On the origin of solar proton events: comparison between solar cycles 23 and rising half of 24

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Important “selection effects”

→ SEPs: in situ & SEP driver: remote observations

→ single location in space (but STEREO!)

→ different satellites (GOES, SOHO, ACE, Wind, STEREO...)

→ protons, electrons, ions

→ different energy channels

→ need for a magnetic connection: Sun–Earth

→ particle transport in different IP conditions

→ different acceleration/transport/selection regimes?

→ space weather risks

SEP topic: O. Malandraki & I. Podgorny talks

Selected open questions

? on the physical link: **particles ↔ accelerator**
→ observations, models

? single vs. multi-point observations in heliosphere
→ 3D particle flux distribution

? prediction model
→ need for novel observations or/and theory?

SEP works (incomplete list):
Cane et al.; Cliver et al.; Dierckxsens et al.; Gopalswamy et al.; Kahler et al.; Klein et al.; Krucker et al.; Malandraki et al.; Posner et al.; Reames et al.; Torsti et al.; Vainio et al.; ...

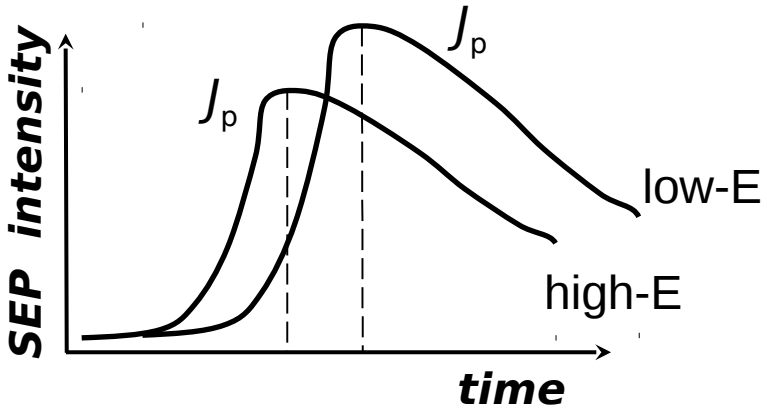
Solar energetic particles

- solar origin

→ follow in time solar eruptive events: flares & CMEs

→ velocity dispersion

- local (CIR/IP) origin



Research directions:

1. Detailed single event studies
2. Modeling (data-driven simulation)
3. Statistical studies: J_p vs. flare class or/and CME speed

Particle data in SC23 & 24$_{1/2}$ (this work)

(I) SEPServer proton list

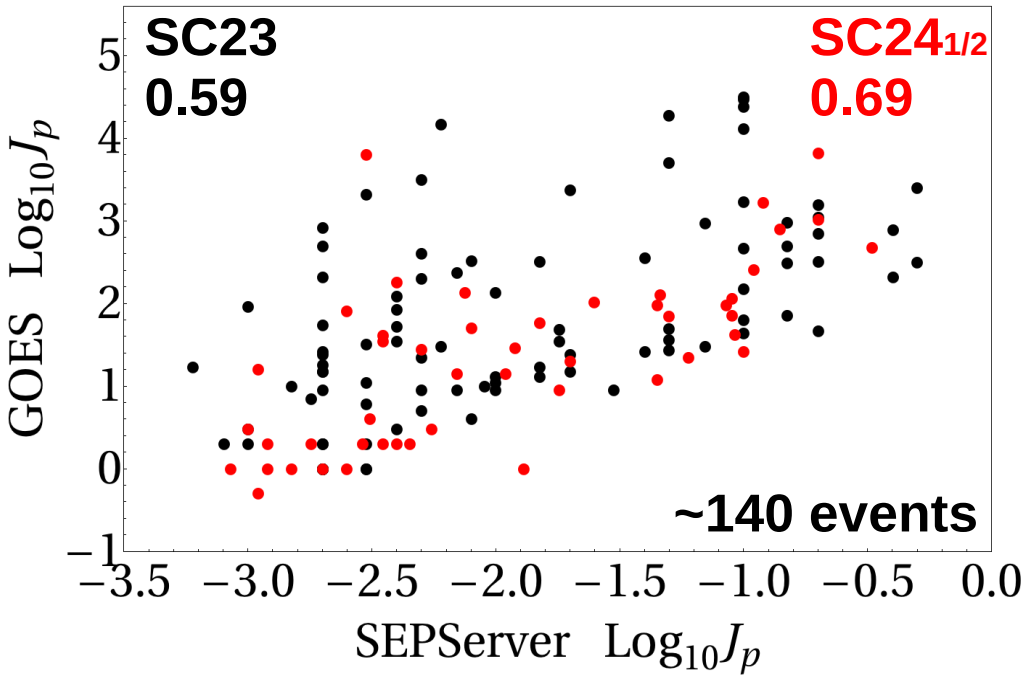
server.sepserver.eu

SOHO/ERNE 55–85 MeV
168 events

(II) GOES proton list

umbra.nascom.nasa.gov/SEP/

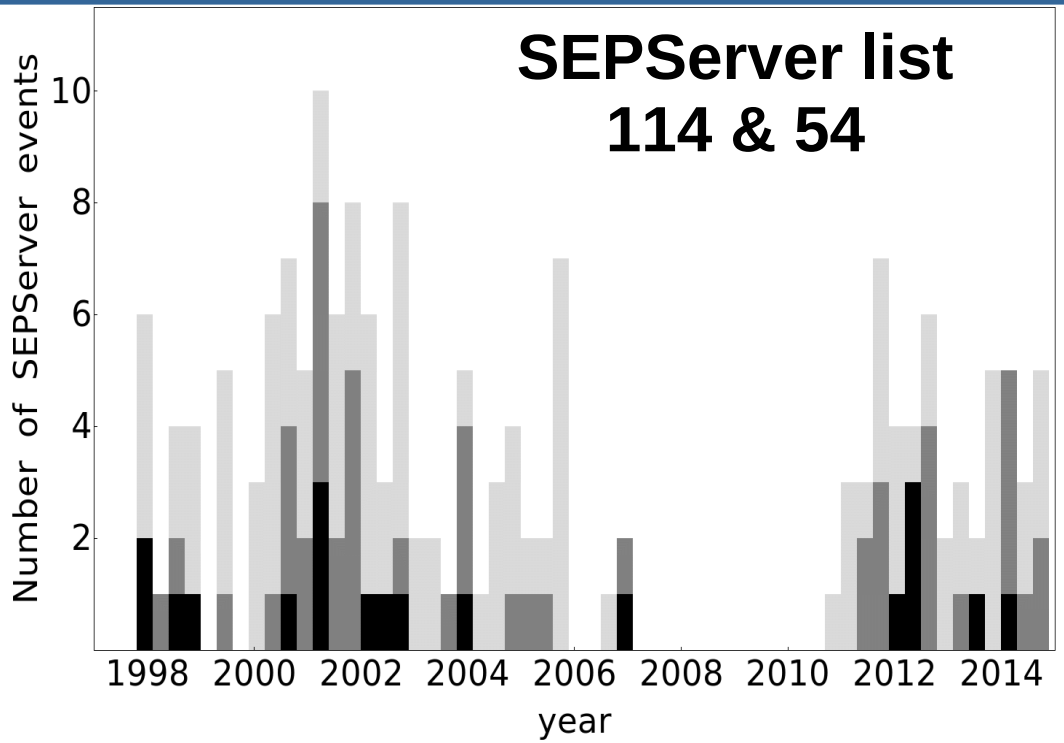
threshold: 10 pfu
→ here:
extended to **183** event (comprehensive study needed)



(III) New particle lists (SOHO, ACE, Wind)

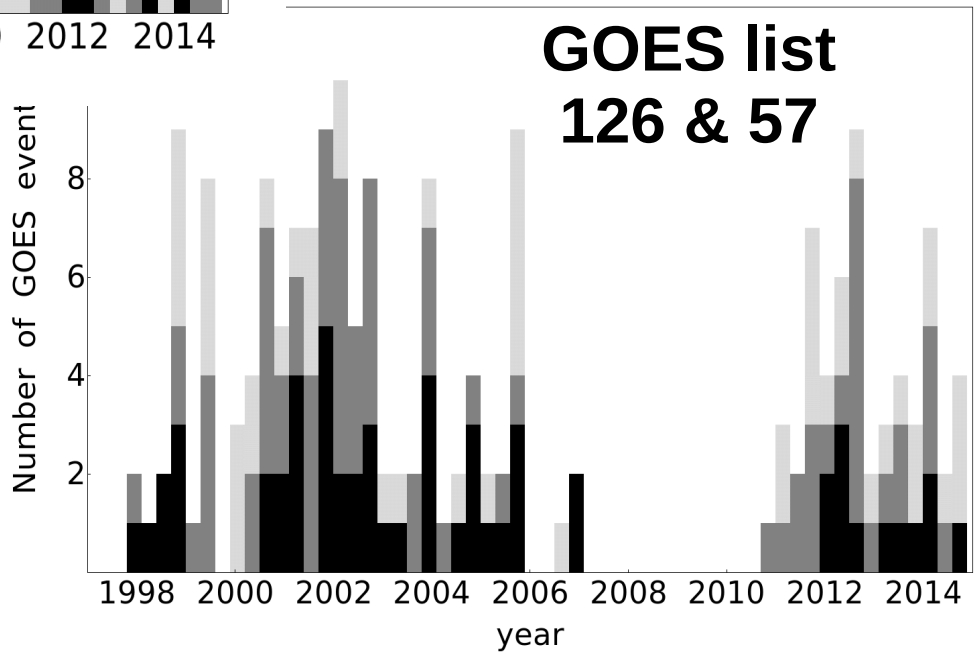
in progress
cdaweb.gsfc.nasa.gov/istp_public/
www2.physik.uni-kiel.de/SOHO/phpeph/EPHIN.htm

Proton intensities in SC 23 & 24 1/2



$J_p \geq 0.1$ (black)
≈ 0.01–0.1 (gray)
< 0.01 (light-gray)

≡ length color bar
SC24: fewer (intense) SEPs

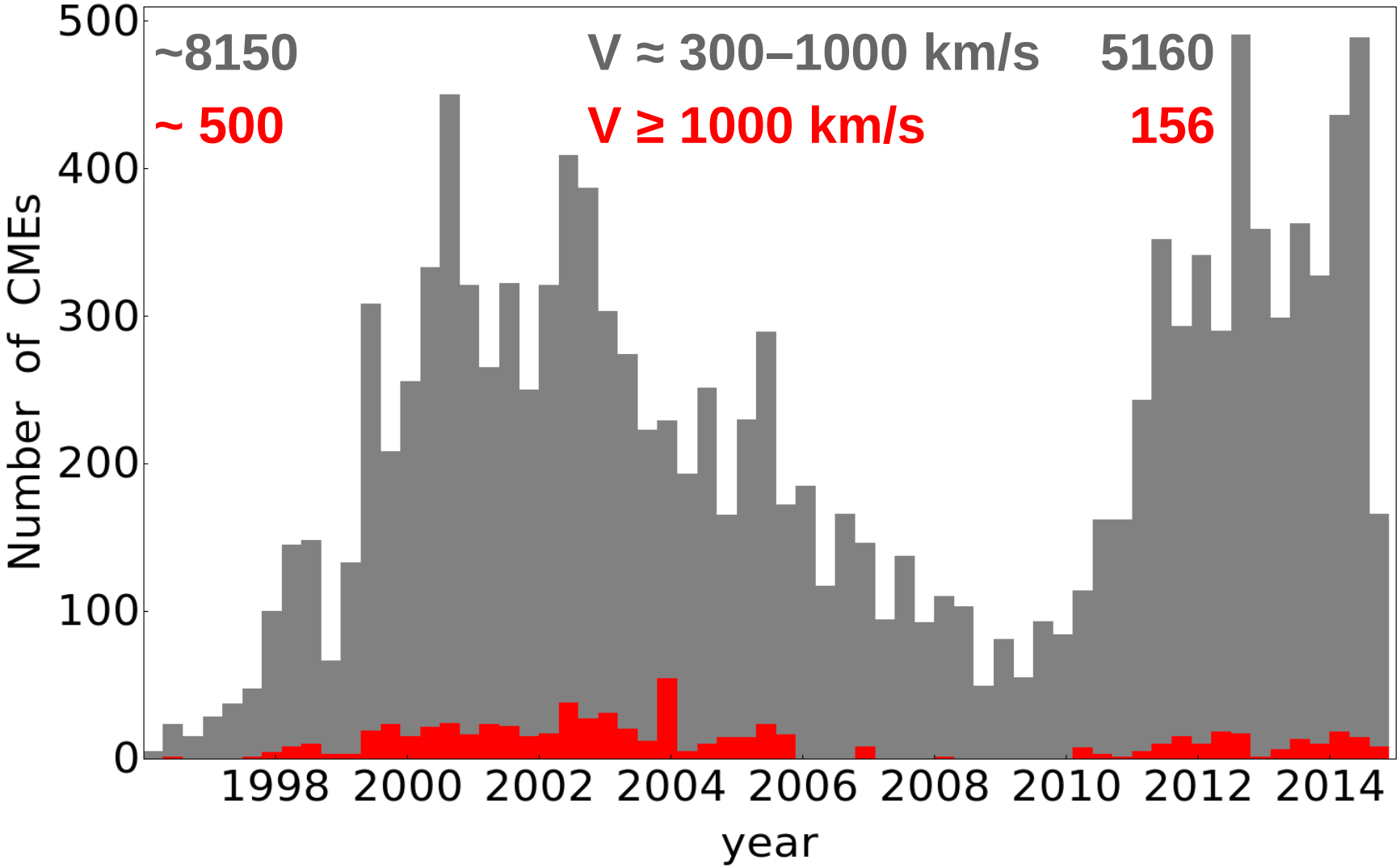


GOES: bias to strong events

$J_p \geq$ 100 (black)
$\approx$ 10–100 (gray)
$<$ 10* (light-gray)
* incomplete listing

CMEs in SC 23 & 24$_{1/2}$

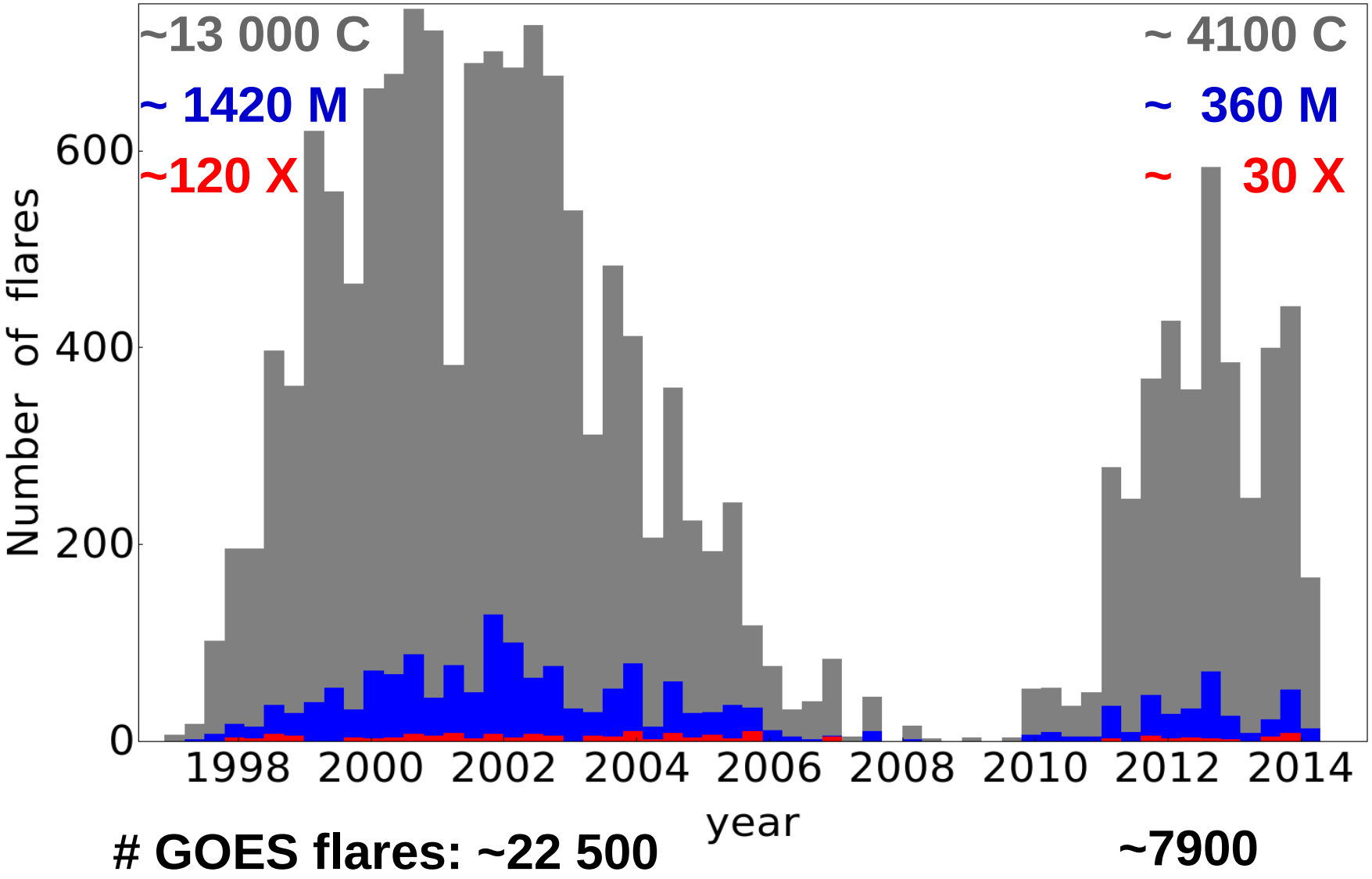
- *strong projection effects for **disk center** events!*



 # all LASCO/CDAW CMEs: ~14 000 **~10 200**

Solar flares in SC 23 & 24$_{1/2}$

- ***partially occulted*** *SXR emission for* ***limb*** *events!*



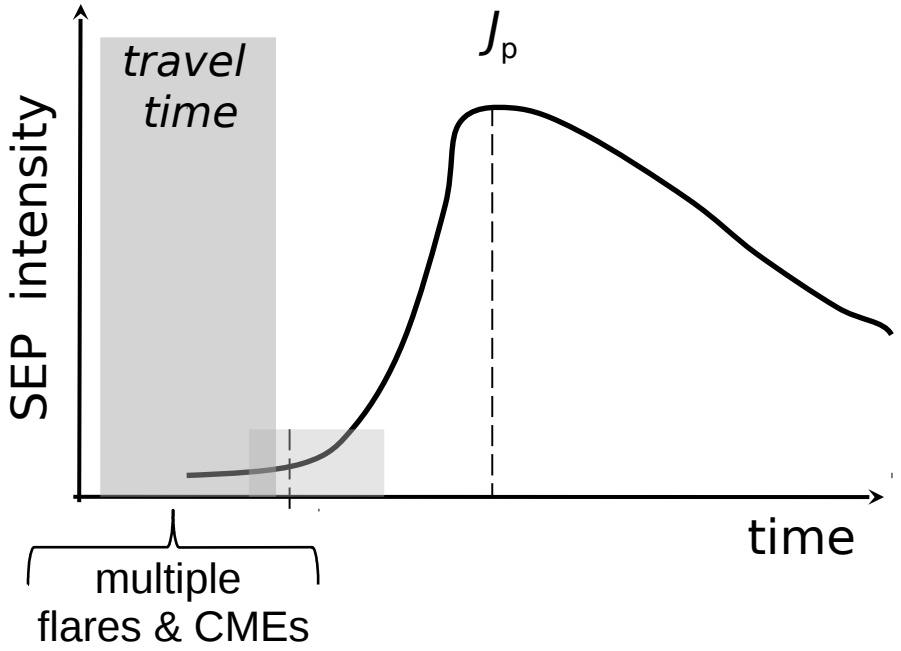
 # GOES flares: ~22 500 **~7900**

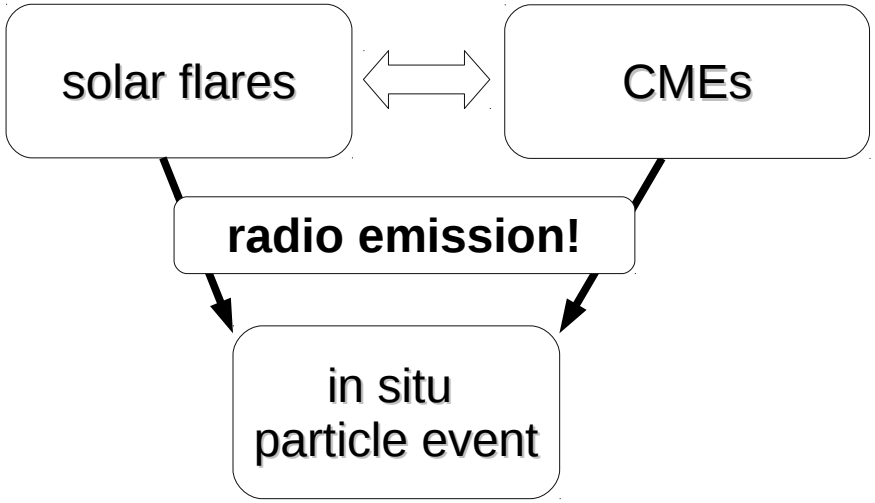
SEPs → flare/CME association

Selection criteria (this work):

- time: variable window
- strength: stronger flare + faster/wider CME
- location: preference to a western candidate
- DH radio emission (decision for on disk activity)

→ degree of subjectivity!





Association: SEP – solar event

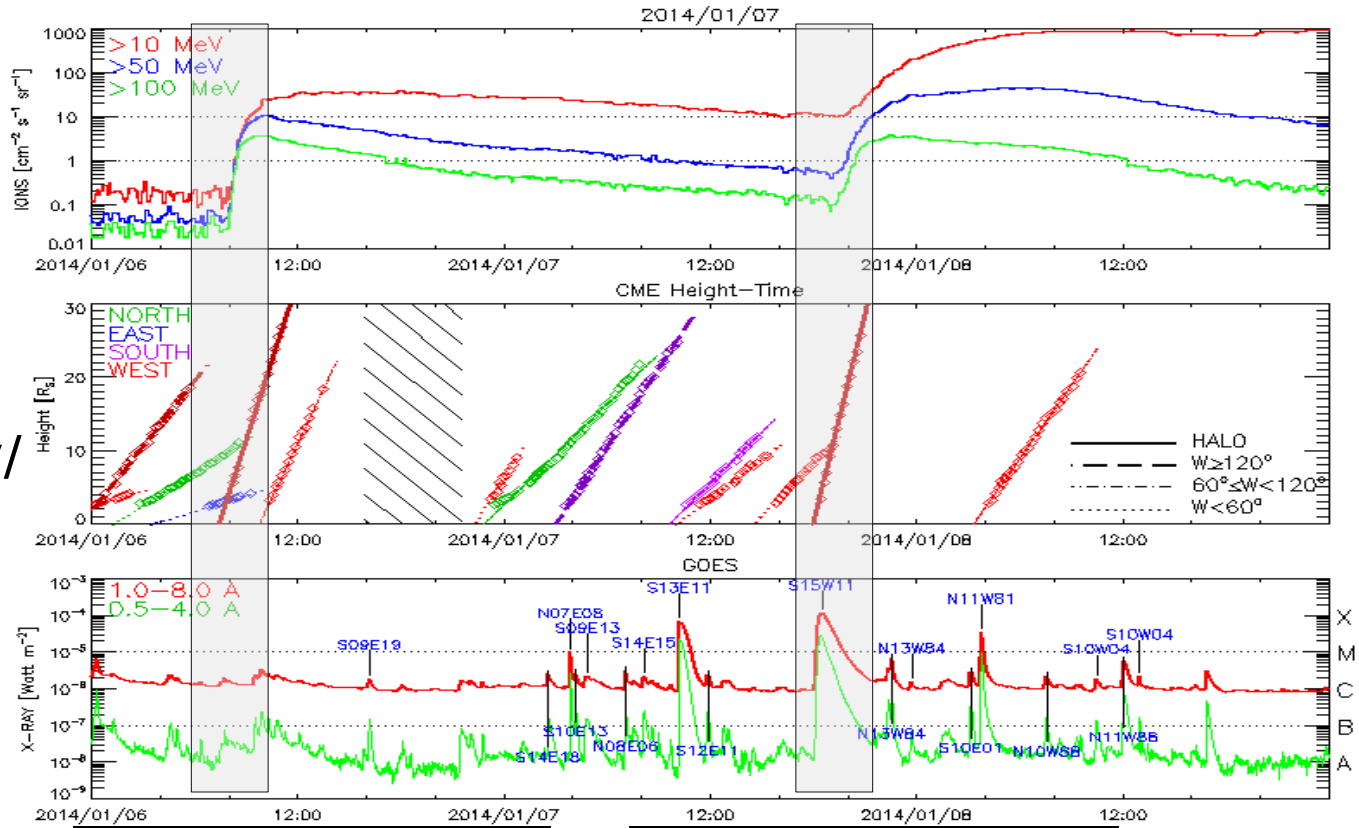
Source

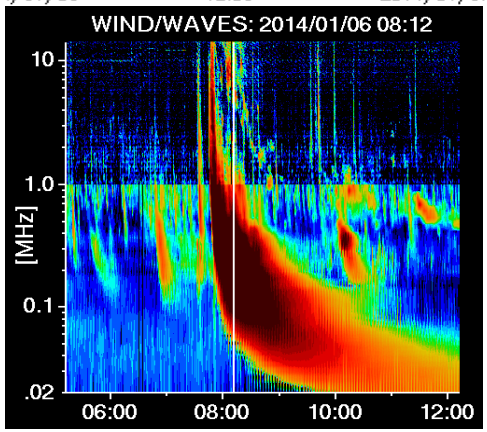
SOHO LASCO
CME CATALOG

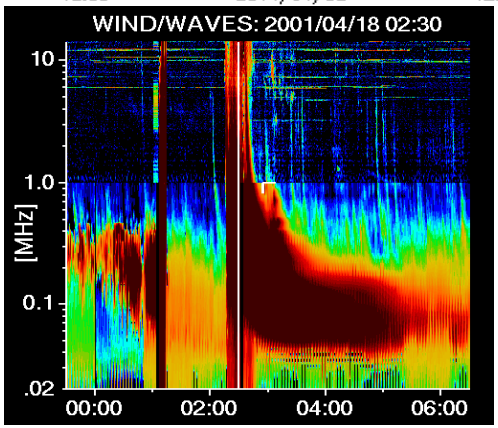
cdaw.gsfc.nasa.gov/
CME_list/

Movies, plots,
& links:

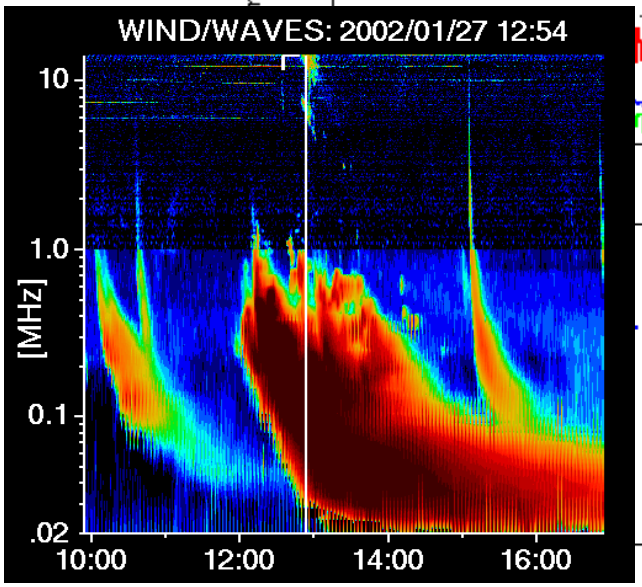
- PHTX
- Java Movie





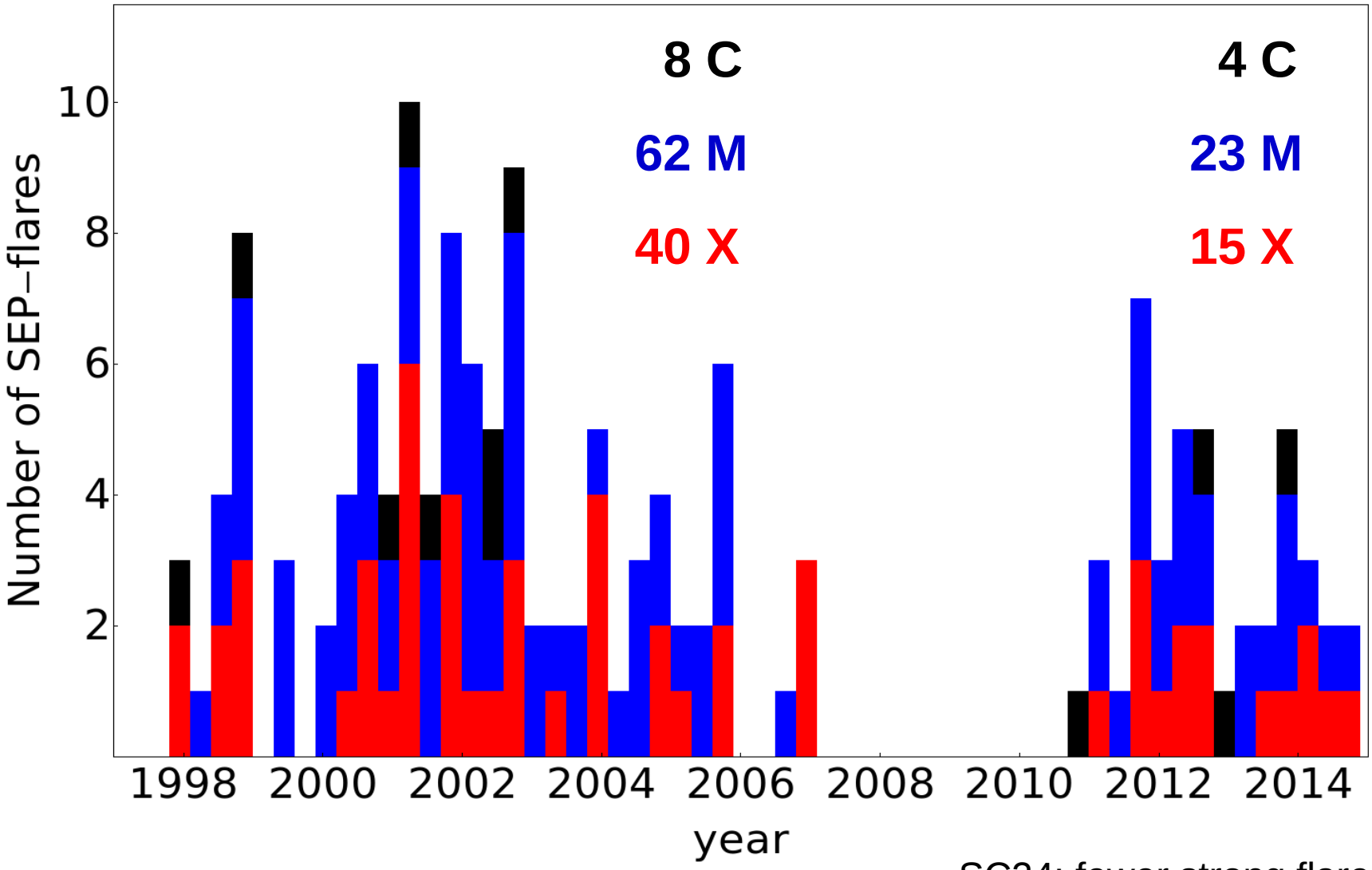


Association: SEP - occulted flare



new association: fewer C-class events

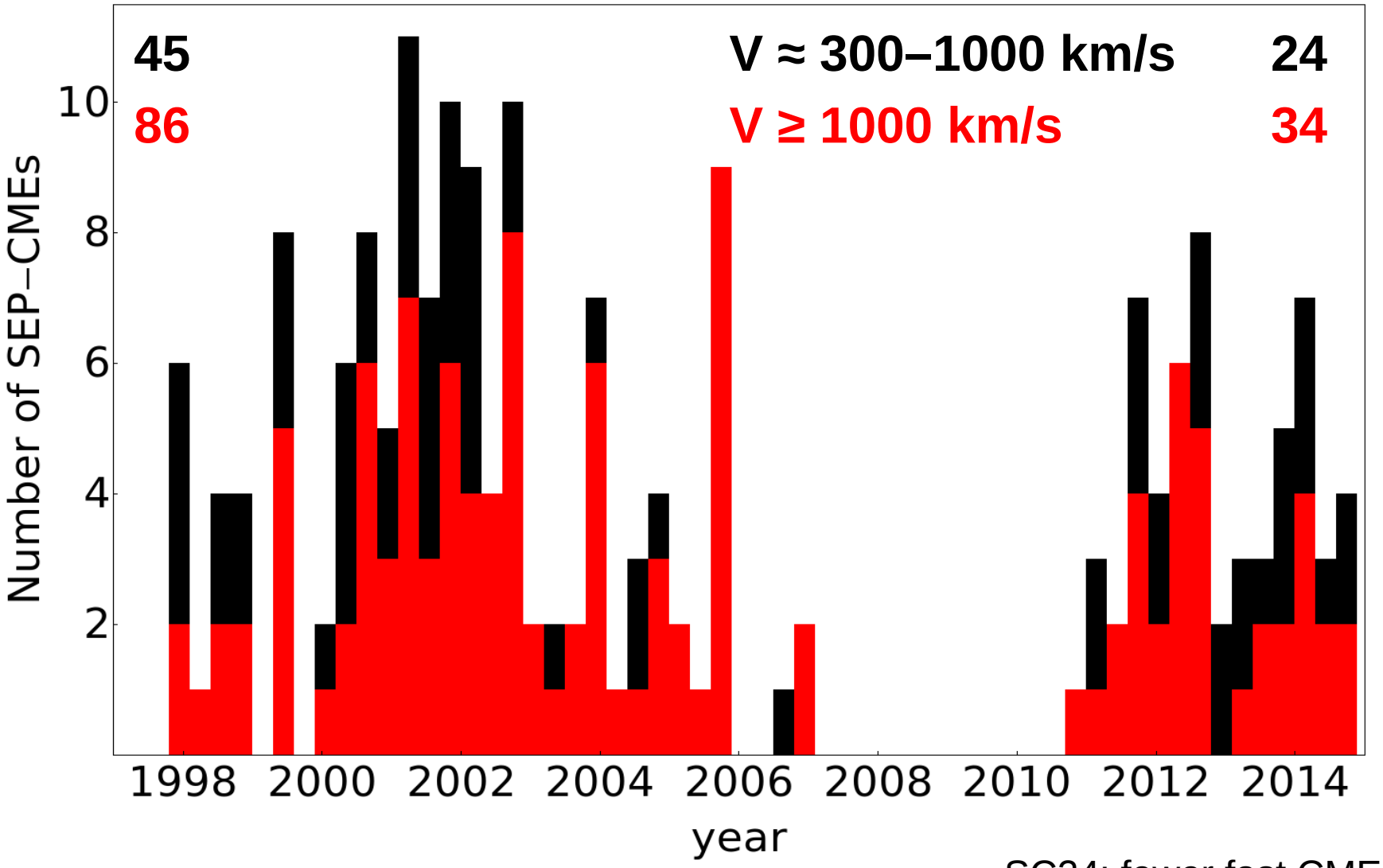
SEP-associated flares in SC 23 & 24 1/2



≡ length color bar

SC24: fewer strong flares

SEP-associated CMEs in SC 23 & 24$_{1/2}$



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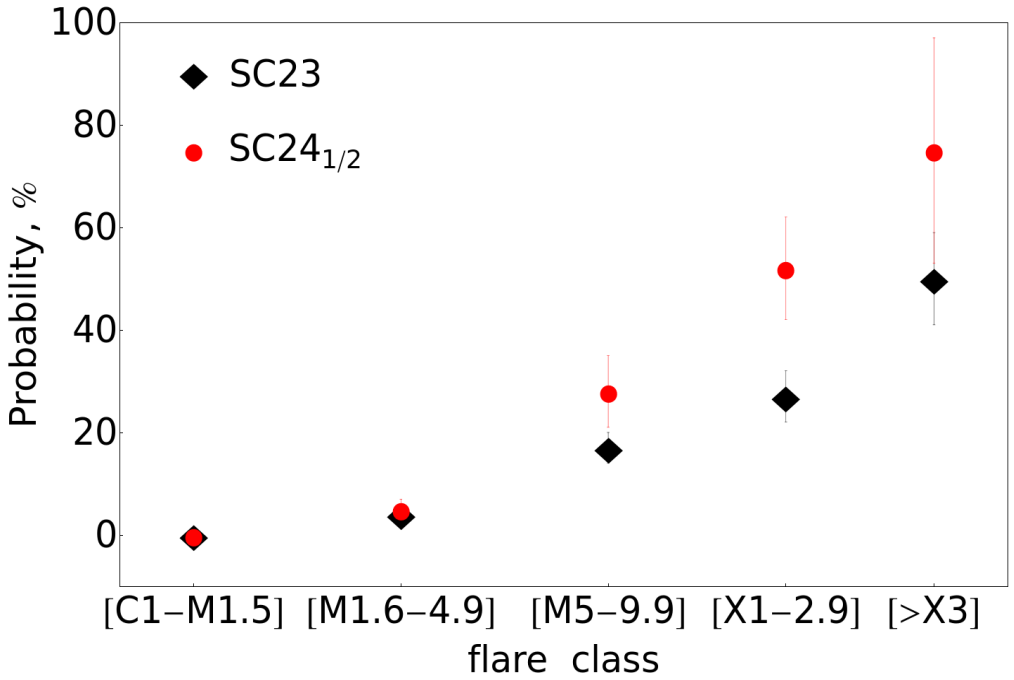
SC24: fewer fast CMEs

Occurrence probabilities



Probabilities (P) =

$$\frac{\#\text{SEP-assoc. flares/CMEs}}{\#\text{flares/CMEs}}$$

Error =

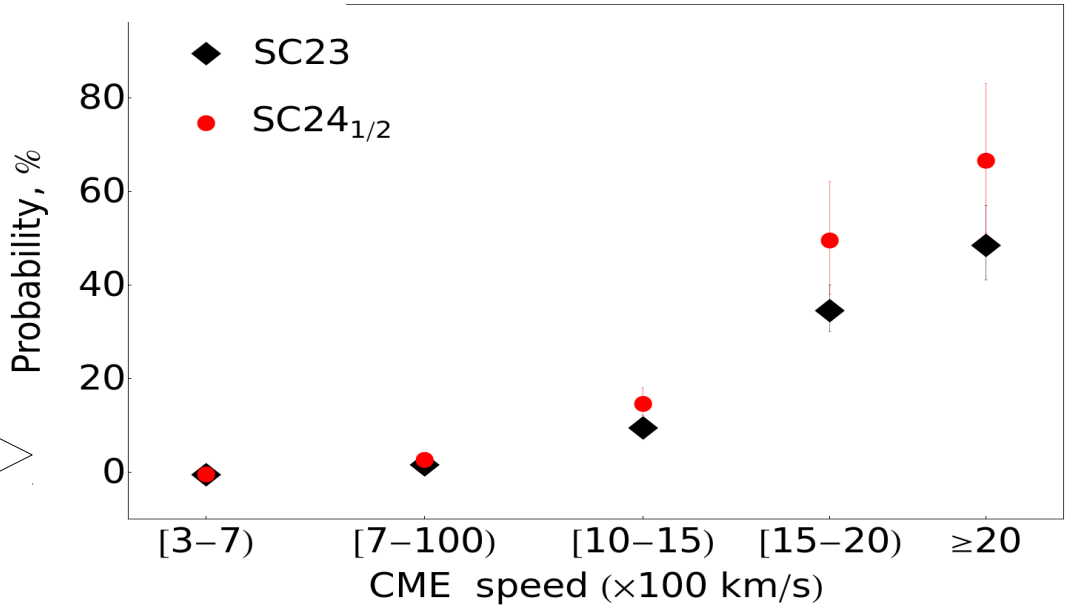
$$\frac{P\,(1 - P)}{\#\text{flares/CMEs}}$$

flares within a class bin to give SEPs

- up to **50–75%** for large flares

CMEs within a velocity bin to give SEPs

- up to **50-67%** for fast CMEs



SXR fluence Φ_{SXR}

- integrated SXR flux (from 1–8 Å GOES) with time (J/m^2)

  onset-to-end + proxy

  onset-to-peak + proxy (rise time . flare class)

→ all give similar c.c. within the uncertainties

Trottet et al. (2015):
fluence (opposite to flare class) and CME speed are statistically significant SEP activity parameters

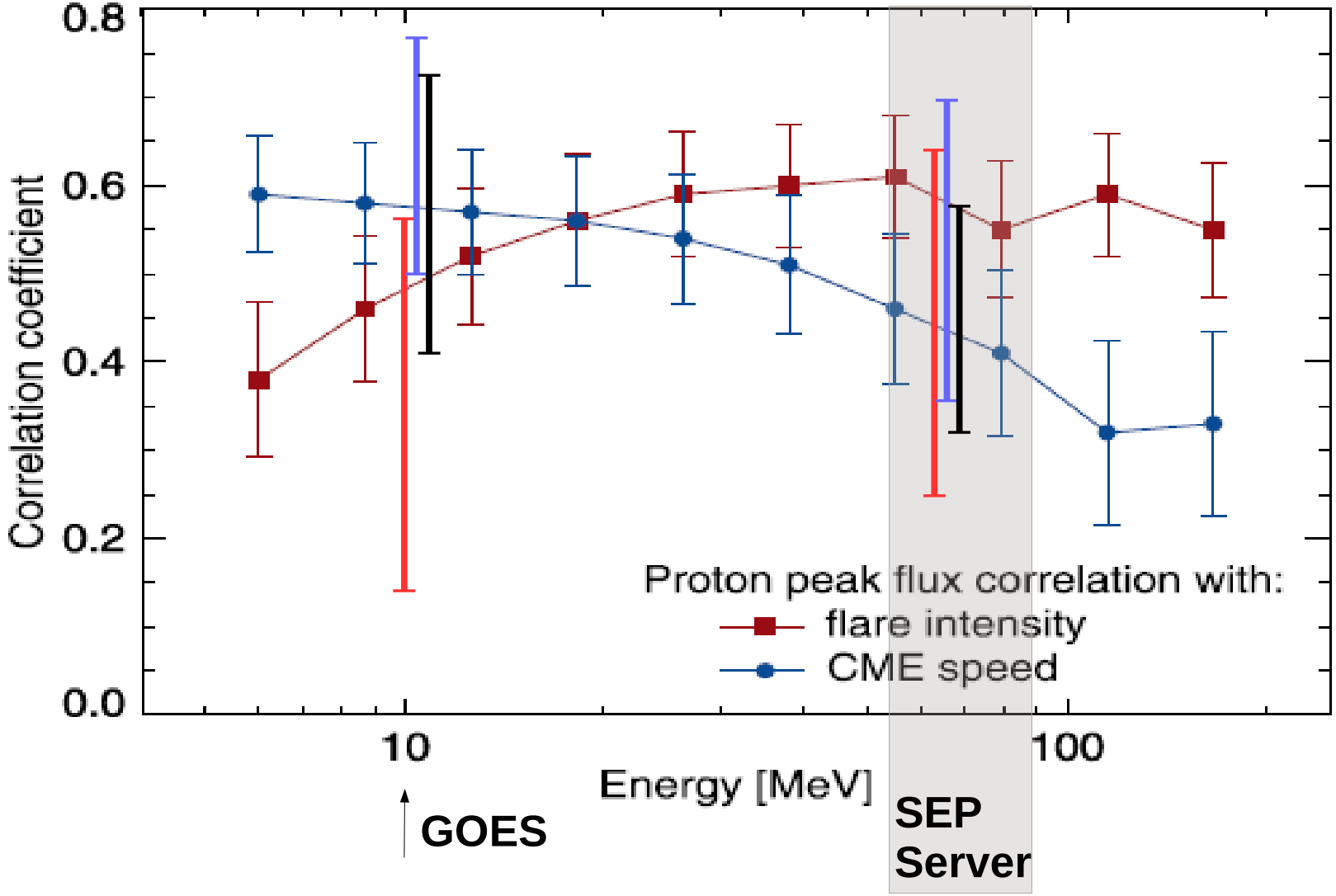
Correlations: linear

Correlation coefficient	SC 23	SC $24_{1/2}$	SC $23\&24_{1/2}$
SEPServer	*(114)*	*(54!)*	*(168)*
$J_p - V_{CME}$	0.40 ± 0.08	↑0.56 ± 0.09	0.45 ± 0.06
$J_p - I_{SXR}$	0.53 ± 0.07	↓0.33 ± 0.12	0.47 ± 0.06
$J_p - \Phi_{SXR}$	0.49 ± 0.08	0.44 ± 0.12	0.48 ± 0.07
GOES+ list	*(126)*	*(57!)*	*(183)*
$J_p - V_{CME}$	0.52 ± 0.06	↑0.66 ± 0.07	↑0.57 ± 0.05
$J_p - I_{SXR}$	0.43 ± 0.08	↓0.24 ± 0.14	↓0.39 ± 0.07
$J_p - \Phi_{SXR}$	0.48 ± 0.07	0.64 ± 0.09	0.52 ± 0.06

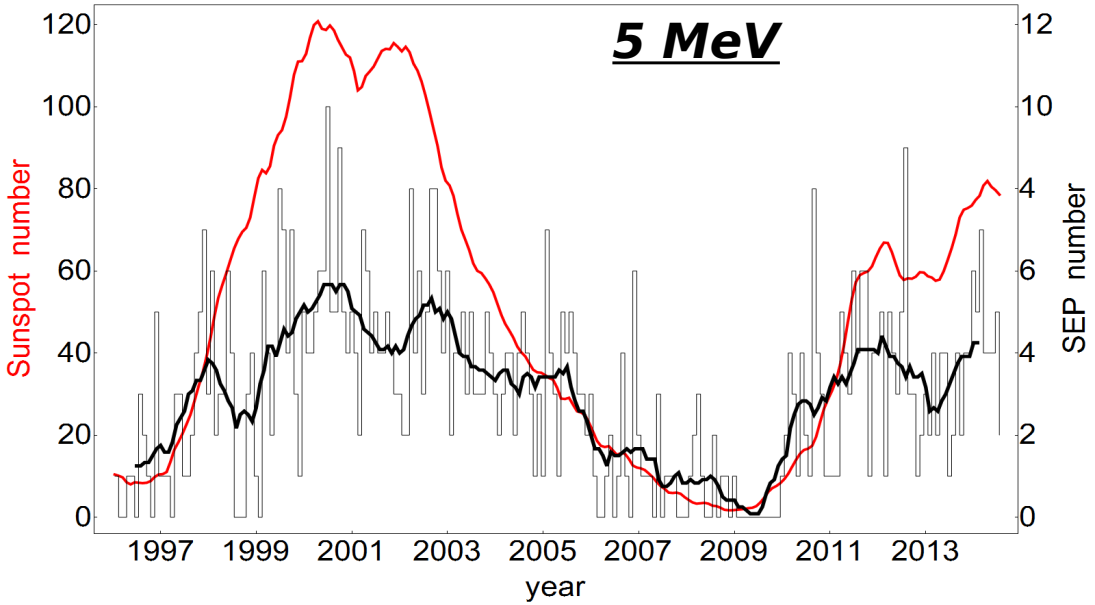
(uncertainties: Wall & Jenkins 2003)

Correlations: linear

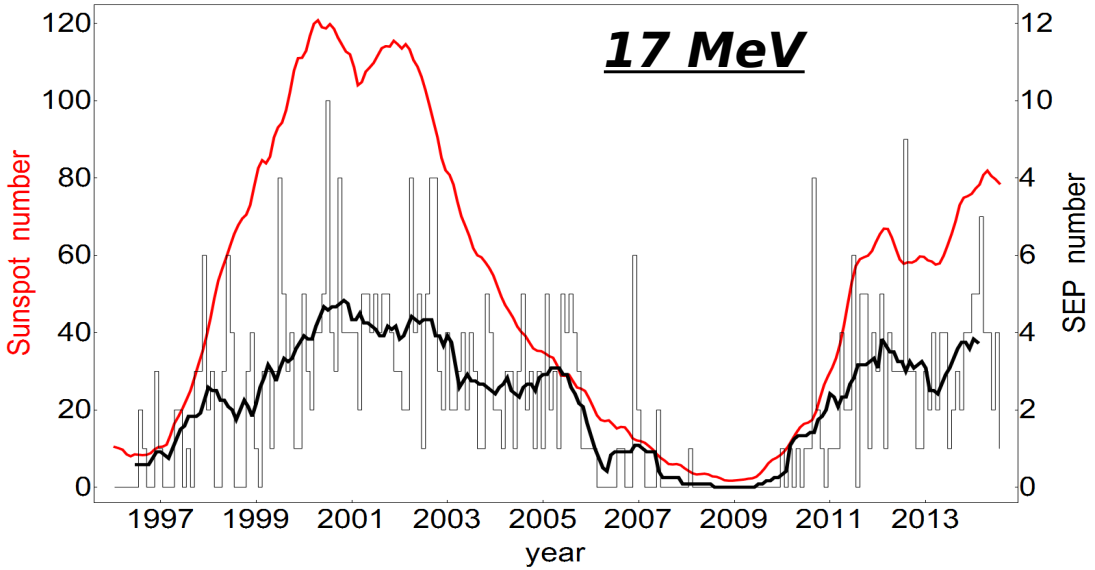
Dierckxsens et al. (2015) energy dependence on c.c.
(background plot: SC23)



SOHO proton list (preliminary results)



 # SEPs SC 23 : ~470
 # SEPs SC 24$_{1/2}$: ~220



 # SEPs SC 23 : ~350
 # SEPs SC 24$_{1/2}$: ~150

Remarks & outlook

on the origin of particle events

- subjectivity while associating flare/CME
- instrument-dependence
- energy-dependence

Caution while choosing & working with SEP-catalogs!

- interplanetary conditions

not considered/ no simple proxy

- new flare and CME parameters for correlation studies (fluence...)
- large statistics: need for more events in SC24 to compare with SC23!
- uncertainty range of correlations
- prediction tools & more: **HESPERIA 2020** project