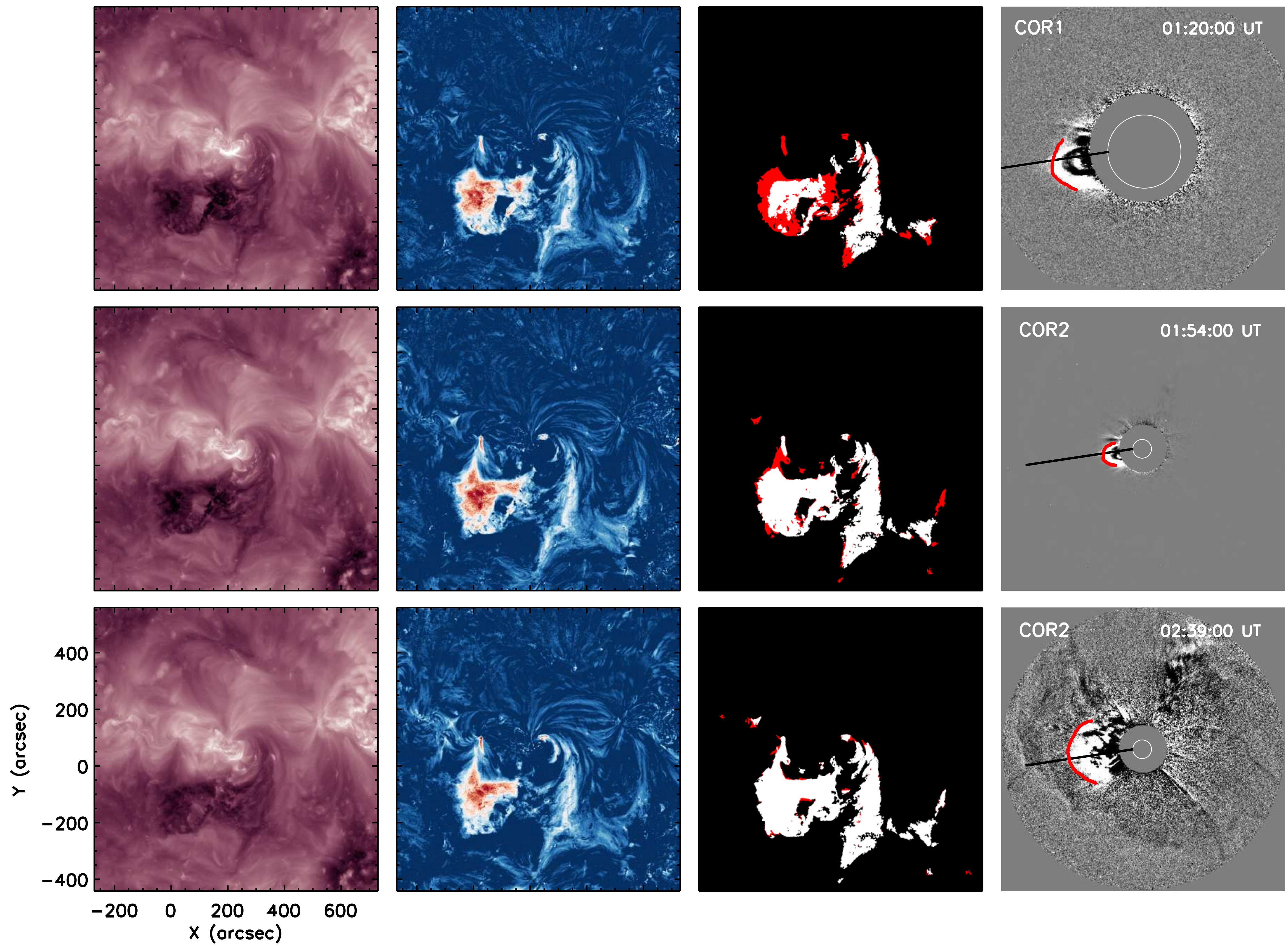


adapted from NASA

Dimming detection

- several dimming detection algorithms are available (e.g. Podladchikova & Berghmans 2005, Reinard & Biesecker 2008, Kraaikamp & Verbeeck 2015, Thompson & Young 2016)
- coronal dimming are extracted from logarithmic base-ratio images using a thresholding algorithm (Dissauer et al. 2018a)




COR1
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COR2
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COR2
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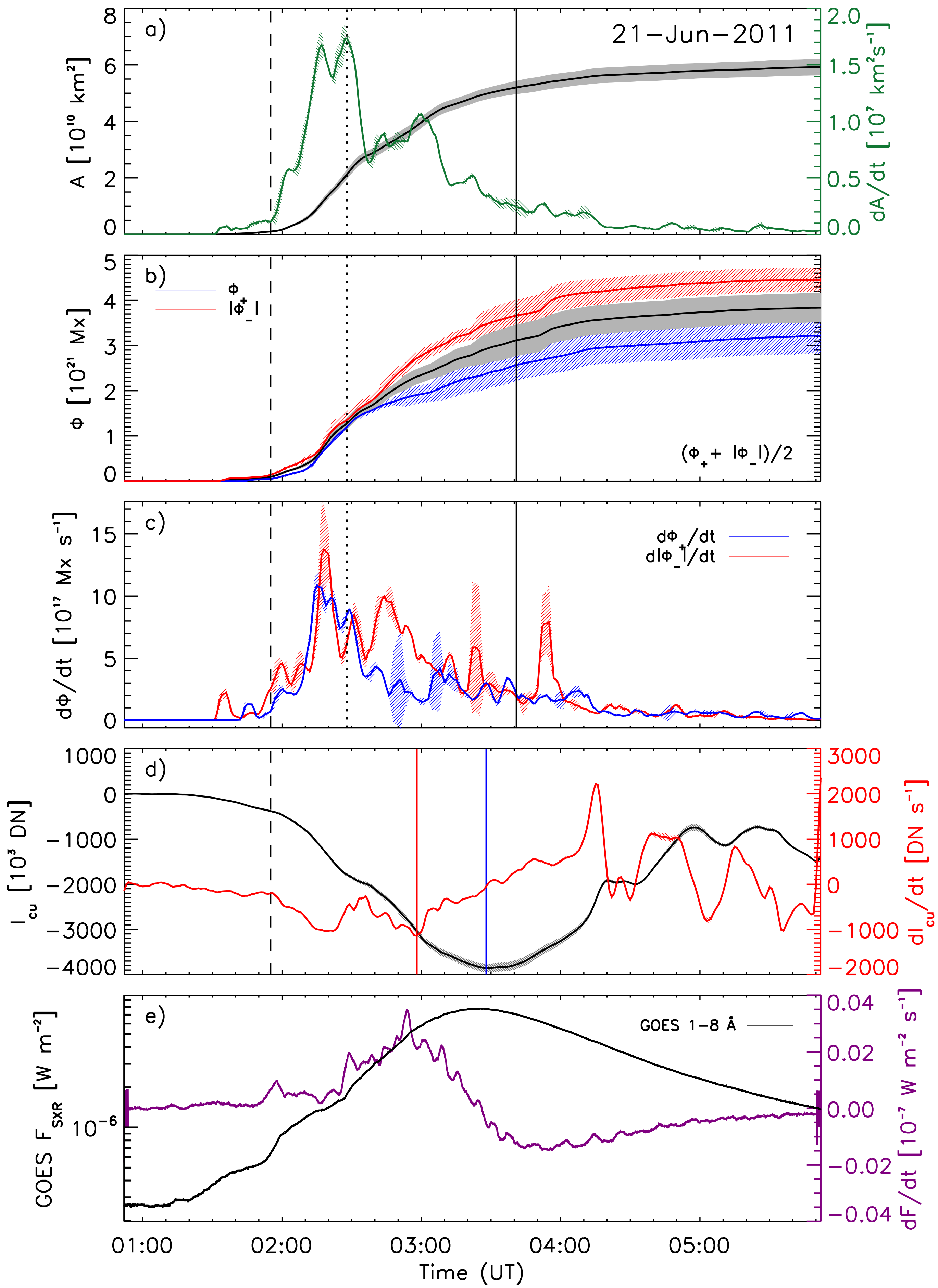
200
0
−200
−400
Y (arcsec)
−200
0
200
400
600
X (arcsec)

Characteristic dimming parameters

- extract parameters that describe the dynamics, morphology, magnetic properties and brightness evolution of coronal dimming regions
- time-integrated quantities using cumulative dimming pixel masks
- study full extent of dimming evolution (e.g. cover also regions of post-flare loops)
- investigate dynamics of dimming properties (time derivatives)



area and area growth rate

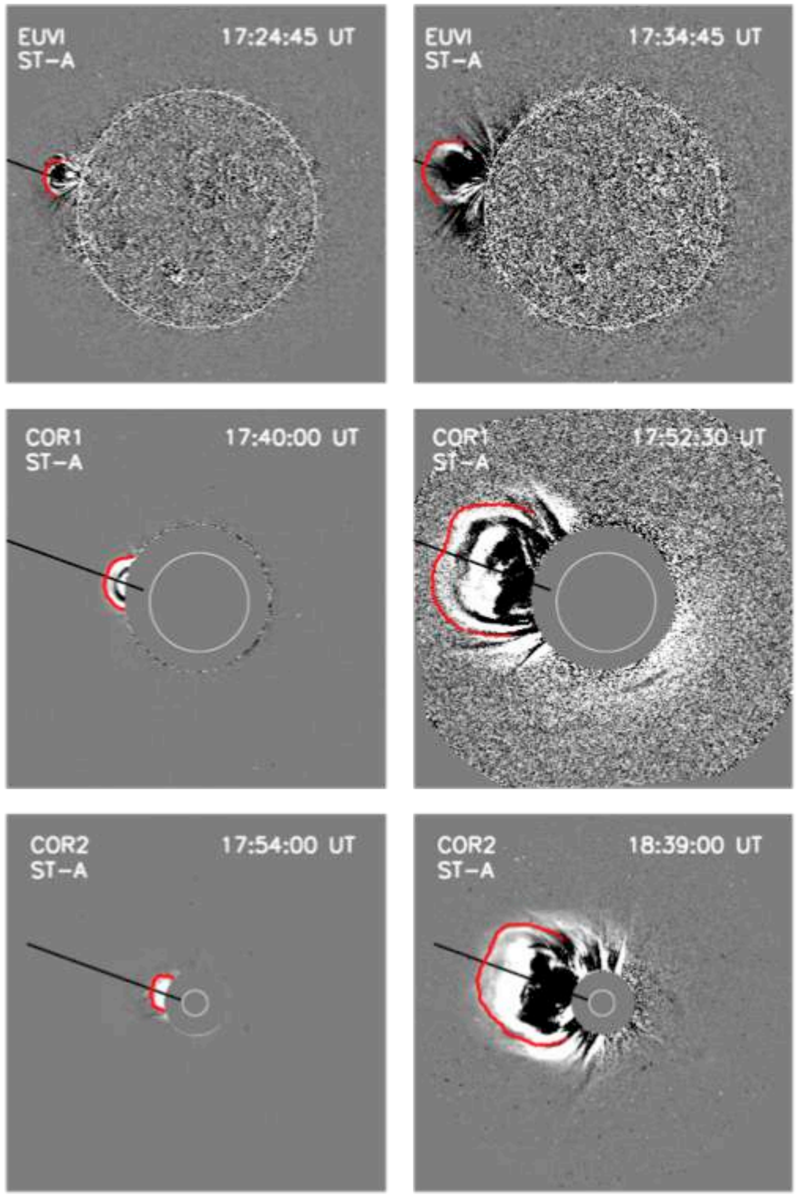
positive, negative, and total unsigned magnetic flux

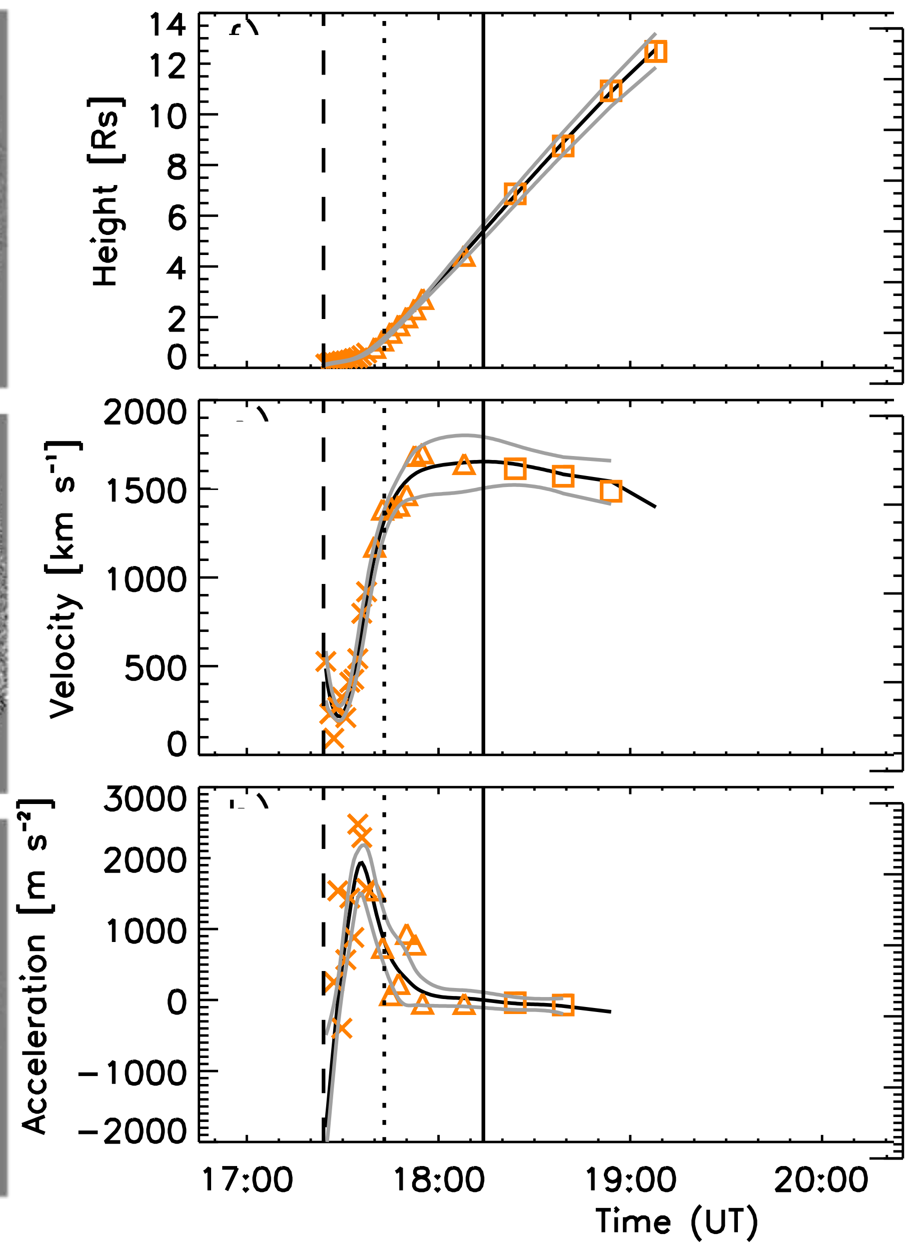
positive and negative magnetic flux rates

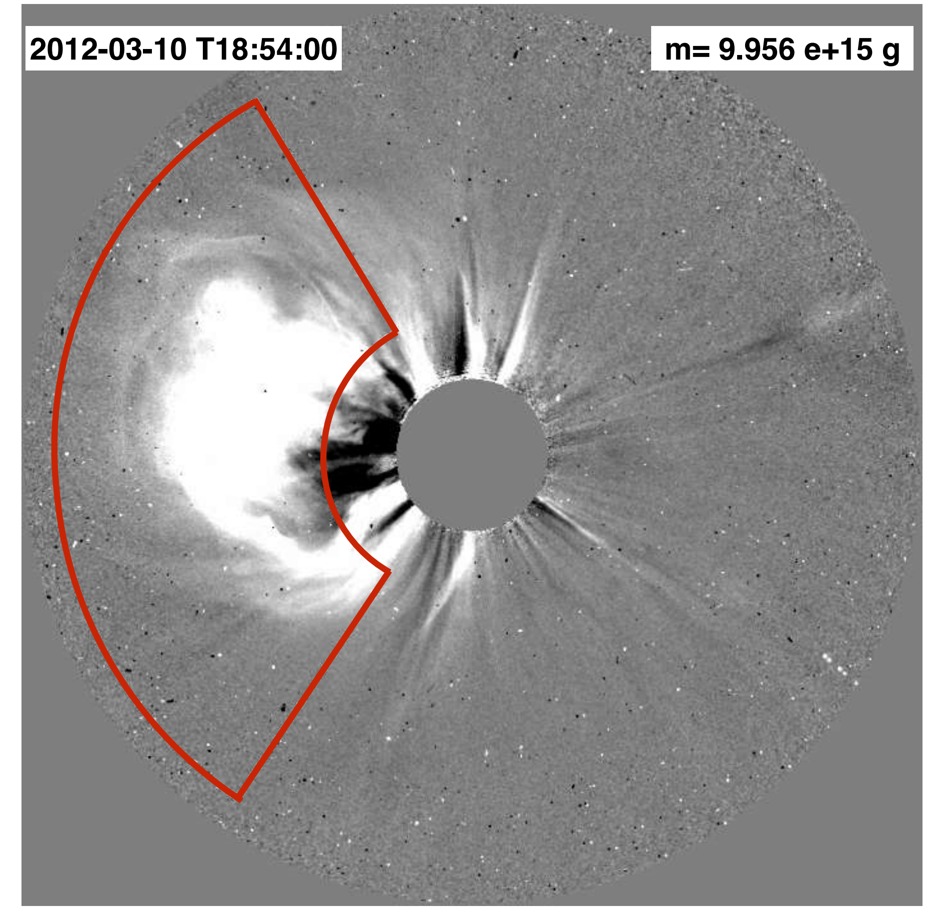
dimming brightness and brightness change rate

GOES flux of the associated flare and its derivative

CME kinematics and mass



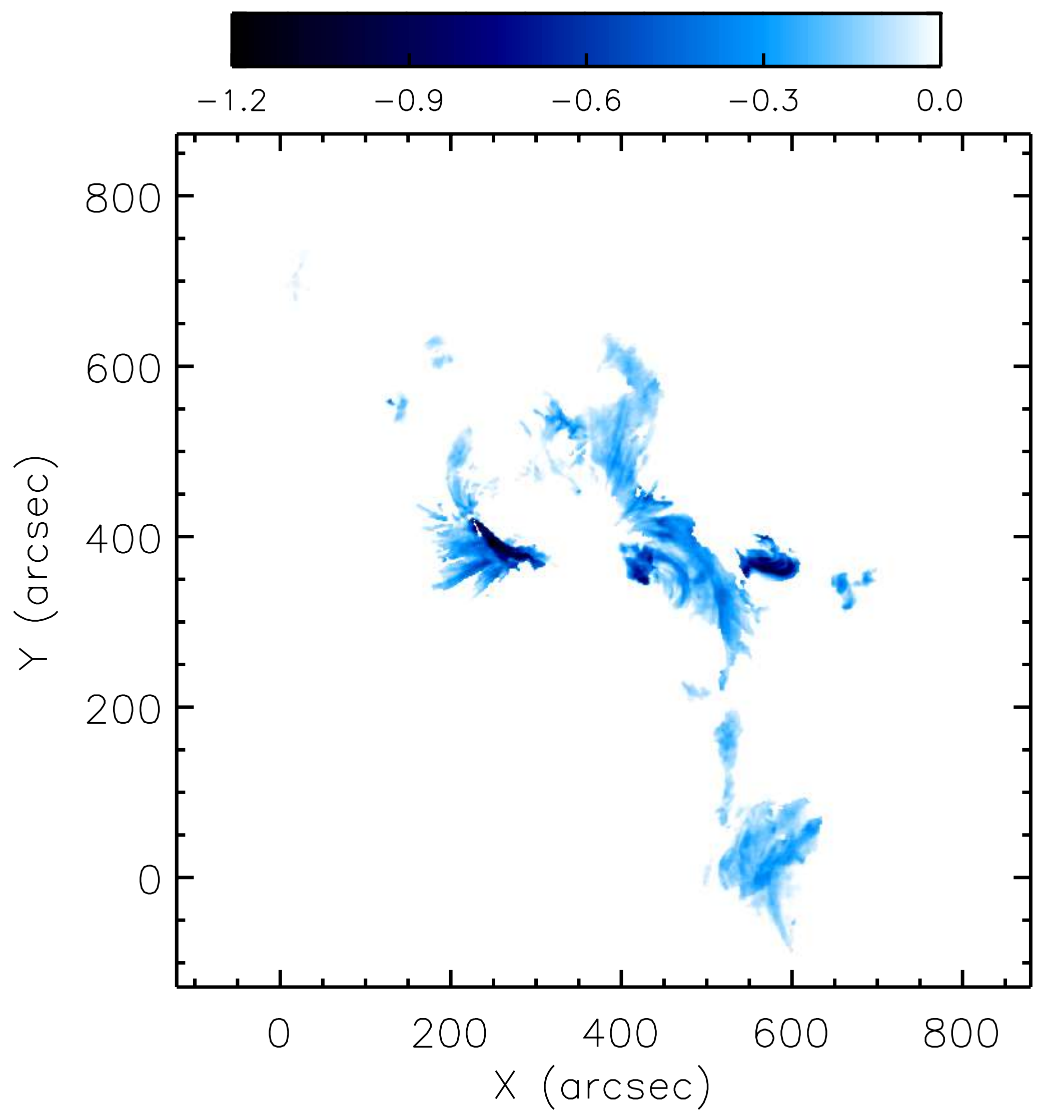


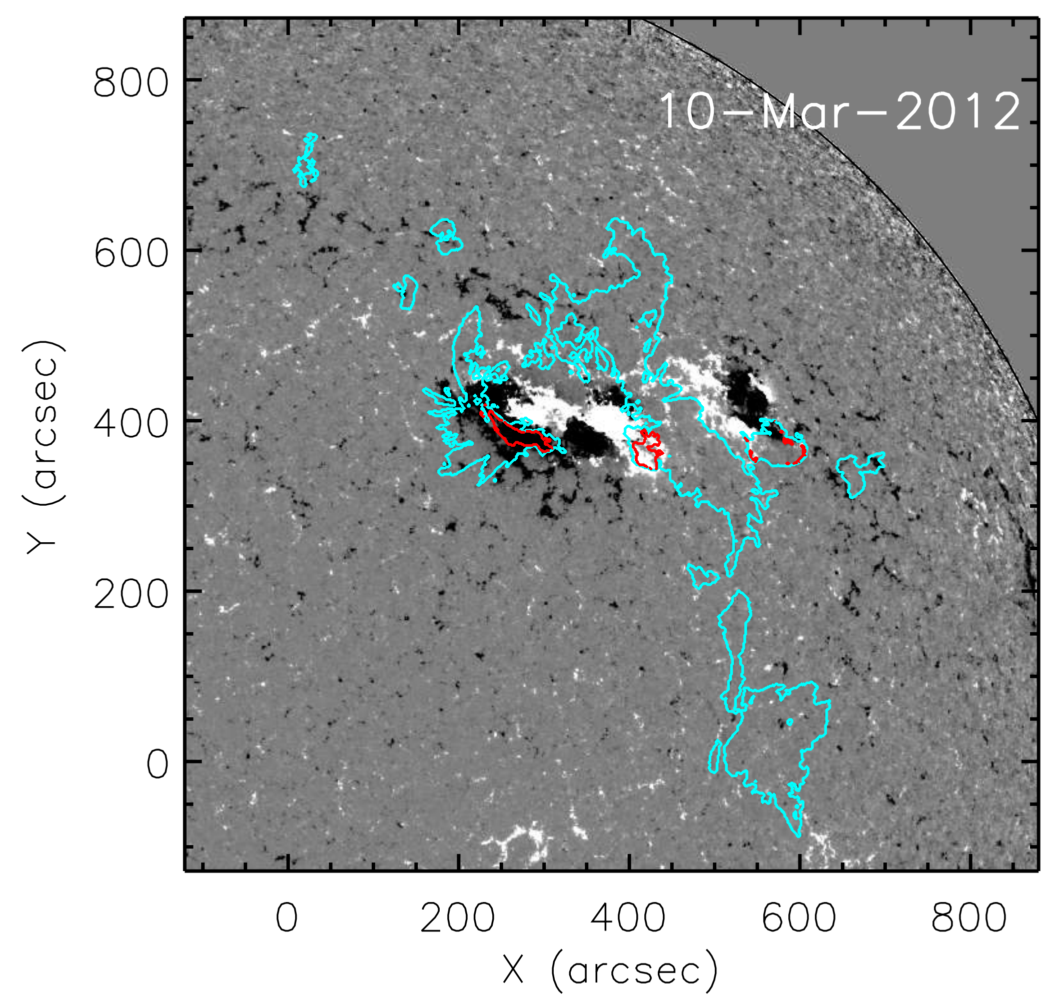


- combine observations of full-disk EUV imagers with coronagraphs using STEREO (Bein et al. 2011)
- derive detailed kinematical profiles using a smoothing algorithm based on the minimization of second derivatives (Podladchikova et al. 2017)
- CME mass calculated via base-difference mass images (Vourlidas 2010, Bein et al. 2012)

Coronal dimming characteristics

- channels sensitive to quiet Sun coronal temperatures (171, 193, and 211 Å) were best suited for dimming detection
- 60% of the events core dimming regions were identified. They contain 20% of the total flux but only account for 5% of the total dimming area





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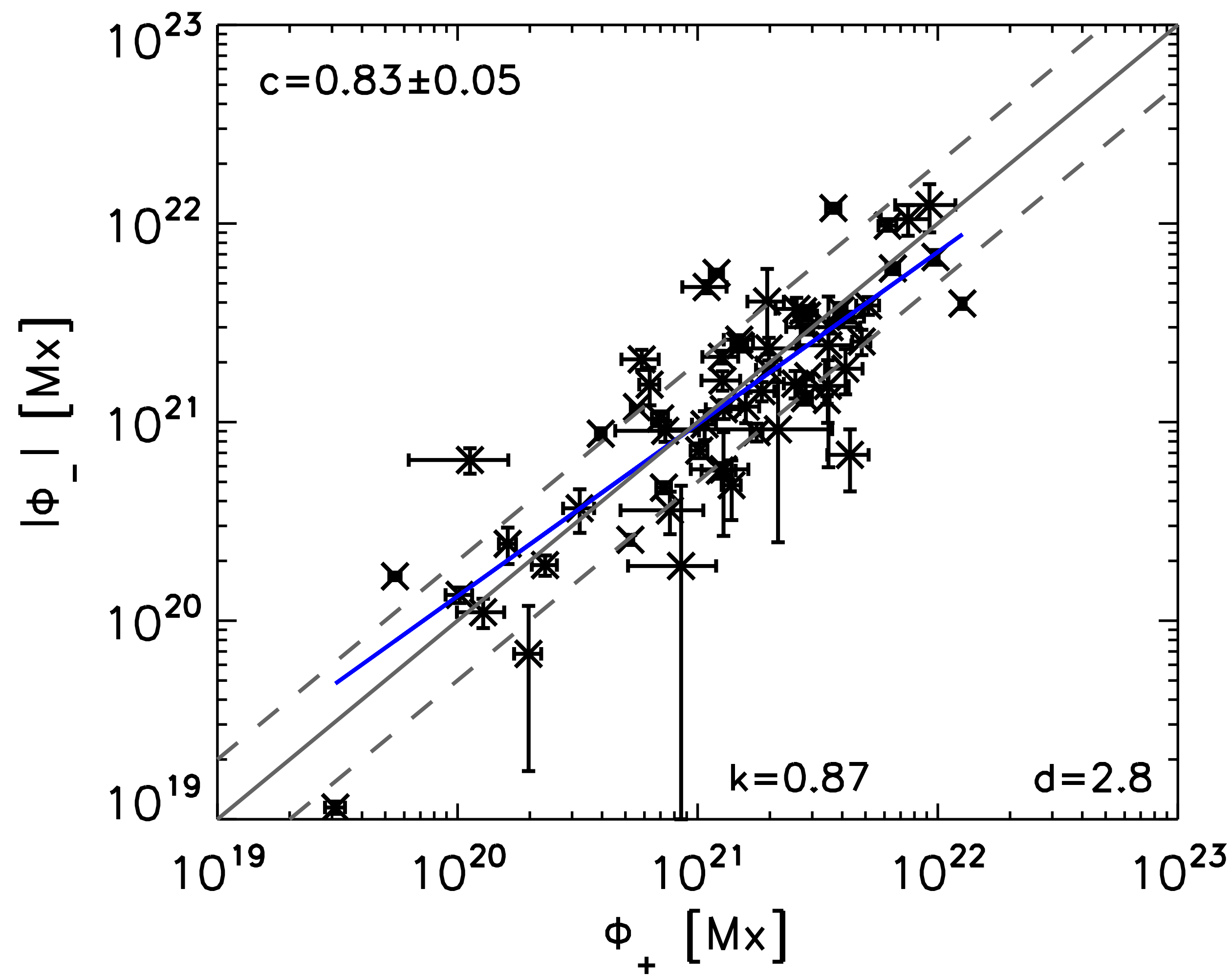
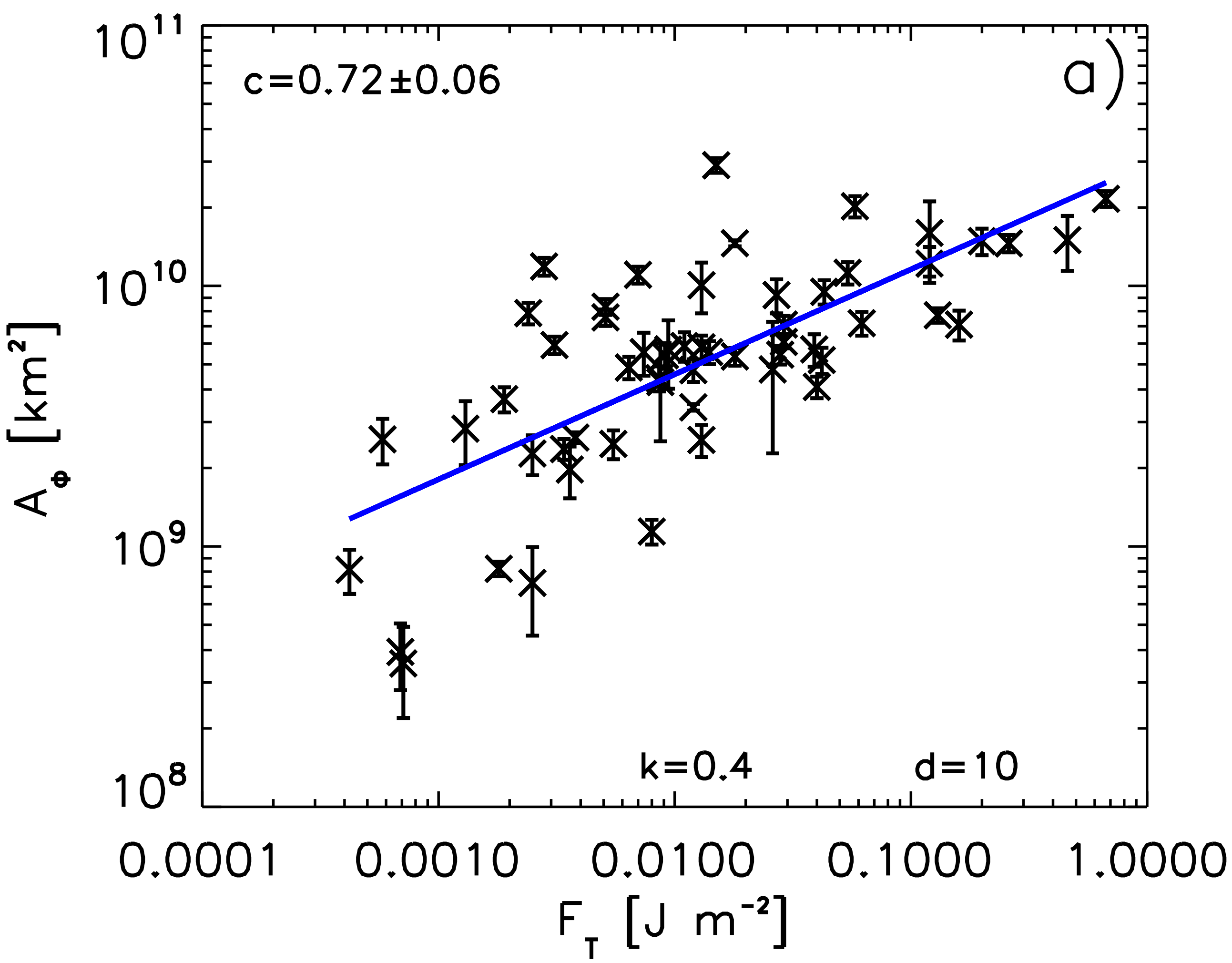
- 60% of the events core dimming regions were identified. They contain 20% of the total flux but only account for 5% of the total dimming area
- the positive and negative magnetic flux in dimming regions are roughly balanced (c=0.83±0.04)

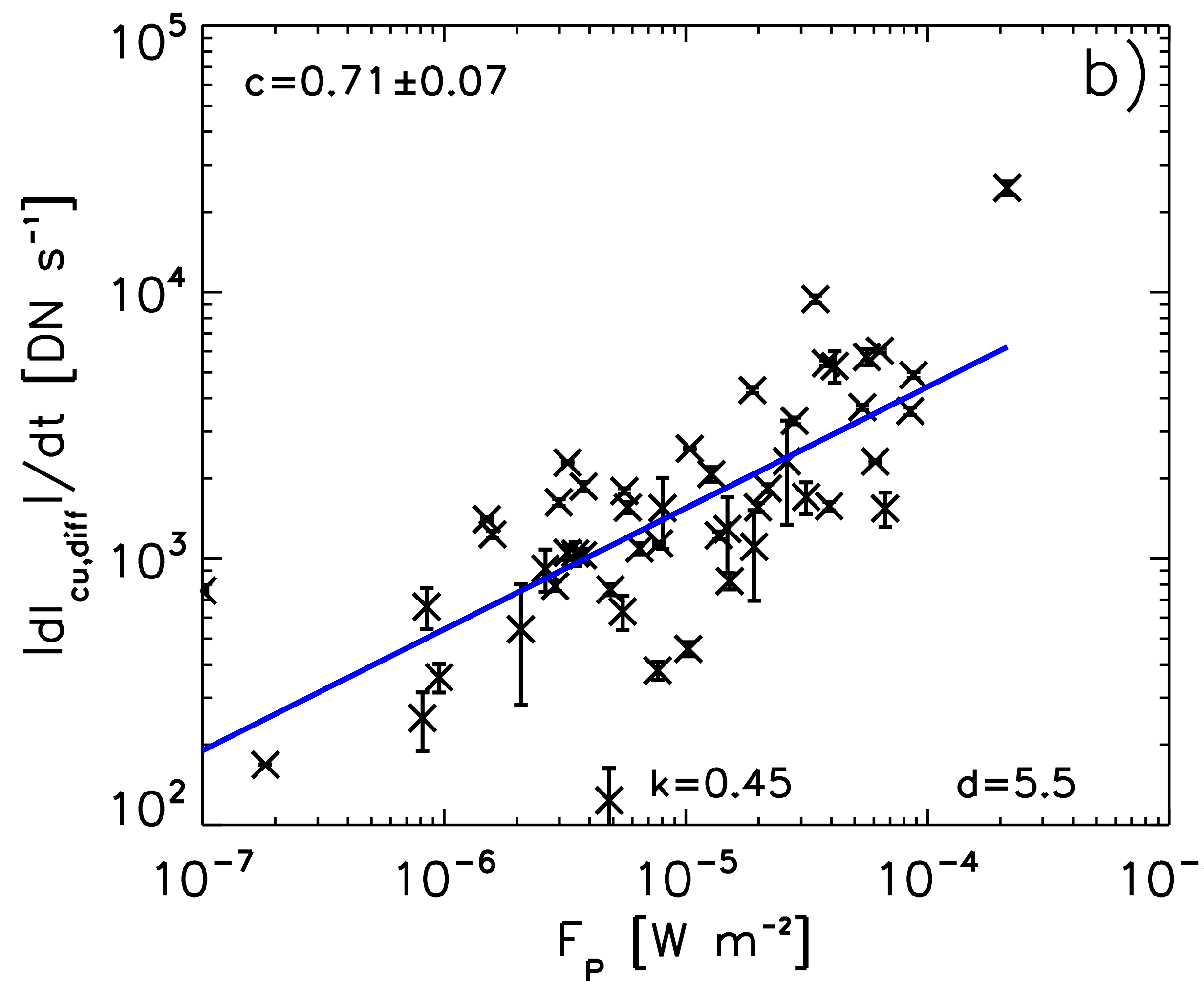


Dissauer et al. 2018b

Dimming - flare relationship

- first-order dimming parameters (dimming area, total unsigned magnetic flux, dimming brightness) strongly correlate with flare fluence (c>0.7)
- second-order dimming parameters (corresponding derivatives) strongly correlate with the flare strength (c>0.6)

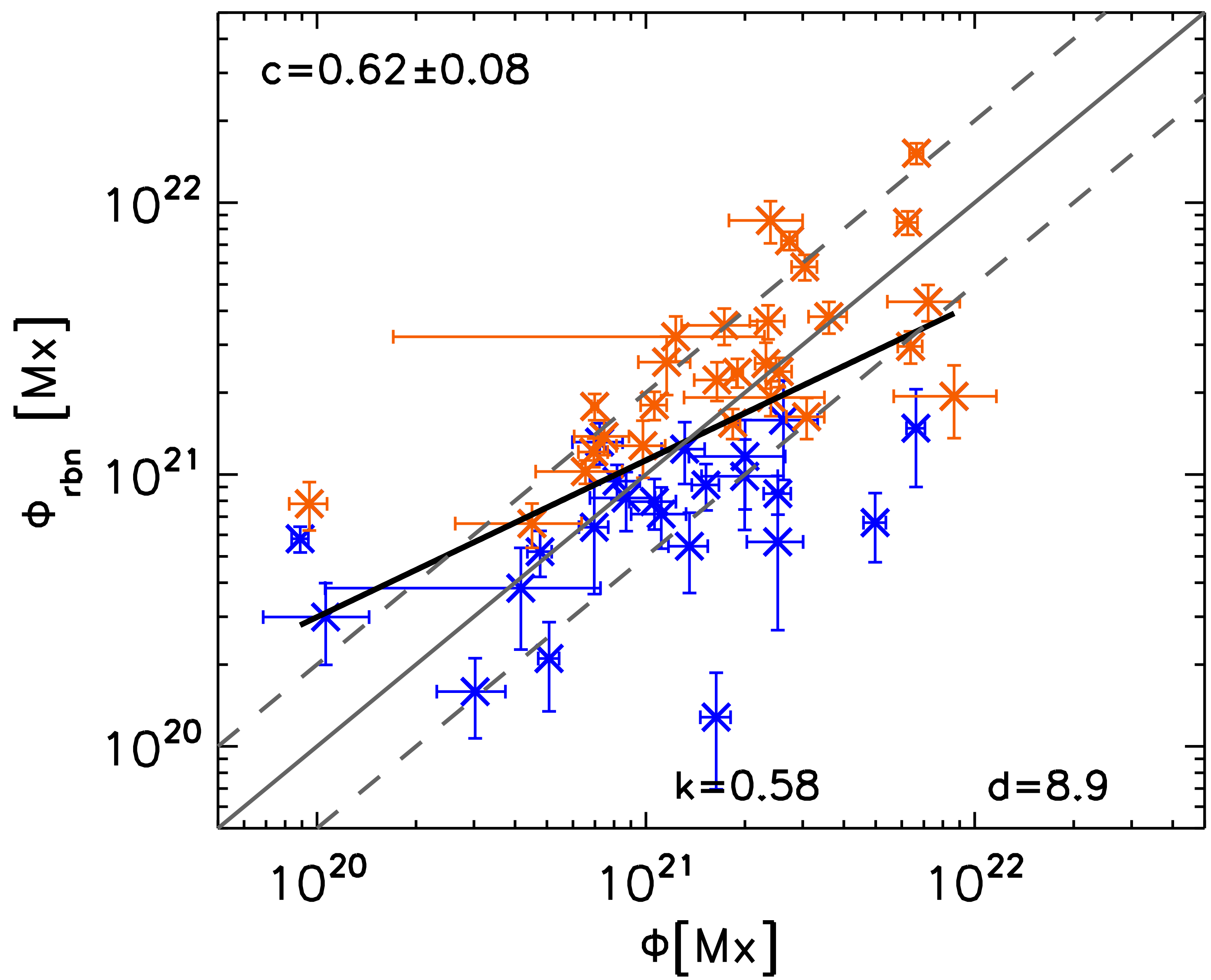




Dissauer et al. 2018b

- strong correlation between the magnetic fluxes of secondary dimmings and flare reconnection fluxes estimated from flare ribbon observations (Kazachenko et al. 2017)

- for strong flares (>M1.0) the reconnection and secondary dimming fluxes are roughly equal

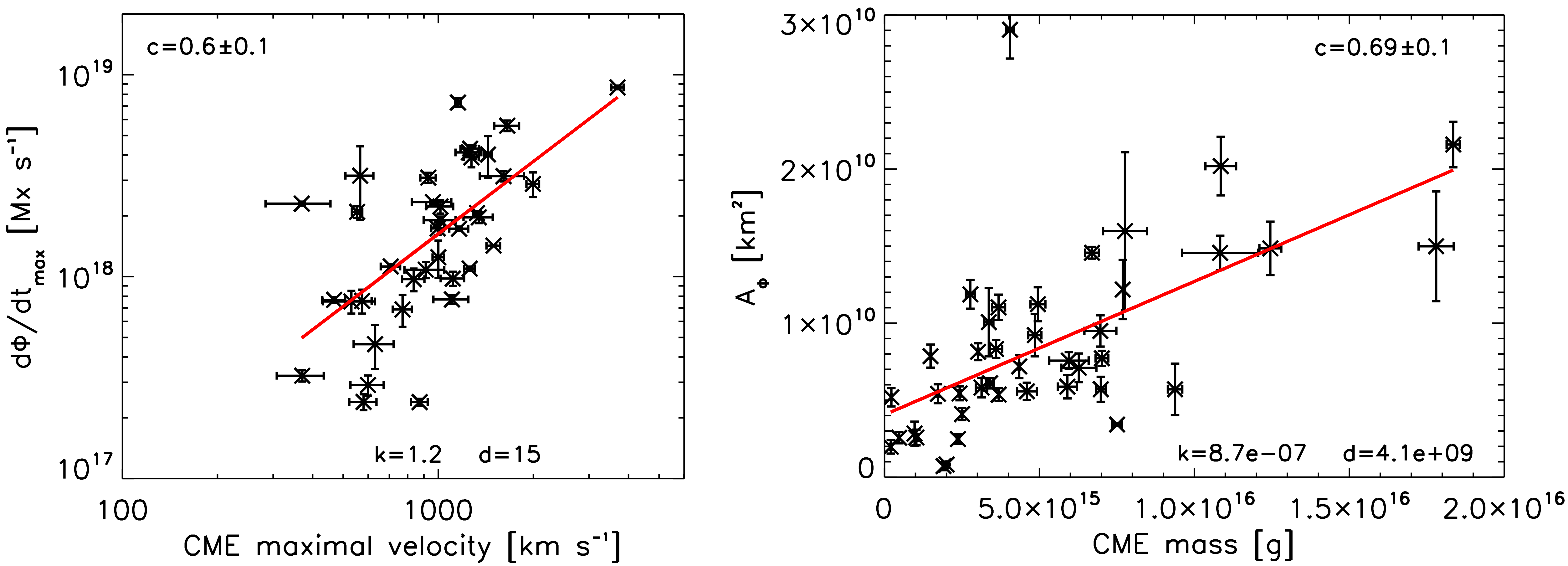


Dissauer et al. 2018b

- Secondary dimmings map overlying fields that are stretched during the erupting and closed down by magnetic reconnection, adding flux to the erupting flux rope

Dimming - CME relationship

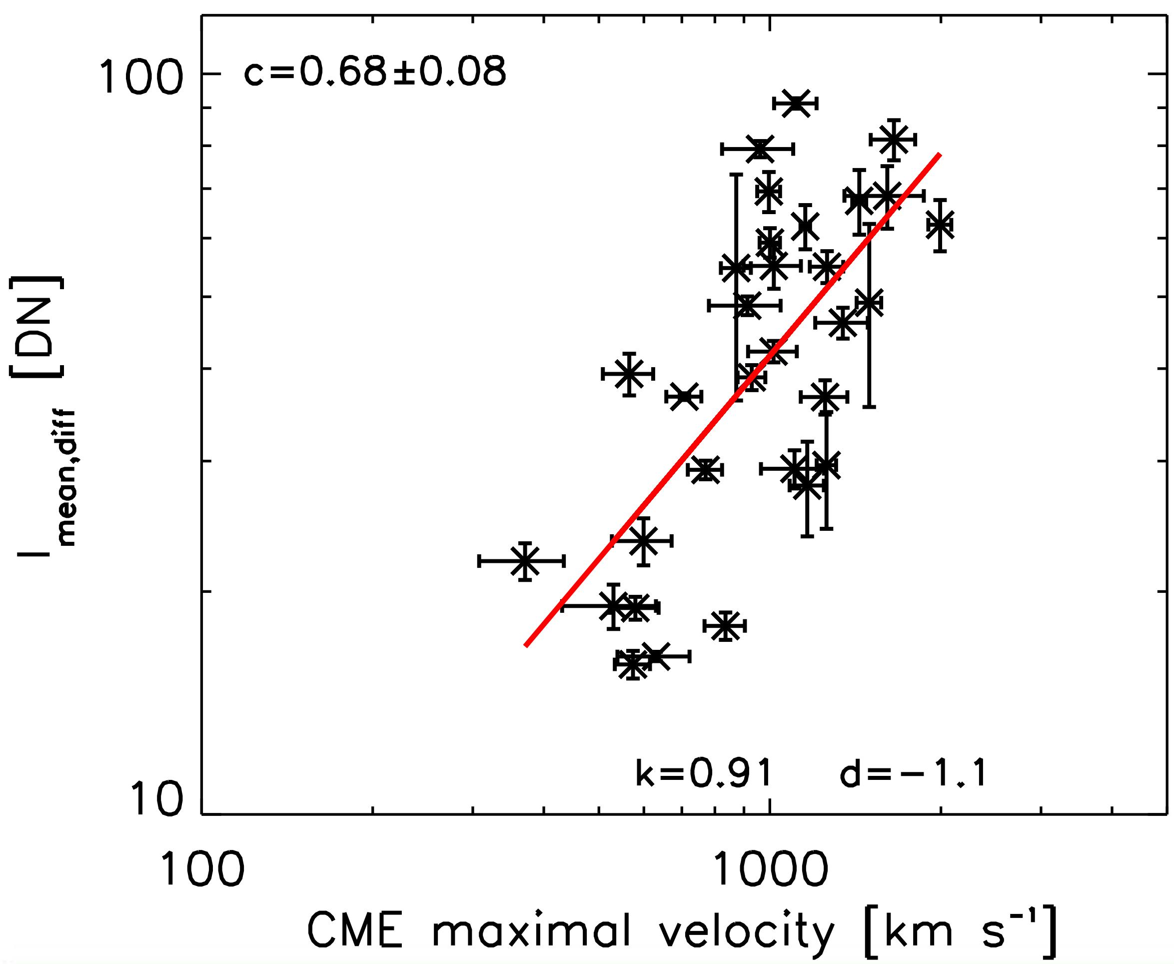
- strong correlation between the magnetic flux rate of the dimming and the maximal speed of the CME (c=0.6±0.10)
- first-order dimming parameters strongly correlate with the CME mass (c~0.6-0.7)
- in agreement with Mason et al. 2016



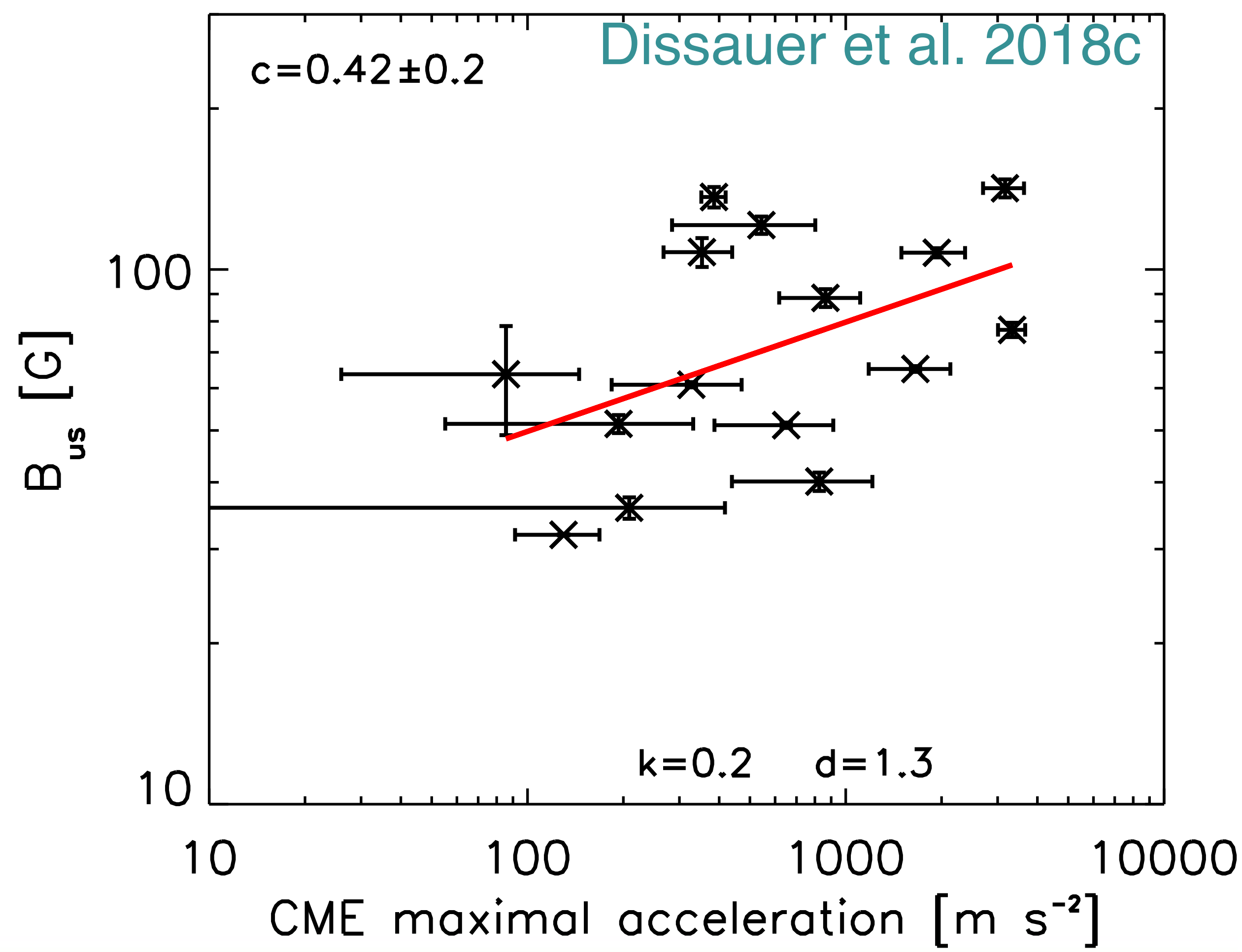
Dissauer et al. 2018c, ApJ submitted

Dimming - CME relationship

- mean intensity of the dimming strongly correlates with the CME maximal speed (c=0.68±0.08) → the lower the CME starts in the corona, the faster it propagates
- mean unsigned magnetic field density tends to correlate with the CME maximal acceleration (c=0.42±0.20) → stronger fields in the CME source region are related to stronger Lorentz forces accelerating the CME
- Jin et al. 2009: spectroscopic observations with Hinode/EIS → velocity of dimming outflows correlated with the magnetic field strength and the relative intensity changes of dimmings.



Dissauer et al. 2018c



Summary

- performed statistical analysis on 62 dimming/flare/Earth-directed CME events
- If CMEs occur together with flares, coronal dimming statistically reflect properties of both phenomena
- The area of the total dimming, i.e. including both core and secondary dimmmings, its total brightness and the total unsigned magnetic flux show the highest correlations with the flare fluence ($c>0.7$) and the CME mass ($c>0.6$)
- Their corresponding time derivatives, describing the dimming dynamics, strongly correlate with the GOES flare class ($c>0.6$) and the maximum speed of the CME ($c\sim0.6$)
- balance between positive and negative magnetic flux within the dimming regions as well as the strong correlation between the flare reconnection fluxes → same amount of magnetic flux is added to the erupting structure that is reconnected during the associated flare (Lin et al. 2004)
- results confirm feedback relationship between flares and CMEs (Vršnak et al. 2008, 2016)

detection method: Dissauer et al. 2018a, arXiv:1802.03185

dimming-flare relationship: Dissauer et al. 2018b, arXiv:1807.05056

dimming-CME relationship: Dissauer et al. 2018c, submitted to ApJ