Solar energetic particles and accompanied solar phenomena: Statistical studies in solar cycle 23 and rising half of solar cycle 24

Rositsa Miteva
Space Research and Technology Institute – Bulgarian Academy of Sciences
rmiteva@space.bas.bg

Collaborators
K.-L. Klein (France); S.W. Samwel (Egypt); M.V. Costa-Duarte (Brazil);
A. Veronig, M. Temmer, I. Kienreich (Austria);
A. Nindos, A. Kouloumvakos, O. Malandraki (Greece);
H.A.S. Reid (UK)

Main topics

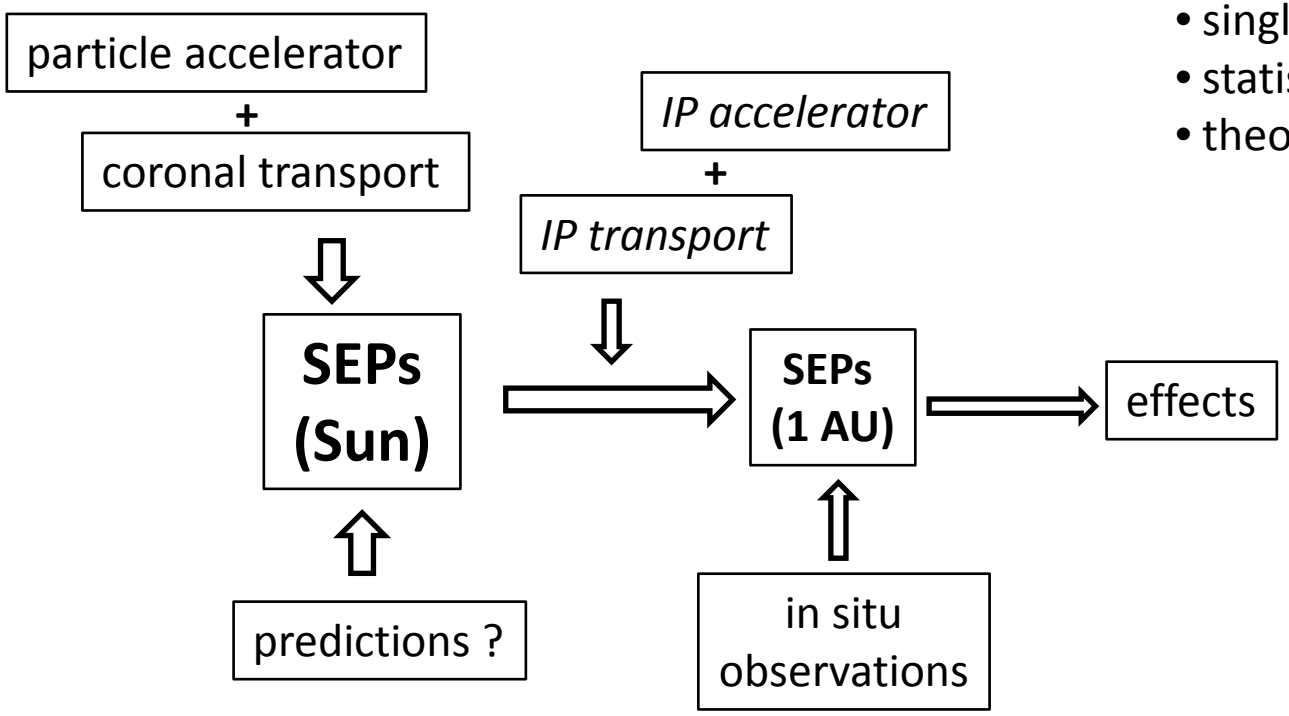
I. **SEP origin: flare vs. CME**
II. **SEP correlations and interplanetary conditions**
III. **SEPs and radio burst diagnostics**
IV. **Outlook to solar cycle 24**

UN/Japan Workshop on Space Weather, Fukuoka, 3 March 2015

I. SEP events: intensity enhancements of charged particles

- SEP importance: space weather agent, prediction?
- follow solar activity, stronger western preference
- near Earth perspective, single point measurement vs. STEREO and out-of-ecliptic view
- bi-modal (Reames 1999…) vs. plateau-like (Cane et al. 2010, Klein & Posner 2005…) distribution of SEP characteristics

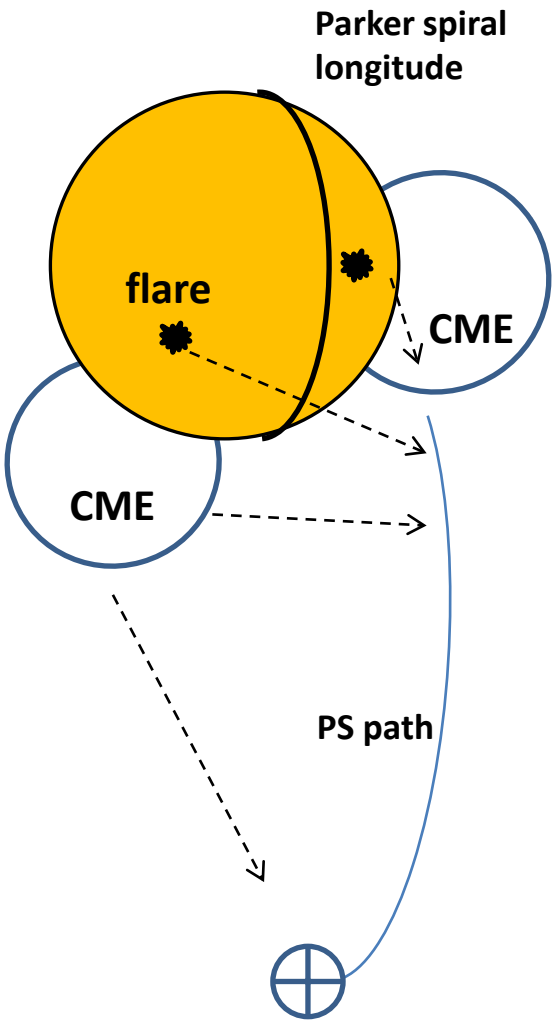
- ***Tentative scheme***



SEP study approach

- single event observations
- statistical studies
- theoretical modeling

I. On the solar origin of SEP events: flares and CMEs



Observational limitations

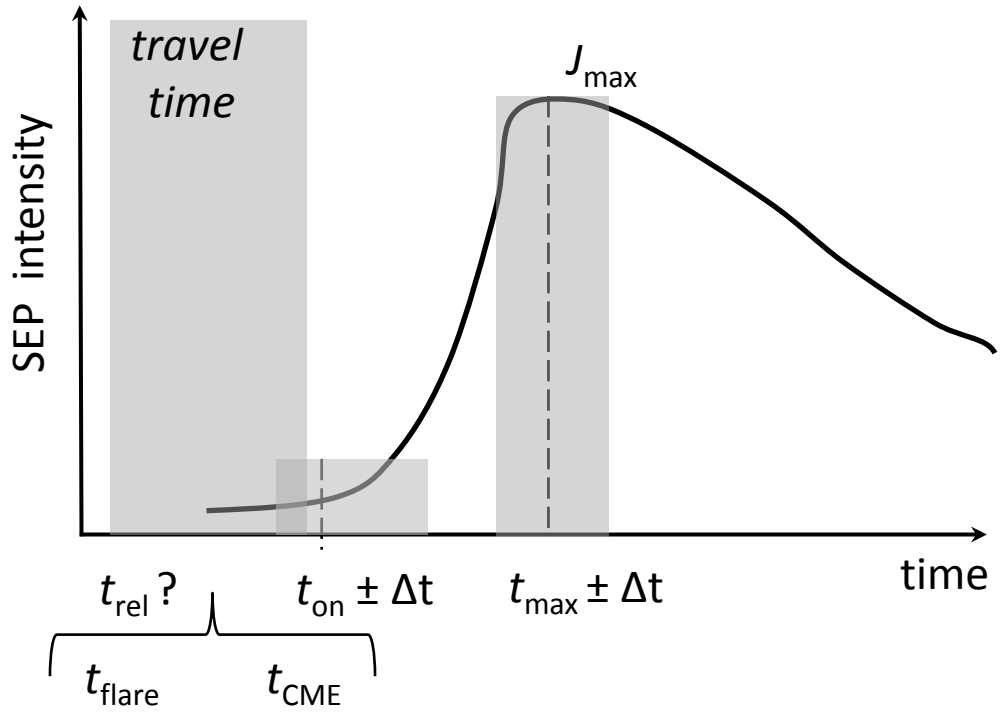
Time profile (peak SEP intensities vs. time) at 1 AU

→ particle release at the Sun

(proxy for scatter-free propagation along PS)

→ SEP origin

(occurrence, timing, phys. properties of flares and CMEs)



SEP event lists in solar cycle 23 (1997–2008)

Cane et al. (2010): 1997–2006, ~280 proton events > 25 MeV

Laurenza et al. (2009): 1995–2005, ~90 proton events > 10 MeV

Vainio et al. (2013): 1997–2006, ~115 proton events ~68 MeV

Dierckxsens et al. (2015): 1997–2006, ~90 proton events ~ 10 MeV

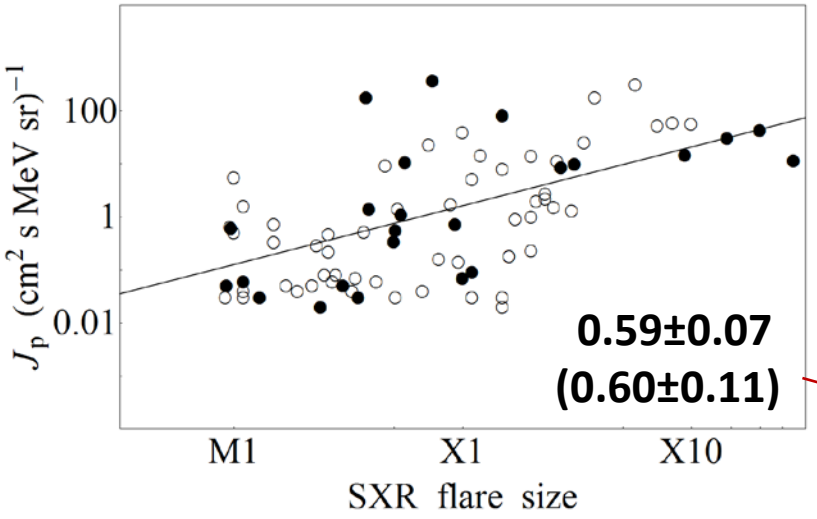
GOES proton list + many other partial coverage lists…

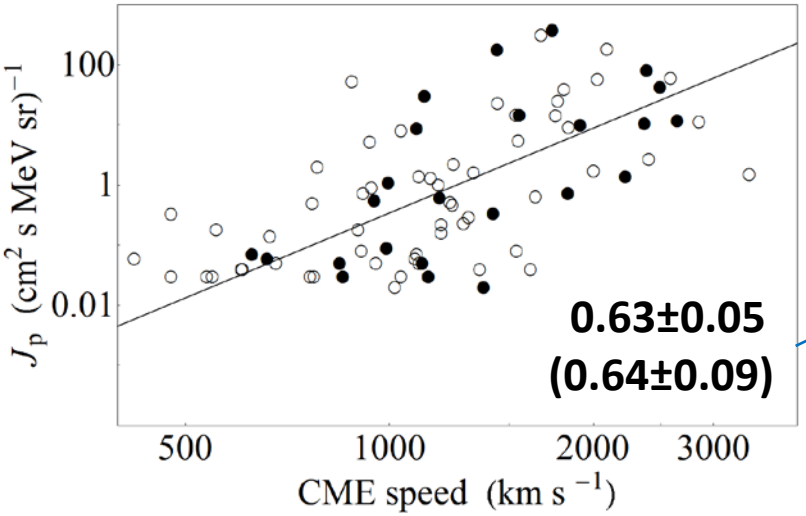
→ at different energies, instruments…
→ SEP time, intensity and associated flares/CMEs/radio emissions
→ linear correlation coefficients between SEP intensity and flare/CME properties

SEP origin from correlation studies:
J_{max} vs. SXR flare size (fluence)/CME speed (AW): **too simplistic!**

II. SEP correlation analysis: looking at the entire SEP sample

Miteva, Klein, Malandraki and Dorian (2013)



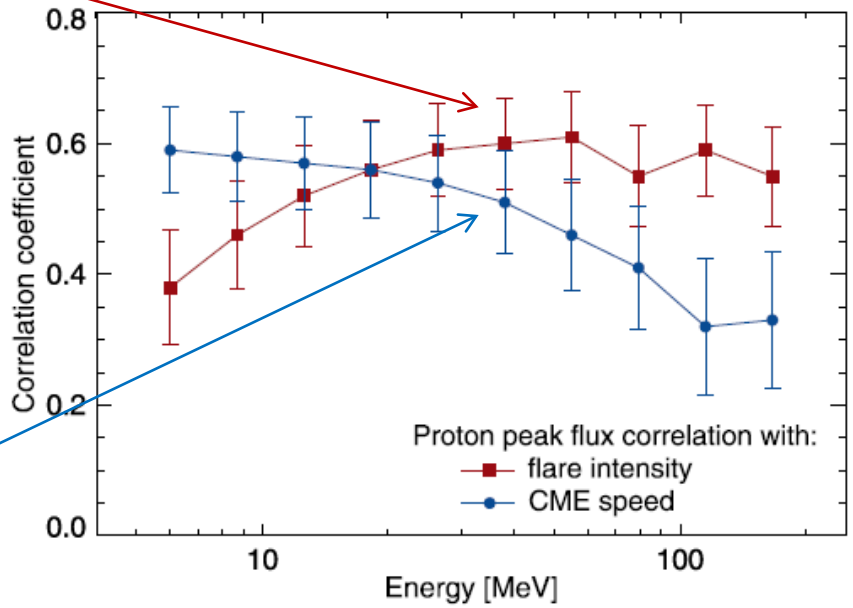


GOES protons 15–40 MeV
open circles: western events
(filled circles: limb events > W60)

Other studies

Cane et al. (2010) cc = 0.6 for both
Gopalswamy et al. (2003) cc = 0.6 (CME) , cc = 0.4 (flare)
Kahler (2001,1982) cc = 0.7 (CME), cc = 0.5 (flare)

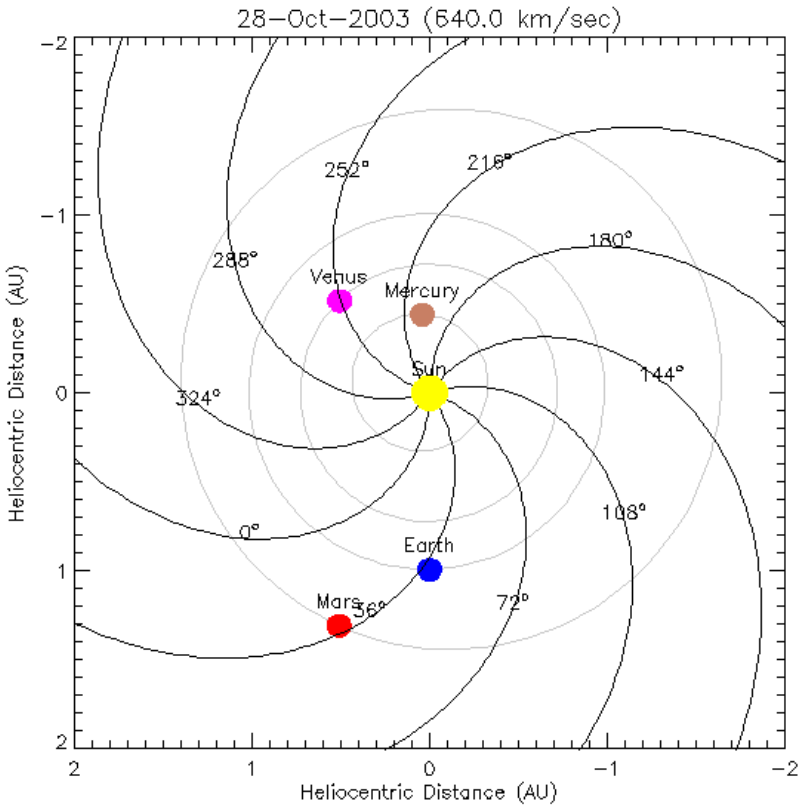
Dierckxsens et al. (2015)
energy dependence of cc



II. SEP correlation analysis: IP conditions as ordering parameter

‘quiet’ solar wind

plot: HELIOS service tool

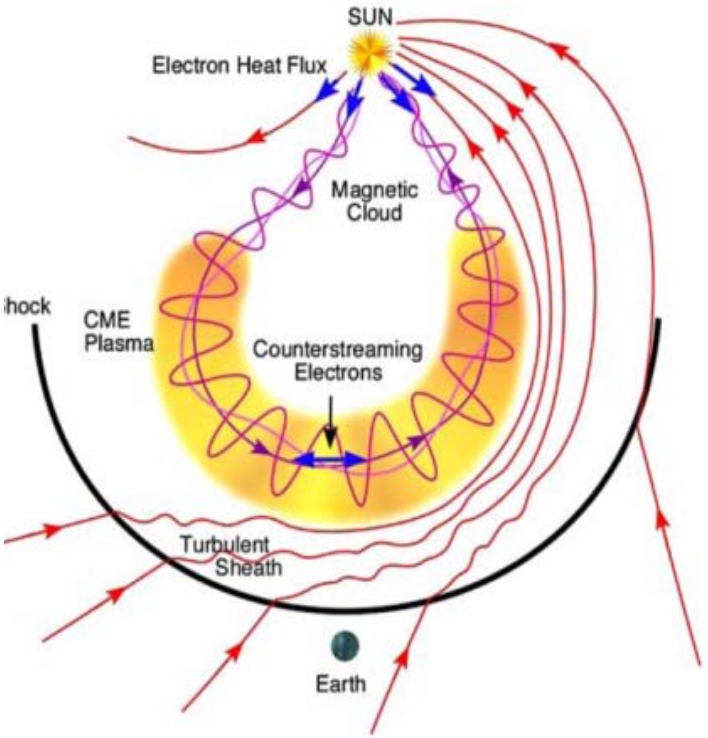


52% (68/132) West

71% (34/48) East

ICME disturbance

cartoon: Zurbuchen and Richardson (2004)
catalog: Richardson and Cane (2010)



20% (27/132) West

17% (8/48) East

+ rest: SEPs in the vicinity of ICMEs

II. SEP correlation analysis: ICME vs. quiet solar wind

• SEP peak intensity vs. SXR flare size
→ higher cc for protons/electrons propagating in ICME compared to solar wind conditions (but the trend is lost for the limb proton cases)

• SEP peak intensity vs. CME linear speed
→ no dependence on IP conditions

others: Kahler and Vourlidas (2014)…
+ other ordering parameters: seed particles; interacting CMEs

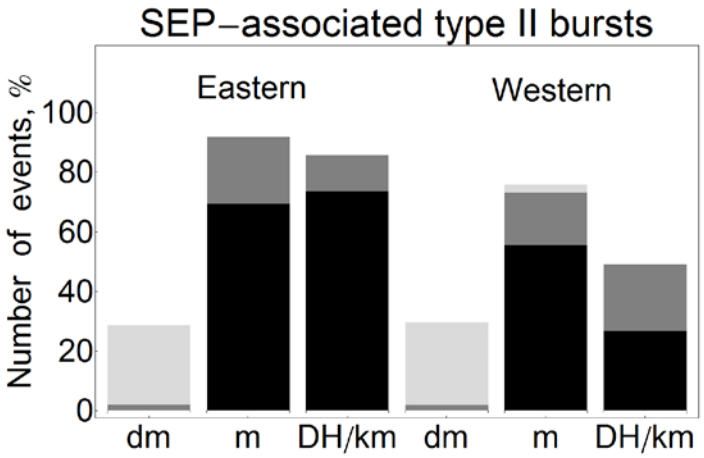
Bias and limitations of the <u>statistical approach</u>

• use of simplistic relations to characterize acceleration (efficiency and time evolution?)
• projection effects (CME speed)
• small number of SEP events (large uncertainties of the cc)
• different trends for electrons and protons (for similar time profiles)
• blurring effect in the correlations: time-dependent acceleration, unknown particle injection profile and efficiency, coronal and IP transport effects…

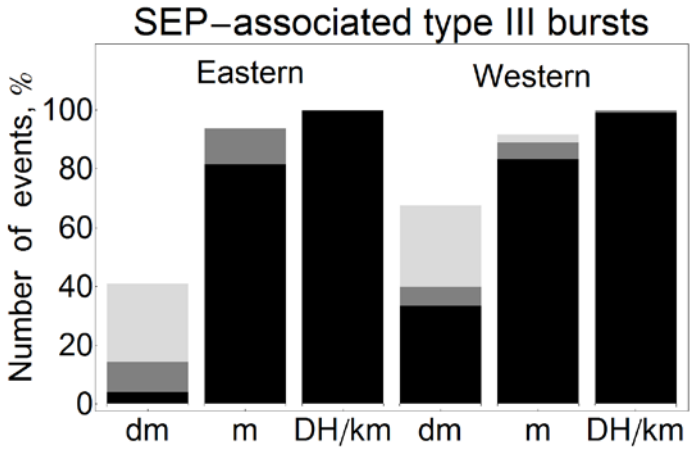
→ not a suitable method to <u>clearly</u> discriminate the particle accelerator

III. Radio emission: alternative indicator for the SEP origin

Shock signature



Electron beams signature



→ counting radio bursts

~180 particle events (~70% western) associated with ≥ C9 flares, located ±90°

Miteva et al. CEAB (2013) Eastern+Western SEPs	*Other results*
• **~75% with DH-IIs**	*63% Cliver et al. 2004*
	100% Gopalswamy 2003
~80% with m-IIs	*82% Cliver et al. 2004*
• **~100% with DH-IIIs**	*~90% MacDowall et al. 2003*
~90% with m-IIIs	*100% Cane et al. 2002*
~40% with dm-IIIs	

black – dynamic radio spectra
dark gray – observatory reports only
light gray – data gap

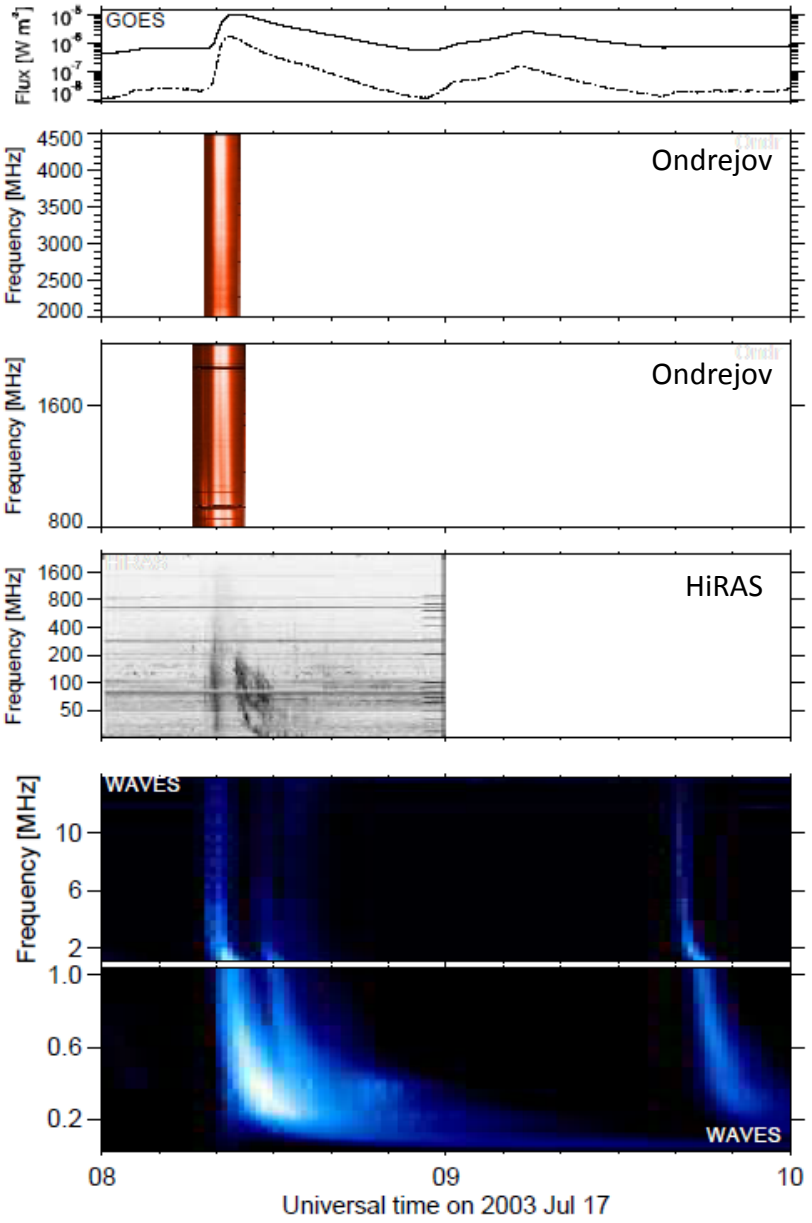
III. Radio emission: alternative indicator for the SEP origin

→ timing the radio bursts

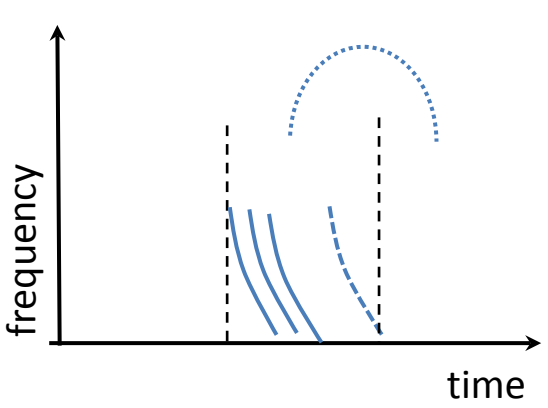
μ-waves
radio signatures
from flares
→ low corona
> few GHz
(RSTN data)

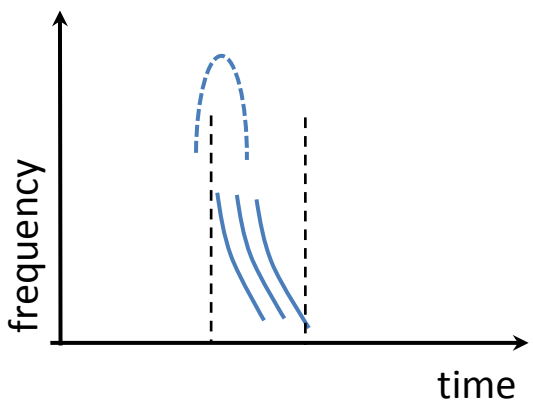
DH type III bursts
radio emission from
escaping particles
→ high corona to IP space
1–14 MHz
(WAVES RAD2 range)

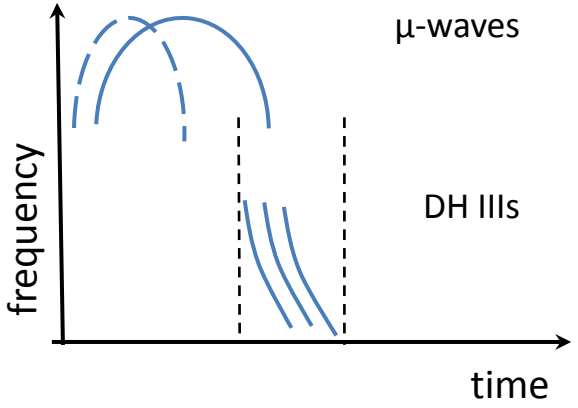
database:
Composite radio spectra of SEP events
http://previ.obspm.fr/RSP

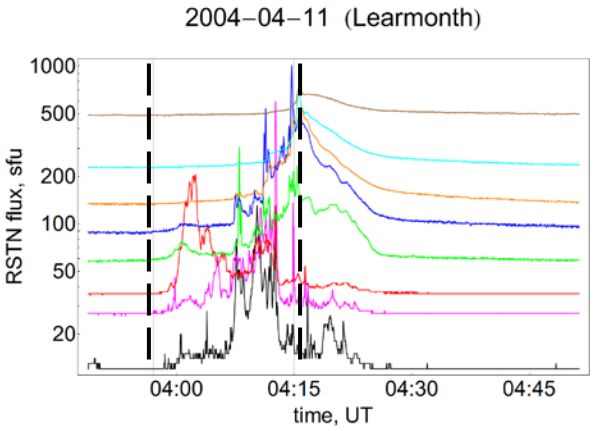


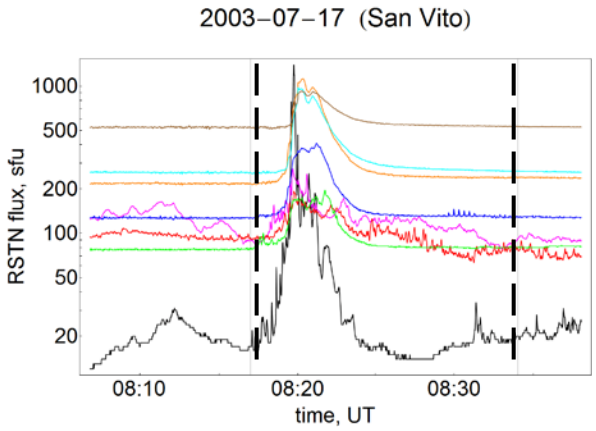
Miteva, Klein, Samwel, Reid, Nindos, Kouloumvakos, in prep. (~130 events)

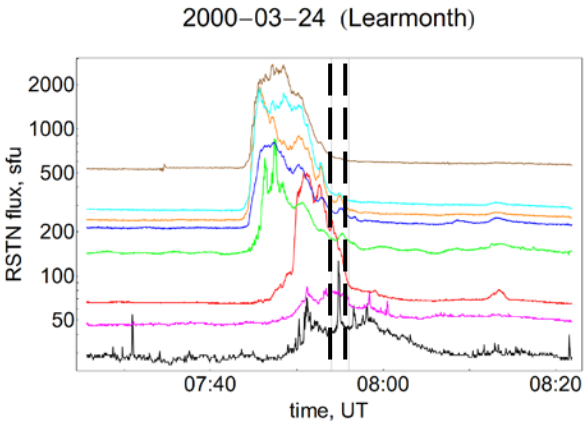












CME related particles
with late flare contribution
(if any)

~35%

Flare related particles
with simultaneous/late
CME contribution

~50%

CME related particles
with flare confinement
(no flare component)

~15%

IV. Looking into solar cycle 24 (2009–present): SEP event lists

GOES: ~35 events (http://umbra.nascom.nasa.gov/SEP/seps.html)

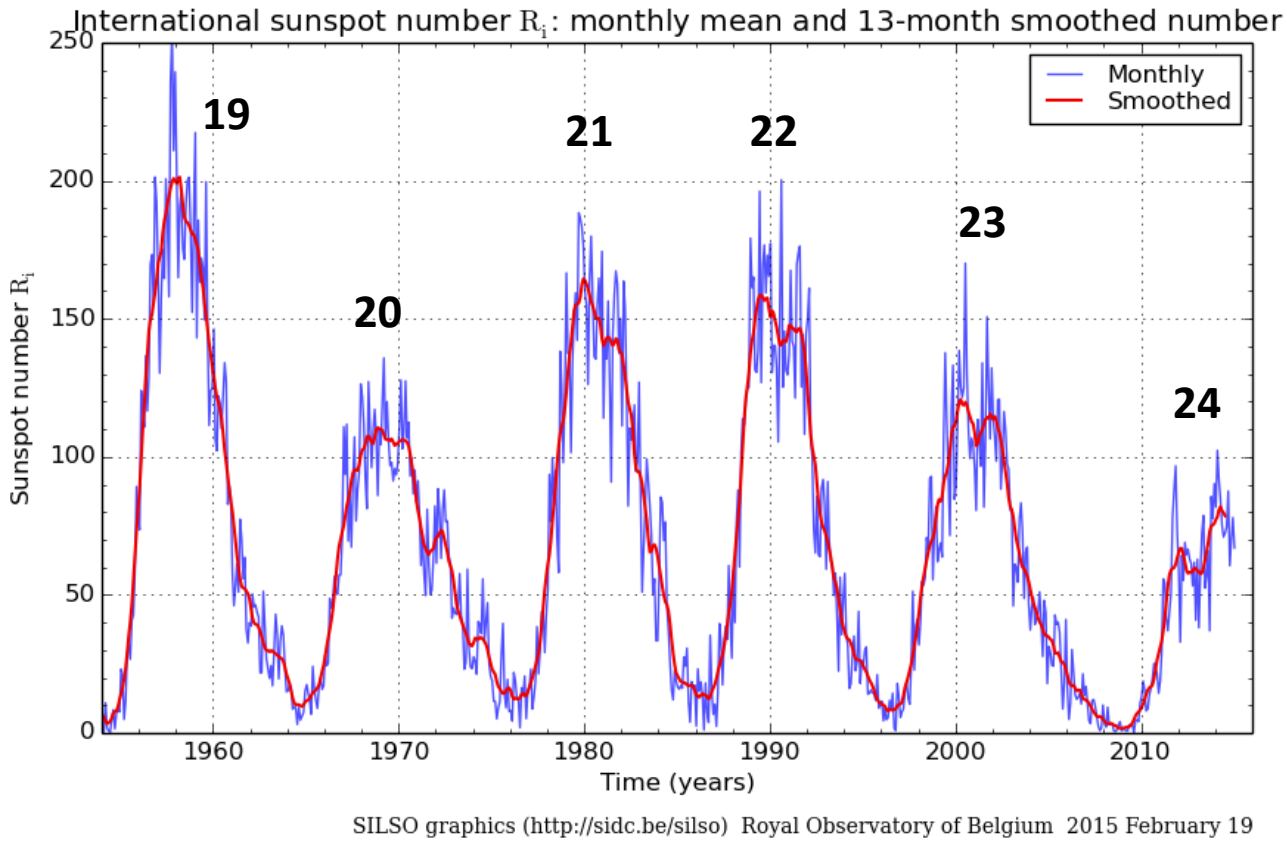
STEREO: Richardson et al. (2014) & Papaioannou et al. (2014)

~210 (2006–2013) ~200 (2007–2012)

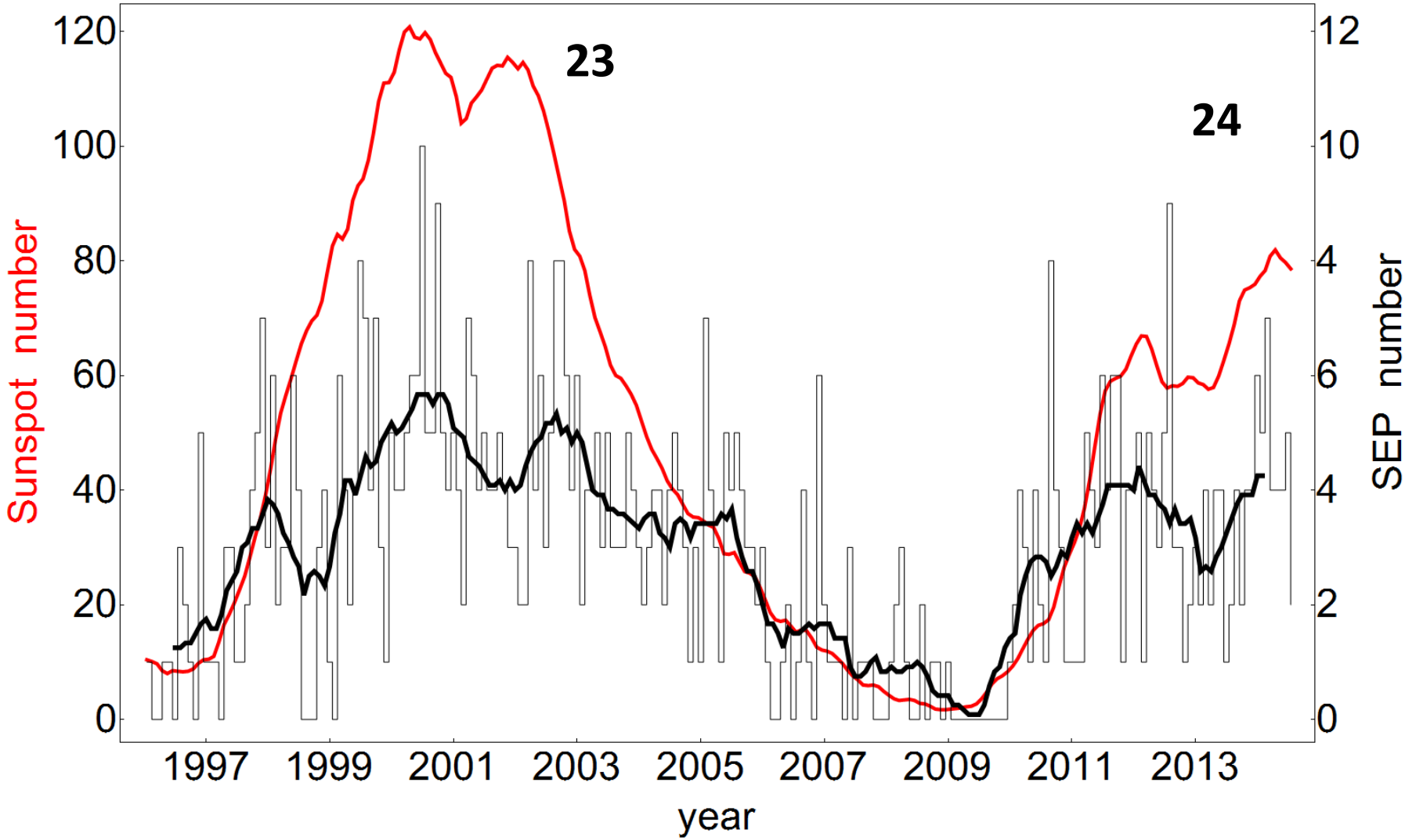
SOHO:

SEPServer (http://server.sepserver.eu/index.php)

Miteva, Samwel and Costa-Duarte: preliminary
(http://www2.physik.uni-kiel.de/SOHO/phpeph/EPHIN.htm)



Sunspots and SOHO proton events <u>>5 MeV</u> in SC 23 and rising half of SC 24

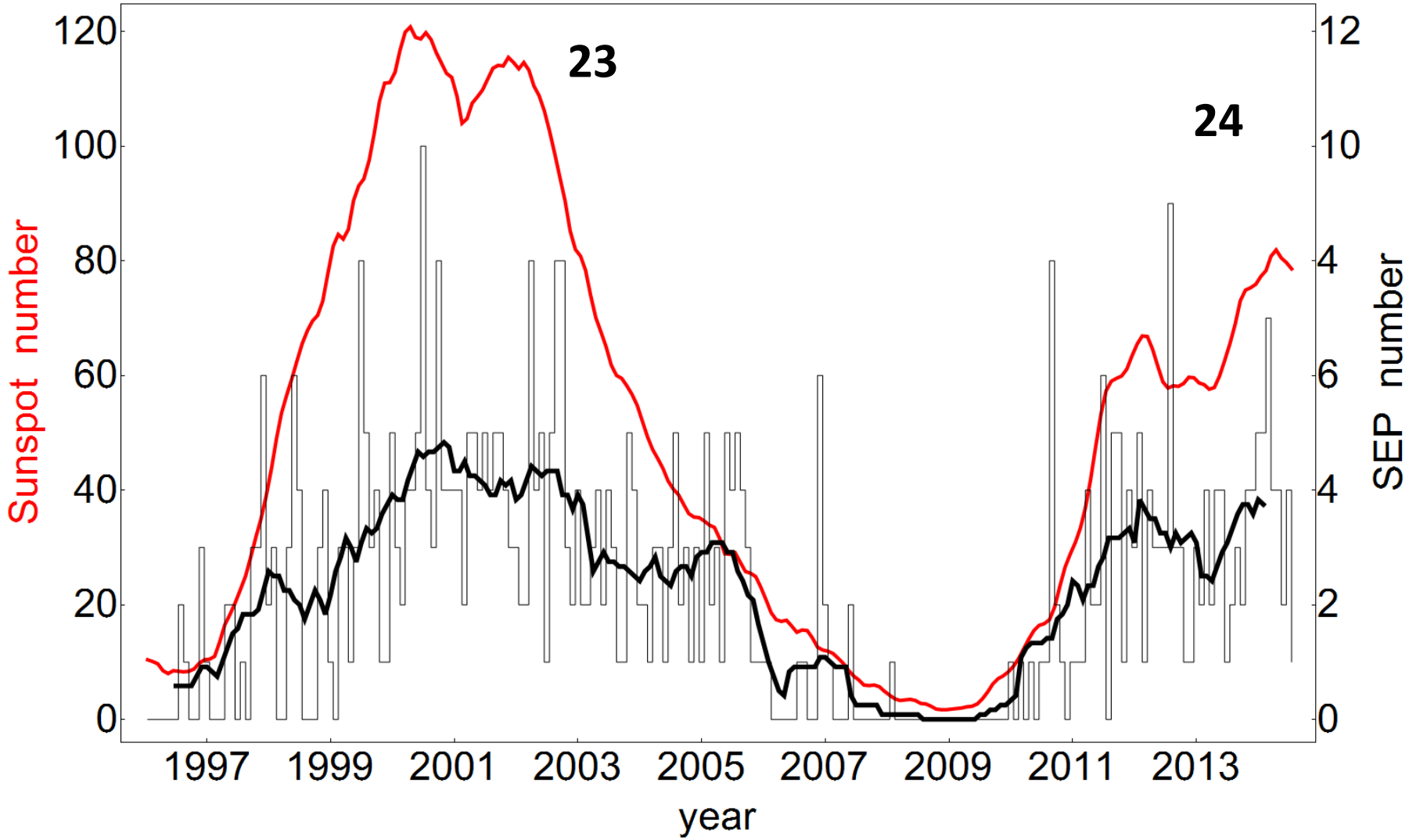


 # SEPs SC 23 (1996–2008): ~470 **# SEPs SC24/2 (2009–2014): ~220**

median: 3/month

Miteva, Samwel and Costa-Duarte (preliminary results)

Sunspots and SOHO proton events <u>>17 MeV</u> in SC 23 and rising half of SC 24



 # SEPs SC 23 (1996–2008): ~350 **# SEPs SC24/2 (2009–2014): ~150**

median: 2/month

Miteva, Samwel and Costa-Duarte (preliminary results)

Outlook

SEP studies

- Need: a comprehensive summary of recent observations and results
- New perspective: STEREO view
- New statistical approach: partial correlations
  (see S. Stefan talk on Friday 6th, 9:00)
- New phenomena: radio bursts, EUV waves
- New observations: going closer to the Sun
- More theory: modeling of different events

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- About
- Housing&Travel
- Practical Information
- Seventh Workshop
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  - Venue - Bellevue
  - Registration 2015
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  - View Abstracts
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- Fifth Workshop
- Fourth Workshop
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- First Workshop
- Earlier Workshops
- Other

Workshop **"Solar Influences on the Magnetosphere, Ionosphere and Atmosphere"**
shop "Solar Influences on the Magnetosphere, Ionosphere and Atmosphere" *Sozopol, Bulgaria* WS-Sozopol Wel

Welcome to: Welcome to Seventh Workshop

Solar Influences
on the Magnetosphere, Ionosphere and Atmosphere

Sunny Beach, Bulgaria, 1-5 June 2015

There are 91 days until the start of the Workshop

Important Deadlines
Registration: May 18, 2015 There are 77 days until the registration deadline
Abstract submission: May 18, 2015 There are 77 days until the abstracts deadline

Scientific Organizing Committee

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Topics:
- ✓ Sun and solar activity
- ✓ Solar wind-magnetosphere-ionosphere interactions
- ✓ Solar influences on the lower atmosphere and climate
- ✓ Solar effects in the biosphere
- ✓ Instrumentation for space weather monitoring
- ✓ Data proccessing and modelling

Presentations:
Oral presentations: 20 min, followed by discussion;
Poster presentations: poster area 1 x 1.50 m.

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БАН ИКИТ

Thank you for your attention!