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Magnetic reconnection rates in eruptive and confined flares

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Introduction

Context:

- Eruptive flares are powered by magnetic reconnection behind the erupting CME/flux rope (“standard CME/flare model”).
- The energy release process in confined flares is less well established.

Aim:

Comparative study of a set of confined & eruptive flares to check for observational differences related to the energy release process:

- Flare ribbon separation and separation motion
- Magnetic reconnection rates and fluxes
- Coronal electric field (local reconnection rates)

Analysis methods

1) Coronal electric field in reconnection region (assumes 2.5D geometry):

(Forbes and Priest 1984)

$$E_c = v_r B_n$$

2) Magnetic reconnection flux and flux change rates

(Priest and Forbes 2000, Hesse et al. 2005)

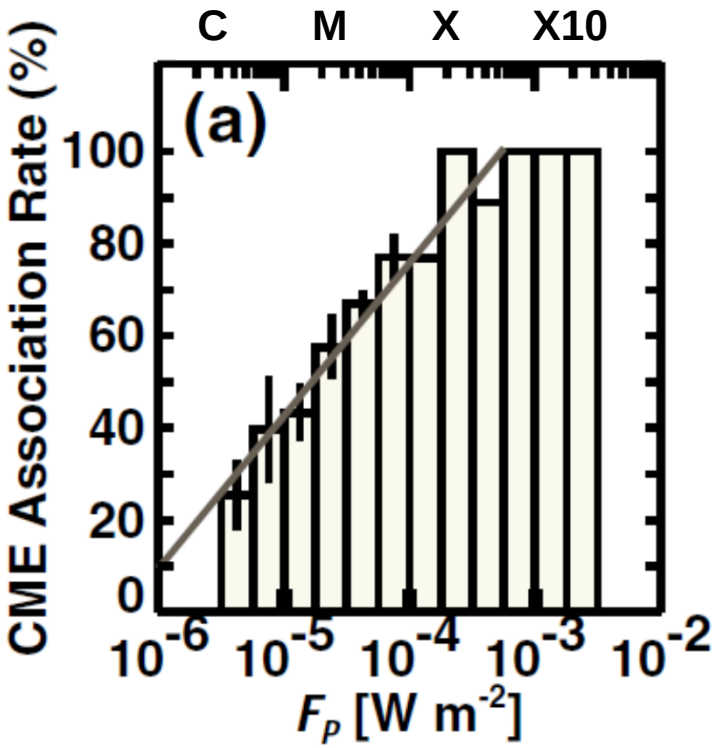
$$\dot{\varphi}(t) = \frac{\mathrm{d}\varphi}{\mathrm{d}t} \approx \frac{\partial}{\partial t} \int B_n(a)\,\mathrm{d}a = \sum_i \frac{a_i(t_k) B_n(a_i)}{(t_k - t_{k-1})}$$

$$\varphi(t_k) = \int_{t_0}^{t_k} \dot{\varphi}(t)\,\mathrm{d}t \approx \sum_{j=1}^{k} \dot{\varphi}(t_j)(t_j - t_{j-1})$$

Data set

Selection:

- Set of ~50 eruptive and confined flares, CMD < 30°
- Flares well distributed over classes (in particular includes large confined events)



GOES-Class	$n_{confined}$	$n_{eruptive}$	n_{total}
B	7	0	7
C	12	3	15
M	7	11	18
X	6	5	11
Total	32	19	51

Yashiro et al. (2006): statistics of
98 X, 692 M, 575 C flares

Data set

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Data set: 2000 – 2015

- MDI and HMI LOS magnetic field maps
- Kanzelhöhe Hα (+ USO for 28-Oct-03 X17 + ISOON for 29-Oct-03 X10 flare)
- Ground-based Hα: - seeing influences
  + homogeneous data set over 2 solar cycles

Data set

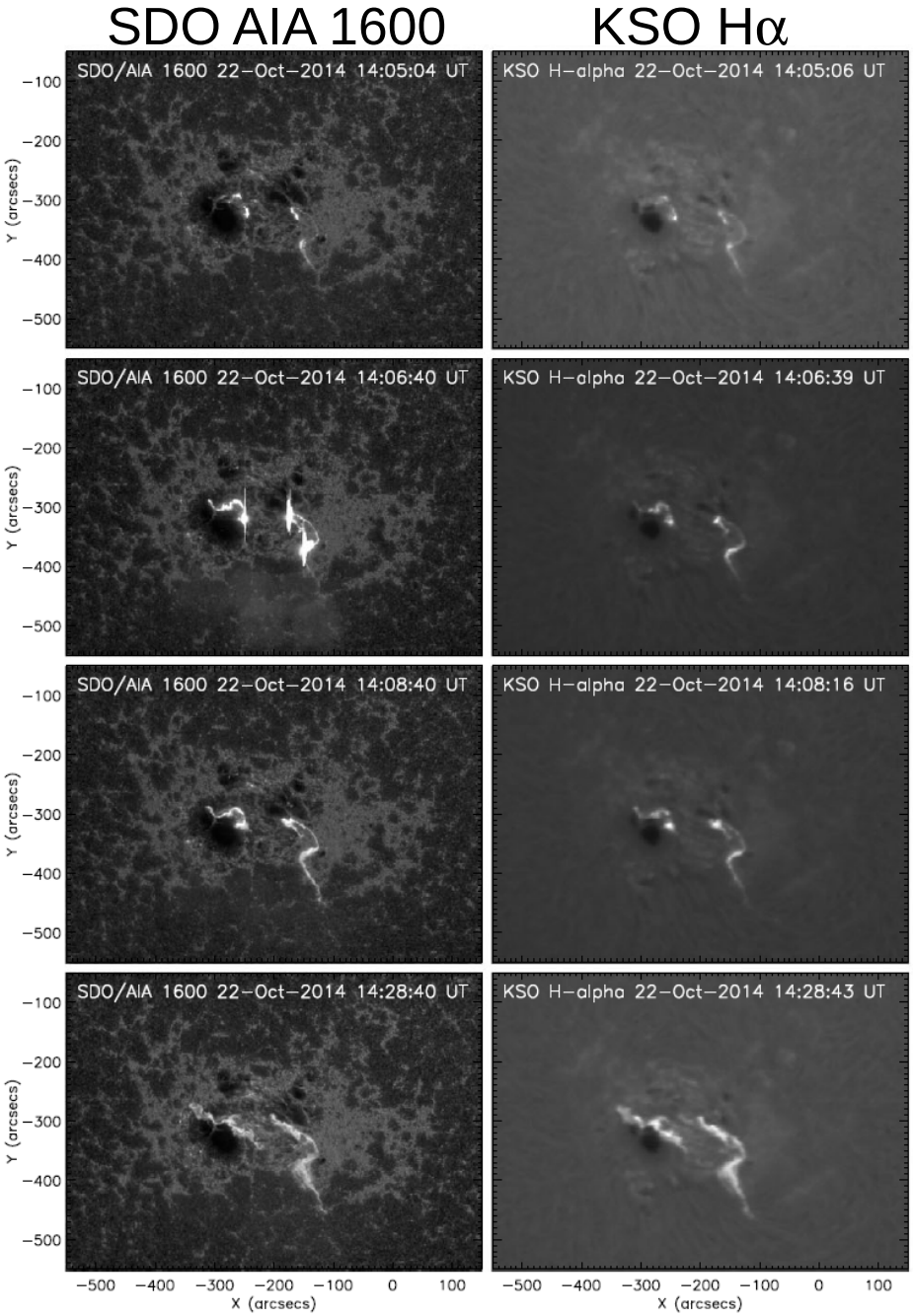
Comparison:

KSO Hα & SDO AIA 1600
22-Oct-2014: X1.6 flare, confined

Movie 1: newly brightened flare area (left) and cumulated flare area (right) on AIA 1600 images

Movie 2: newly brightened flare area (left) and cumulated flare area (right) on HMI LOS magnetic field map

Movie 3: newly brightened flare area (left) and cumulated flare area (right) on KSO Hα images



Example: reconnection flux study

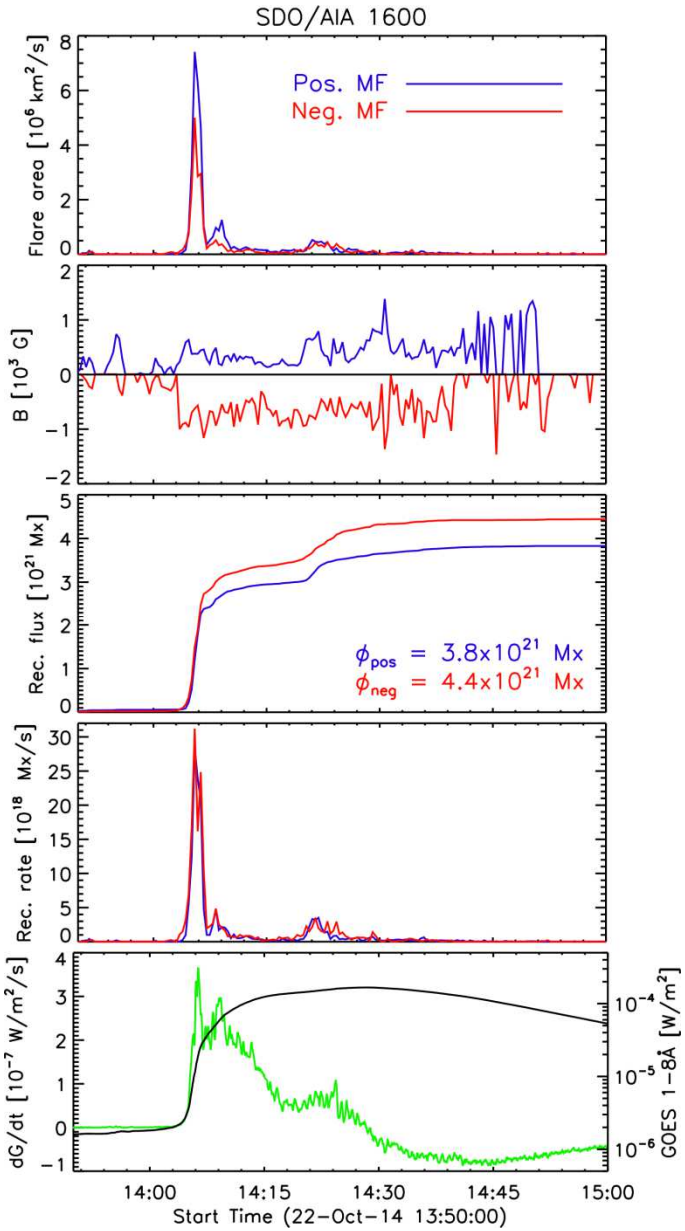
Newly brightened flare area A

Mean field strength in flare pixels <B>

Cumulated reconnection flux $\varphi(t)$

Reconnection rate $\frac{d\varphi}{dt}$

GOES X-ray flux and derivative



Veronig & Polanec (2015)

Example: reconnection flux study

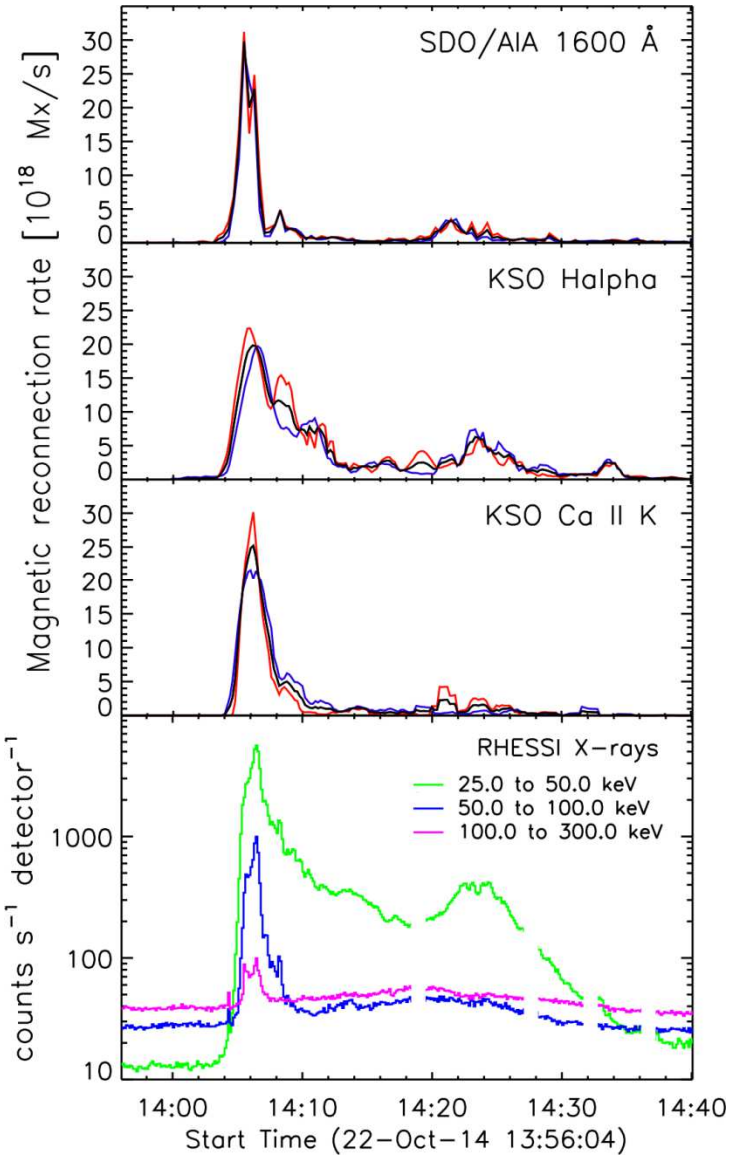
Reconnection rates $\dot{\varphi}(t)$ from:

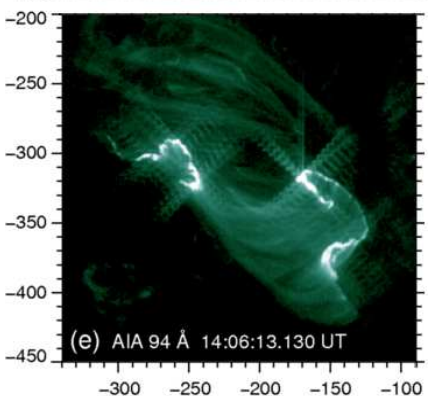
- SDO/AIA 1600 Å
- Kanzelhöhe Obs. Hα
- Kanzelhöhe Obs. Ca II K

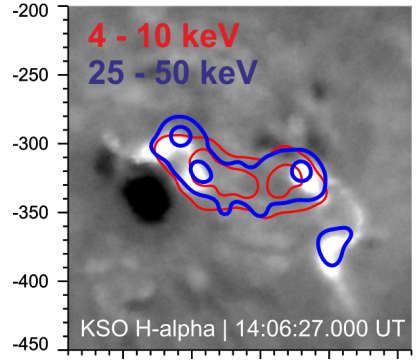
&

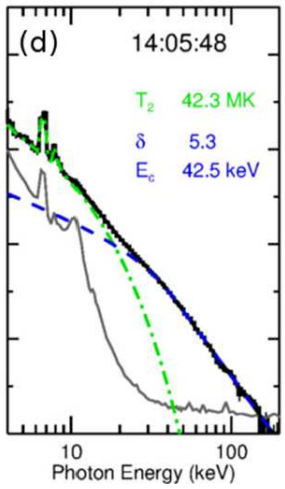
RHESSI HXR flux

peak simultaneously within 1 min





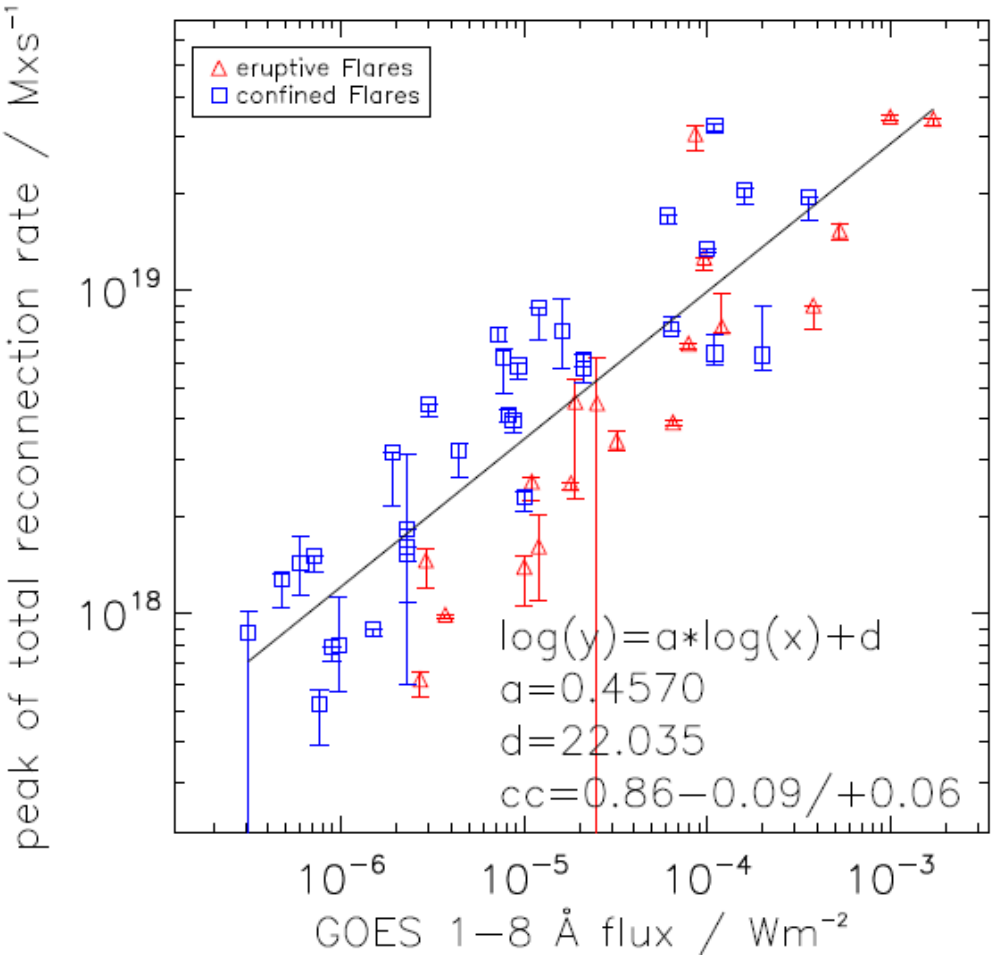




Thalmann et al. (2015)

Results: reconnection flux study

Reconnection rate (Mx/s) against GOES peak flux

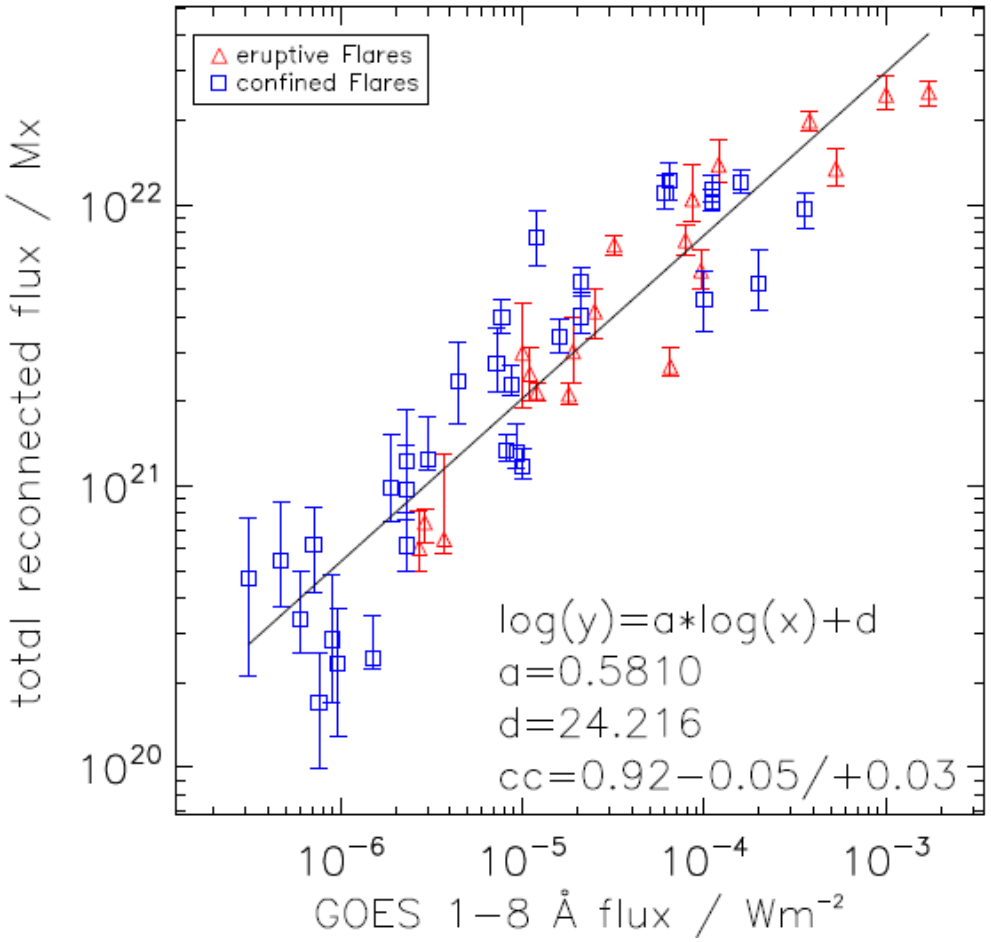


Red: eruptive flares

Blue: confined flares

Results: reconnection flux study

Reconnection flux (Mx) against GOES peak flux

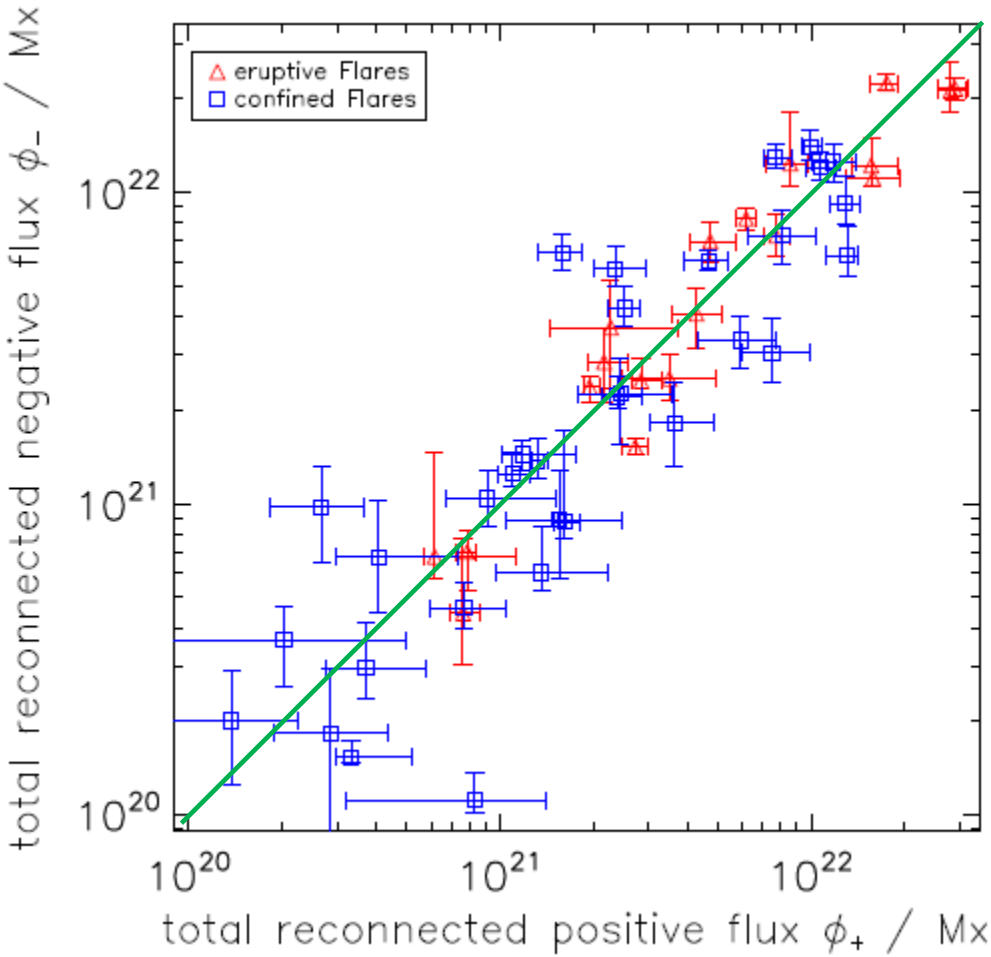


Red: eruptive flares

Blue: confined flares

Results: reconnection flux study

Cross-check: Negative against positive reconnection flux



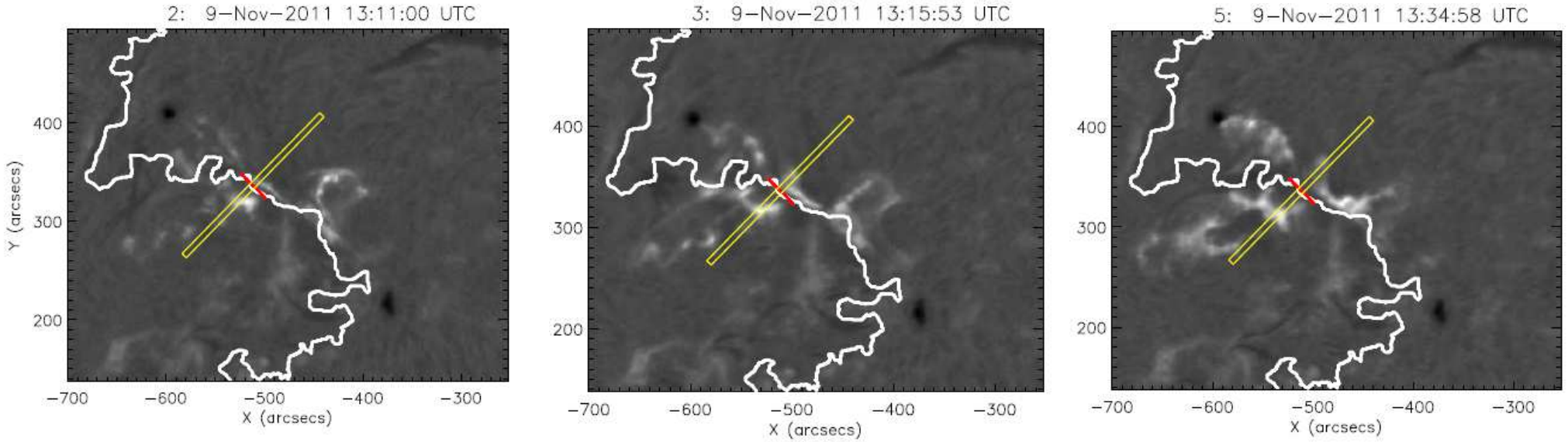
Red: eruptive flares

Blue: confined flares

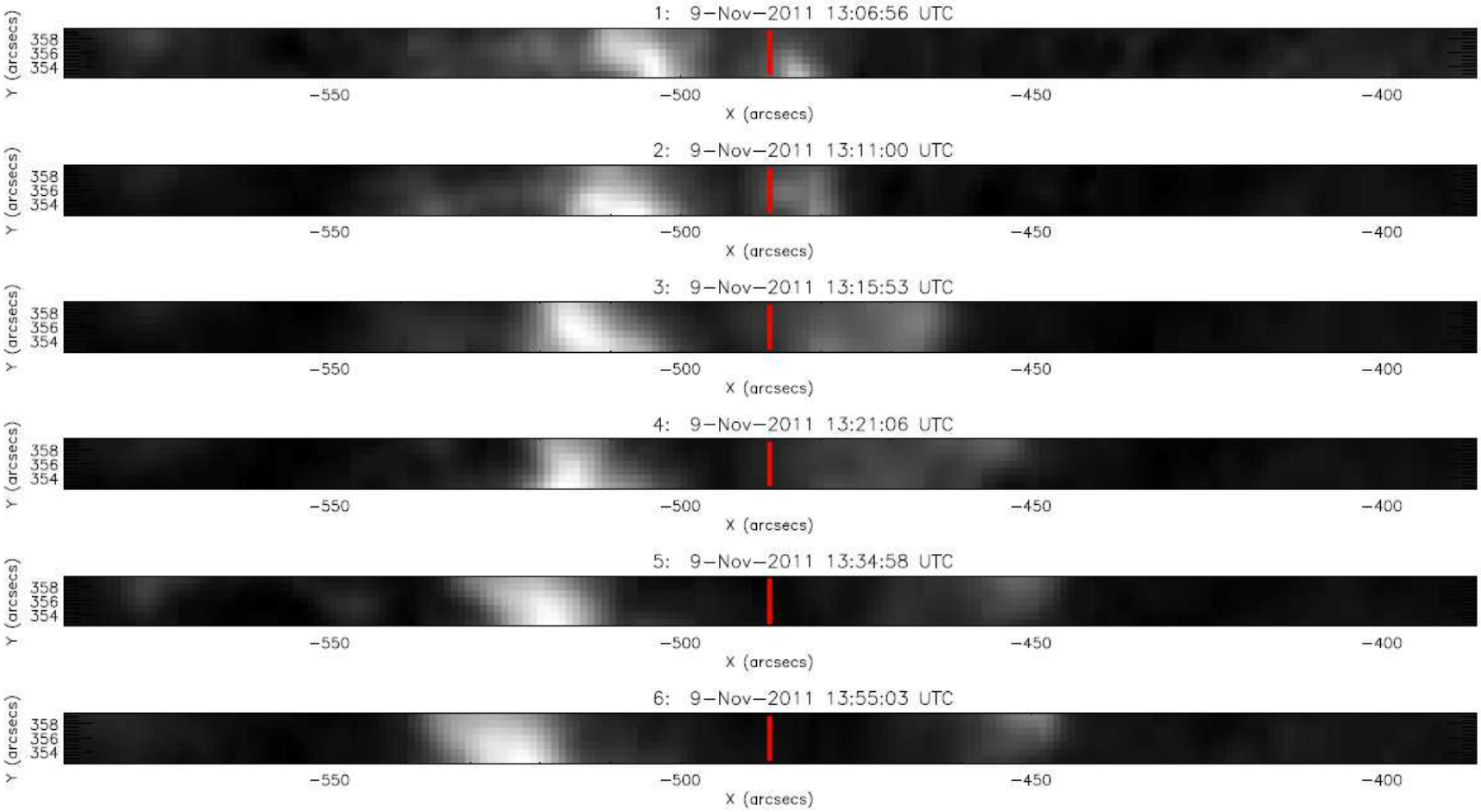
Example: coronal Ec study

9-Nov-2011: M1.1/2N flare, eruptive (v_{CME} = 900 km/s)

Movie



Example: coronal Ec study



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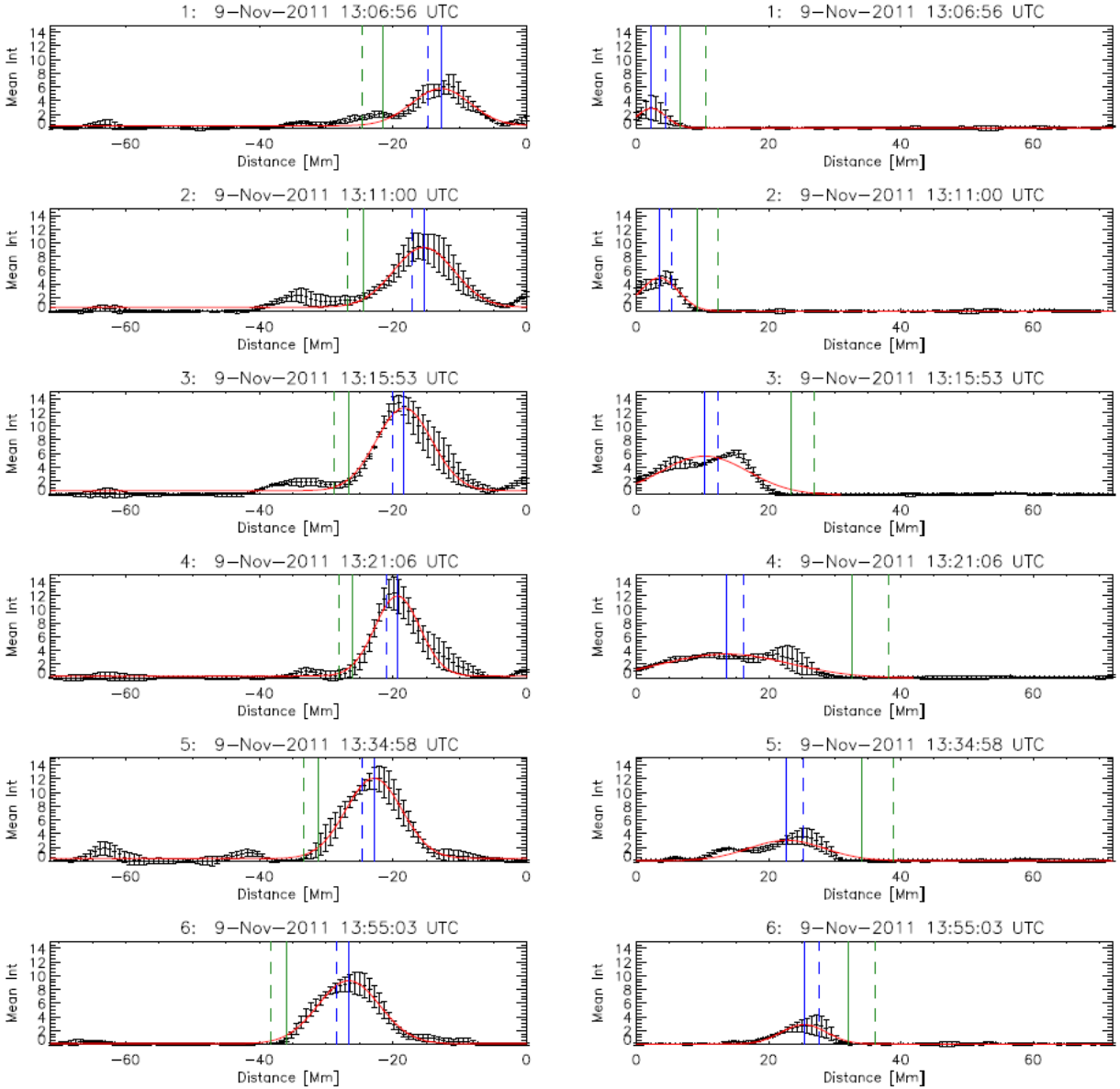


Example: coronal Ec study

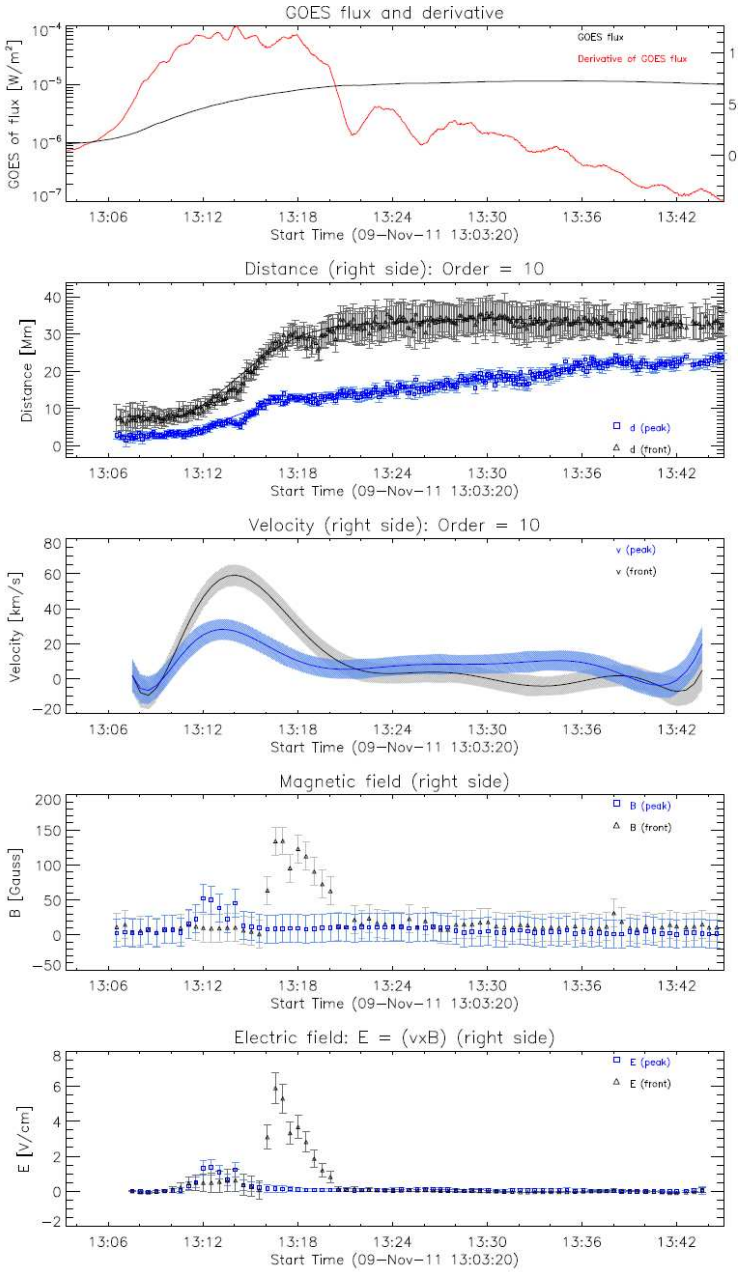
GOES flux & derivative

Ribbon separation

Ribbon separation speed

Underlying phot. B-field

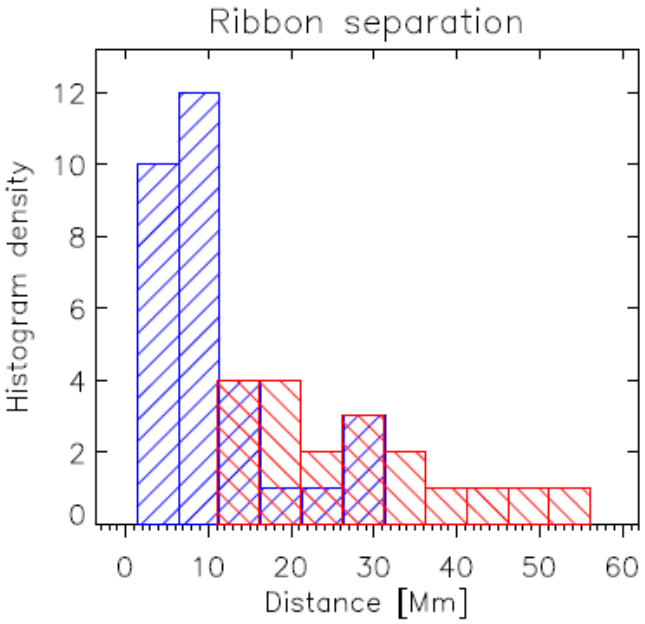
Coronal electric field Ec

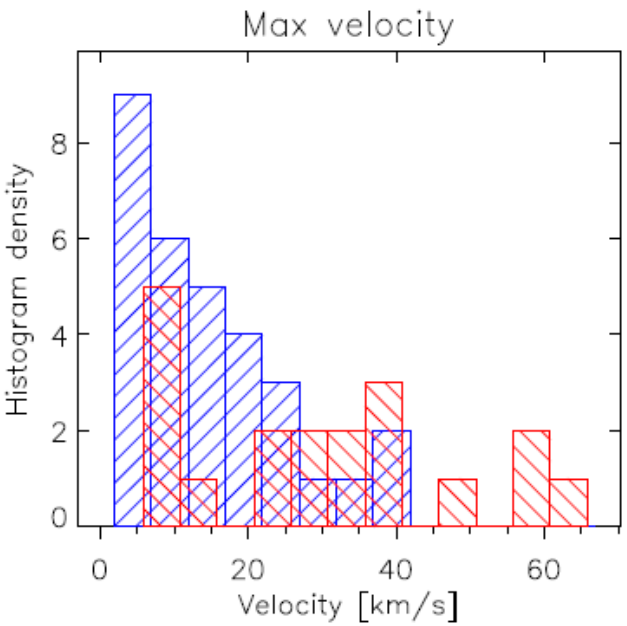


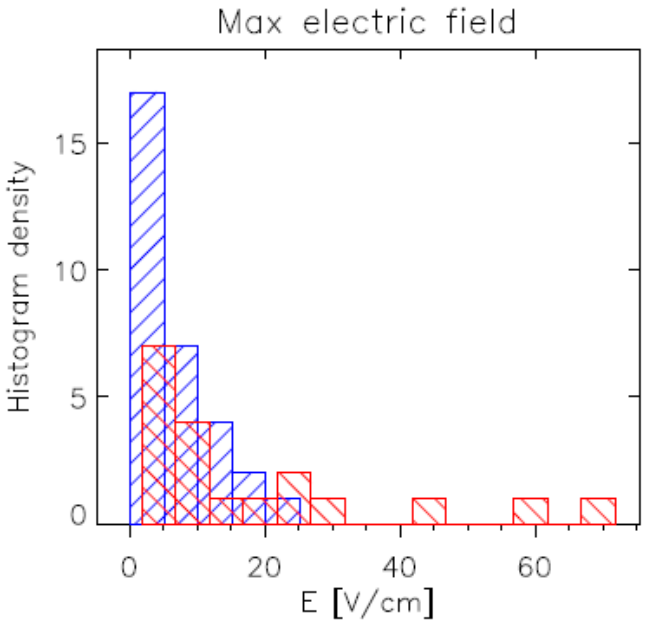
More details:
see Poster by
Jürgen Hinterreiter

Results: coronal Ec study

Red: eruptive events Blue: confined events







Results: coronal Ec study

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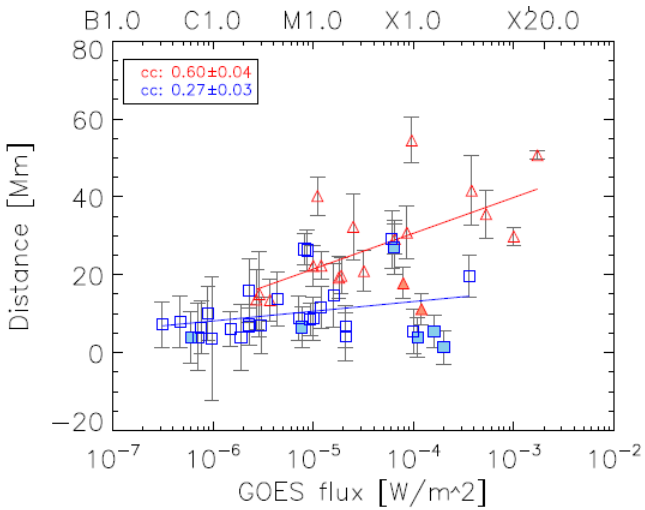
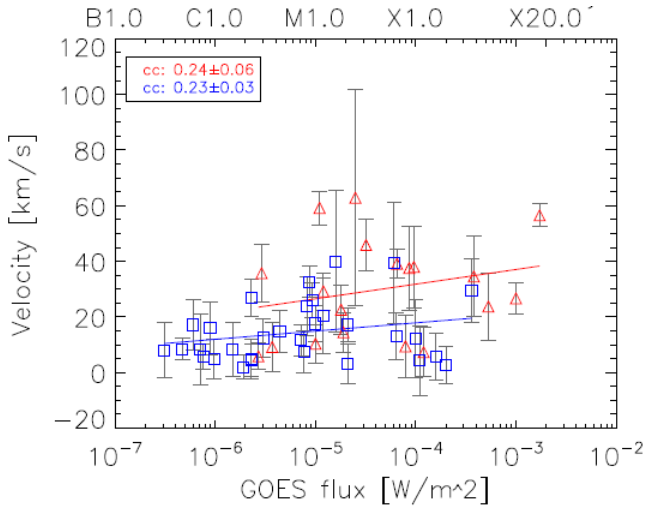
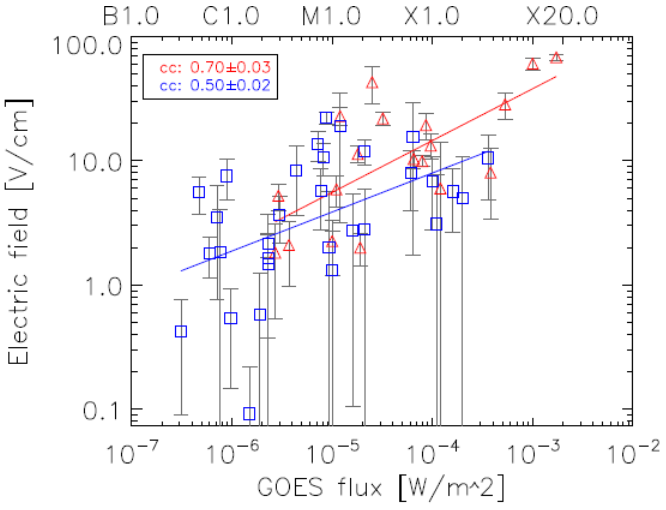
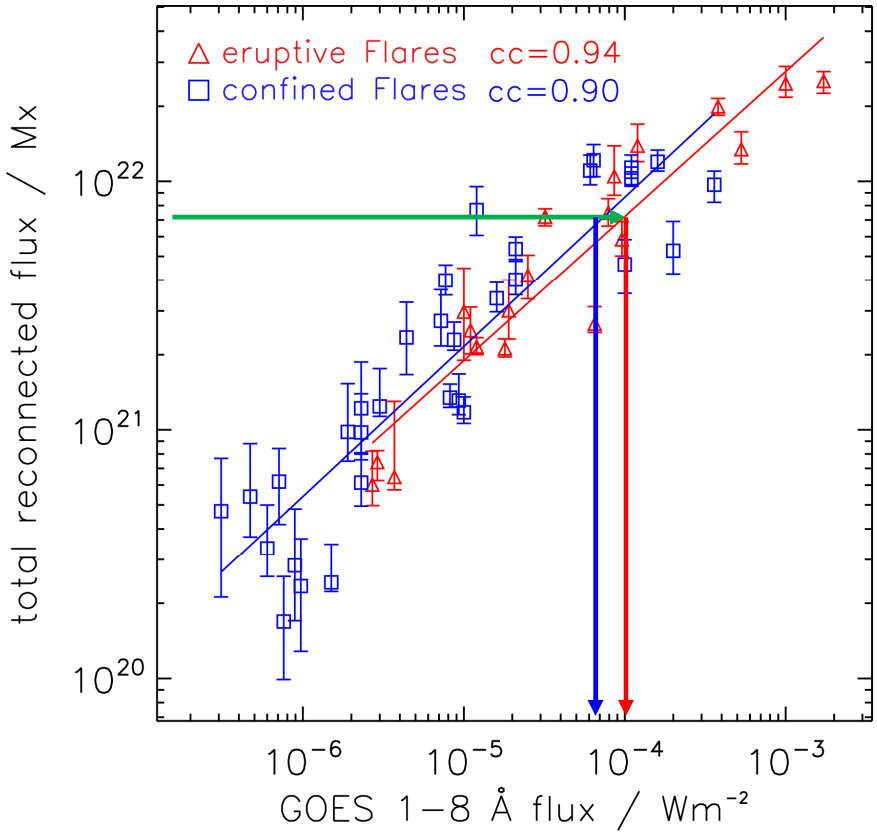






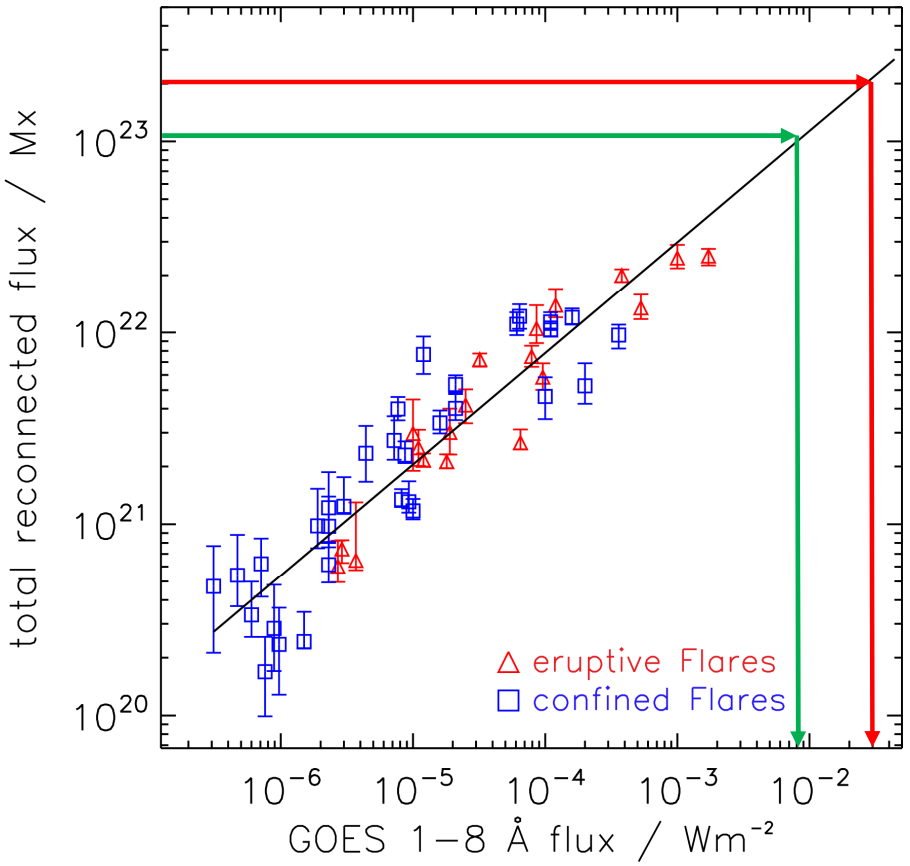
Summary

- Ribbon separation distance and separation speed are statistically smaller in confined flares, and show weaker dependence on GOES class.
- Ec fields are smaller in confined flares: confined flares have all Ec < 20 V/cm, whereas in eruptive flares it may reach up to Ec = 80 V/cm.
- Distinct correlations between reconn. rates and reconnection fluxes with GOES flare class (c > 0.9).
- Small difference for eruptive and confined flares: for same reconnection flux & rates, confined flares reach smaller GOES class



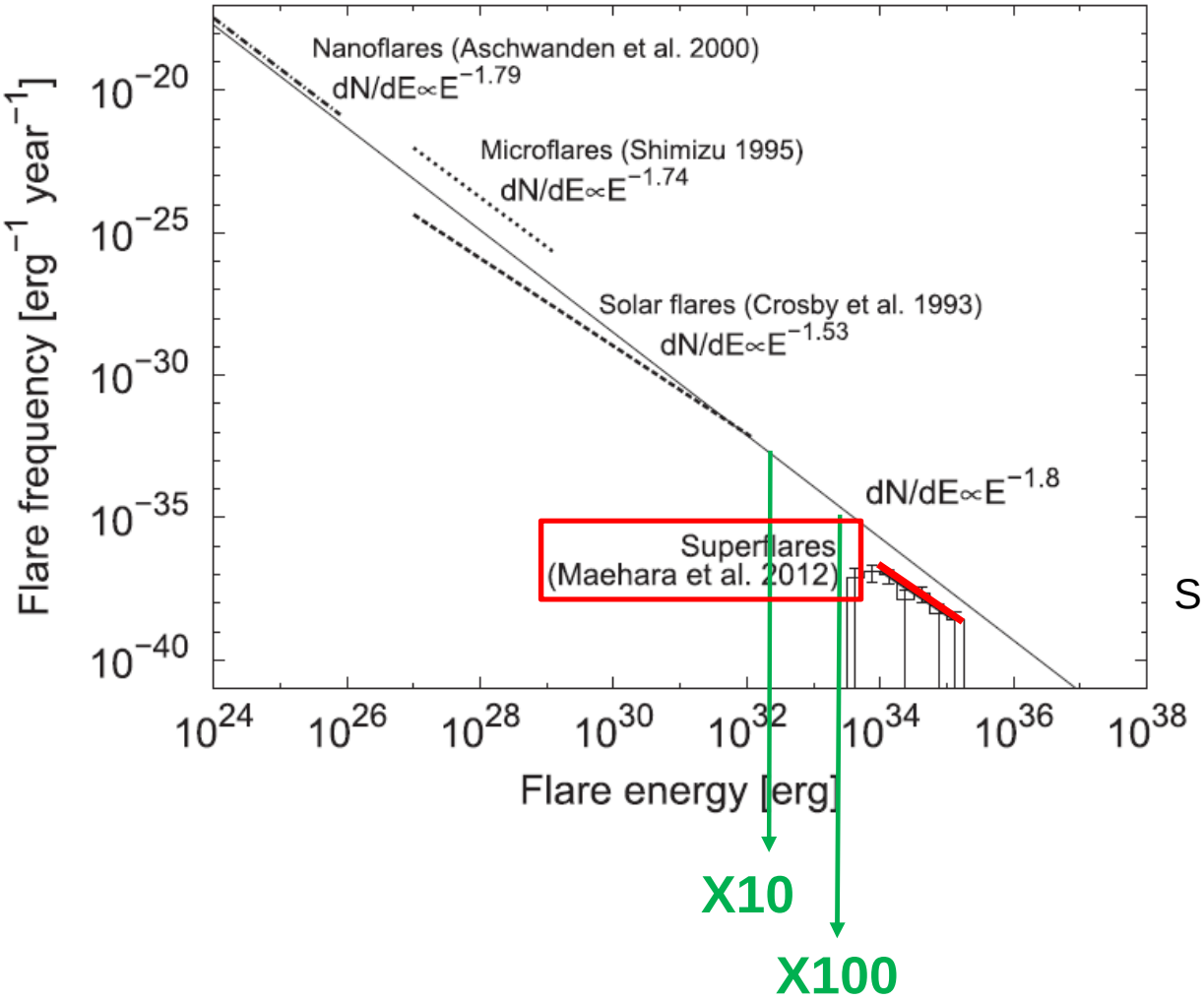
Gedanken experiment: Largest solar flares possible

- AR 12192 was the largest AR on Sun since 25 years
- Maximum magnetic flux in the AR was 2 ·10^{23} Mx on 27 Oct 2014
  (Sun et al. 2015, Thalmann et al 2015)
- Max. estimate: assume all AR flux is reconnected → X250 flare
  half → X100 flare



Gedanken experiment: Largest solar flares possible

X100 flare would be less extreme than the „superflares“ (X1000-ish) suggested from Kepler observations of flares on Sun-like stars (Maehara et al., 2012, Nature 485)



Shibata et al. (2013)

THANK YOU!