Solar energetic particles and space weather

ROSITSA MITEVA

rmiteva@space.bas.bg

Space Research and Technology Institute – Bulgarian Academy of Sciences

The International Workshop "Eruptive energy release processes on the Sun and stars: origins and effects", 10–12 October 2018, Irkutsk, Russia

Contents (observer's perspective)

✓ Particle observations in the heliosphere: trends, SC/longitudinal/latitudinal-dependencies; instrumental effects

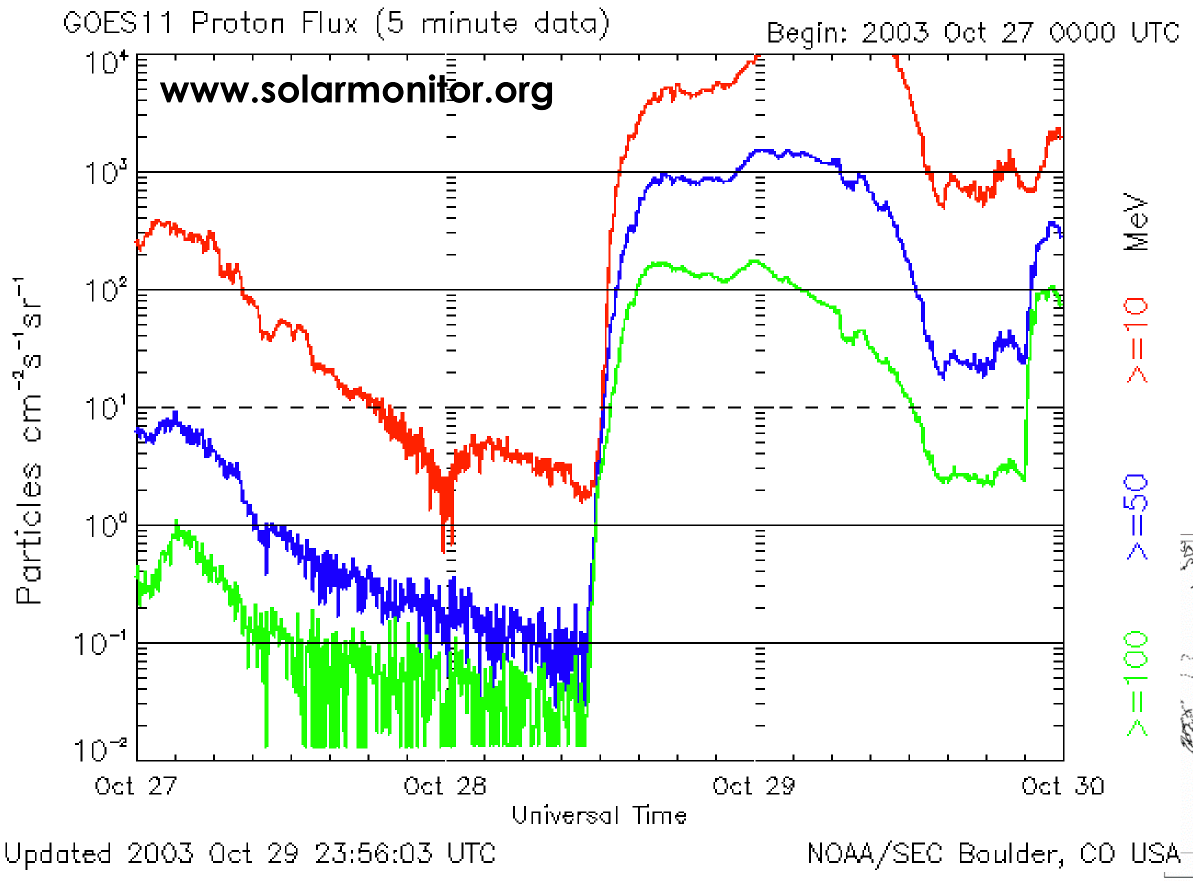
✓ Solar origin associations: procedures and subjectivities

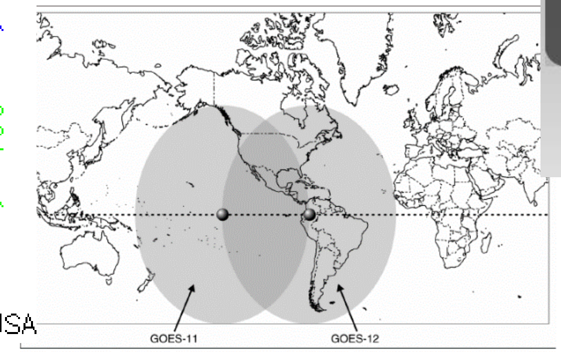
✓ Catalogs: protons and electrons

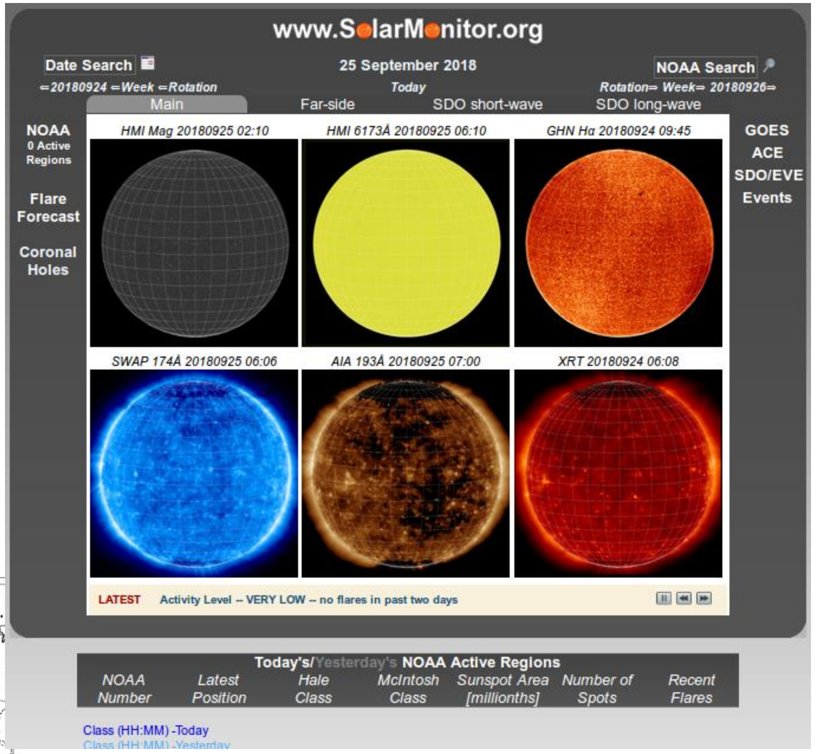
X Detectors, theory, numerical simulations: acceleration, escape, transport, detection

¿ Forecasting (user's perspective)

Solar energetic particles (SEPs): In situ observations

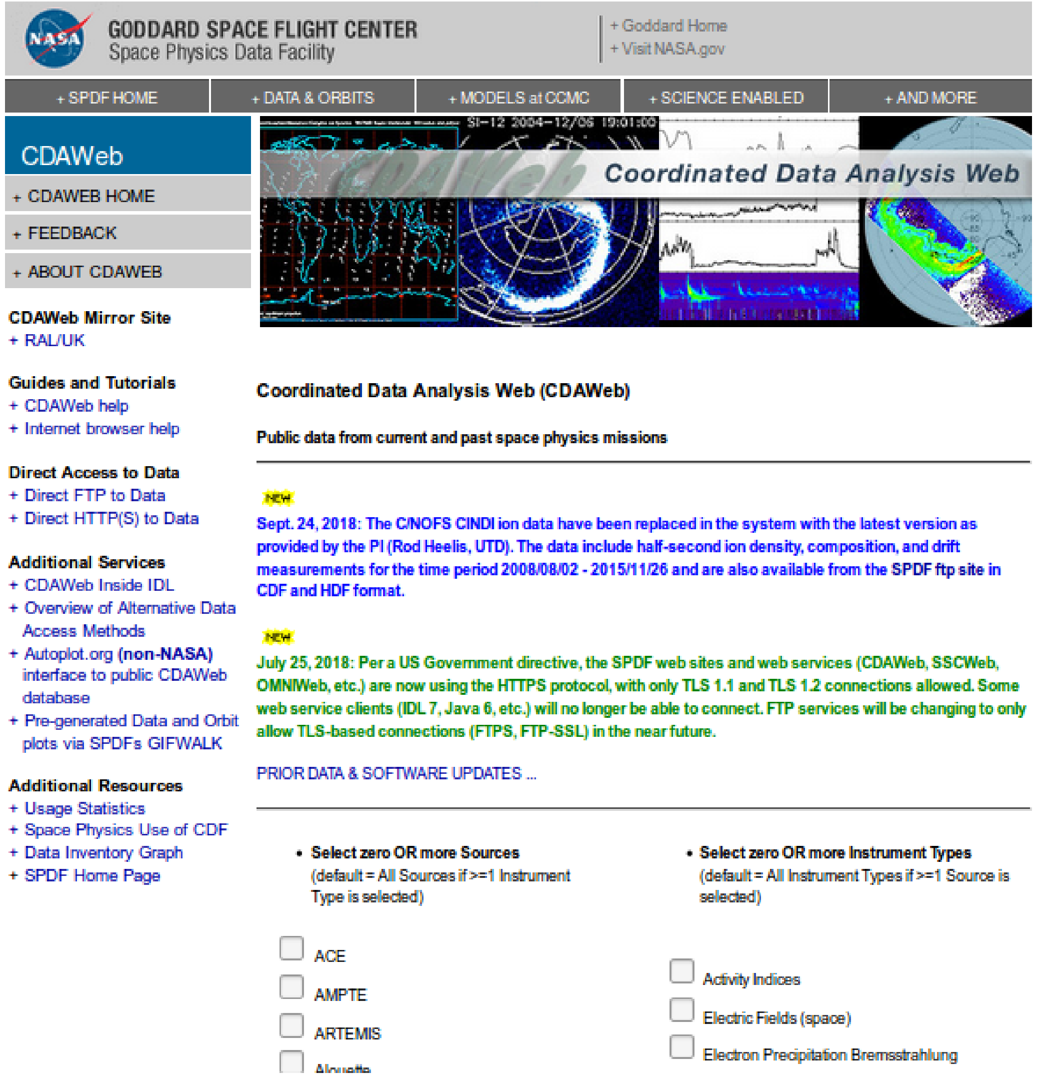






http://www.gpo.gov/fdsys/pkg/GAOREPORTS-GAO-07-1099T/pdf/GAOREPORTS-GAO-07-1099T.pdf

Solar energetic particles (SEPs): Data sources & plotting



GODDARD SPACE FLIGHT CENTER
Space Physics Data Facility

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Coordinated Data Analysis Web

CDAWeb Mirror Site
+ RAL/UK

Guides and Tutorials
+ CDAWeb help
+ Internet browser help

Direct Access to Data
+ Direct FTP to Data
+ Direct HTTP(S) to Data

Additional Services
+ CDAWeb Inside IDL
+ Overview of Alternative Data Access Methods
+ Autoplot.org (non-NASA) interface to public CDAWeb database
+ Pre-generated Data and Orbit plots via SPDFs GIFWALK

Additional Resources
+ Usage Statistics
+ Space Physics Use of CDF
+ Data Inventory Graph
+ SPDF Home Page

Coordinated Data Analysis Web (CDAWeb)

Public data from current and past space physics missions

NEW
Sept. 24, 2018: The C/NOFS CINDI ion data have been replaced in the system with the latest version as provided by the PI (Rod Heelis, UTD). The data include half-second ion density, composition, and drift measurements for the time period 2008/08/02 - 2015/11/26 and are also available from the SPDF ftp site in CDF and HDF format.

NEW
July 25, 2018: Per a US Government directive, the SPDF web sites and web services (CDAWeb, SSCWeb, OMNIWeb, etc.) are now using the HTTPS protocol, with only TLS 1.1 and TLS 1.2 connections allowed. Some web service clients (IDL 7, Java 6, etc.) will no longer be able to connect. FTP services will be changing to only allow TLS-based connections (FTPS, FTP-SSL) in the near future.

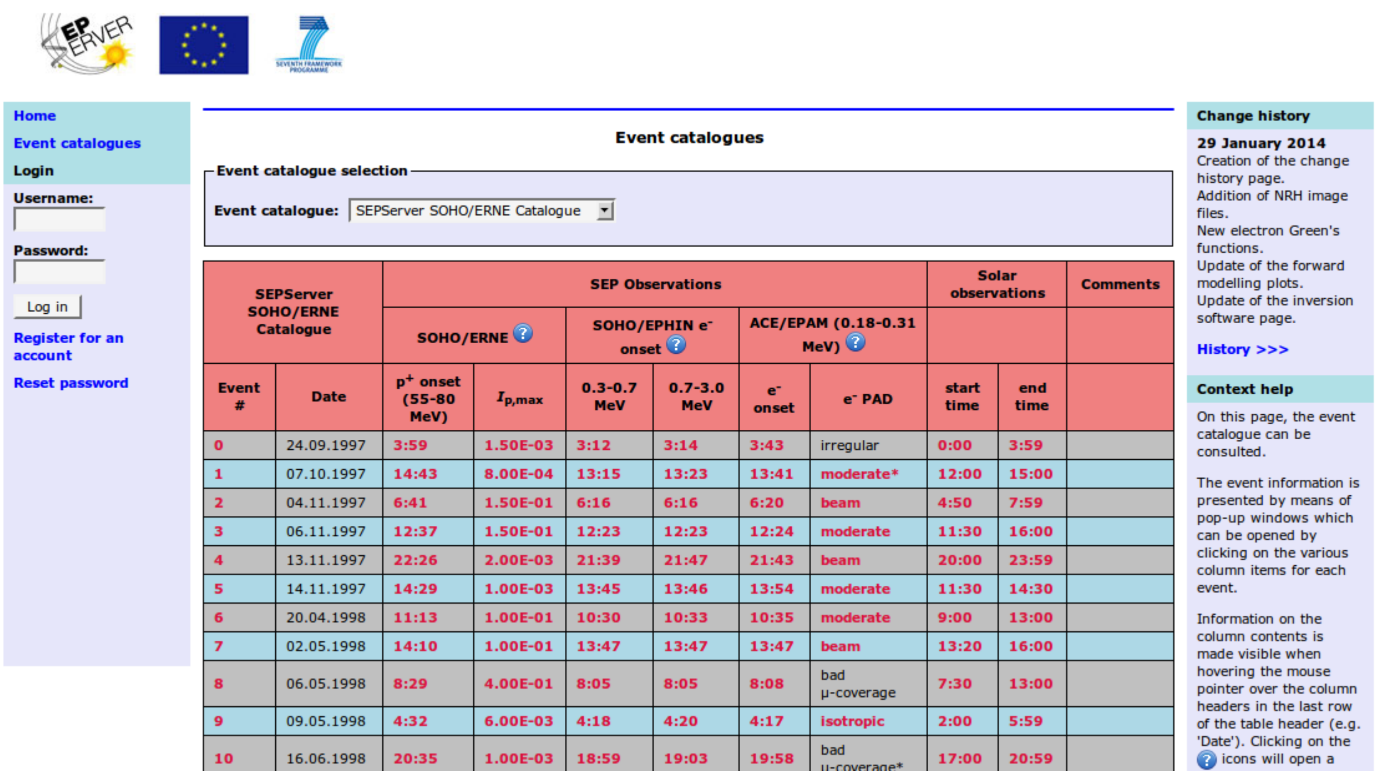
PRIOR DATA & SOFTWARE UPDATES ...

- Select zero OR more Sources (default = All Sources if >=1 Instrument Type is selected)
- Select zero OR more Instrument Types (default = All Instrument Types if >=1 Source is selected)

ACE
AMPTE
ARTEMIS
Alouette

Activity Indices
Electric Fields (space)
Electron Precipitation Bremsstrahlung

https://cdaweb.sci.gsfc.nasa.gov/



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Event catalogues

Event catalogue selection

Event catalogue: SEPServer SOHO/ERNE Catalogue

SEPServer SOHO/ERNE Catalogue		SEP Observations						Solar observations		Comments
		SOHO/ERNE		SOHO/EPHIN e⁻ onset		ACE/EPAM (0.18-0.31 MeV)				
Event #	Date	p^+ onset (55-80 MeV)	$I_{p,max}$	0.3-0.7 MeV	0.7-3.0 MeV	e^- onset	e^- PAD	start time	end time	
0	24.09.1997	3:59	1.50E-03	3:12	3:14	3:43	irregular	0:00	3:59	
1	07.10.1997	14:43	8.00E-04	13:15	13:23	13:41	moderate*	12:00	15:00	
2	04.11.1997	6:41	1.50E-01	6:16	6:16	6:20	beam	4:50	7:59	
3	06.11.1997	12:37	1.50E-01	12:23	12:23	12:24	moderate	11:30	16:00	
4	13.11.1997	22:26	2.00E-03	21:39	21:47	21:43	beam	20:00	23:59	
5	14.11.1997	14:29	1.00E-03	13:45	13:46	13:54	moderate	11:30	14:30	
6	20.04.1998	11:13	1.00E-01	10:30	10:33	10:35	moderate	9:00	13:00	
7	02.05.1998	14:10	1.00E-01	13:47	13:47	13:47	beam	13:20	16:00	
8	06.05.1998	8:29	4.00E-01	8:05	8:05	8:08	bad μ-coverage	7:30	13:00	
9	09.05.1998	4:32	6.00E-03	4:18	4:20	4:17	isotropic	2:00	5:59	
10	16.06.1998	20:35	1.00E-03	18:59	19:03	19:58	bad μ-coverage*	17:00	20:59	

Change history

29 January 2014
Creation of the change history page.
Addition of NRH image files.
New electron Green's functions.
Update of the forward modelling plots.
Update of the inversion software page.

History >>>

Context help

On this page, the event catalogue can be consulted.

The event information is presented by means of pop-up windows which can be opened by clicking on the various column items for each event.

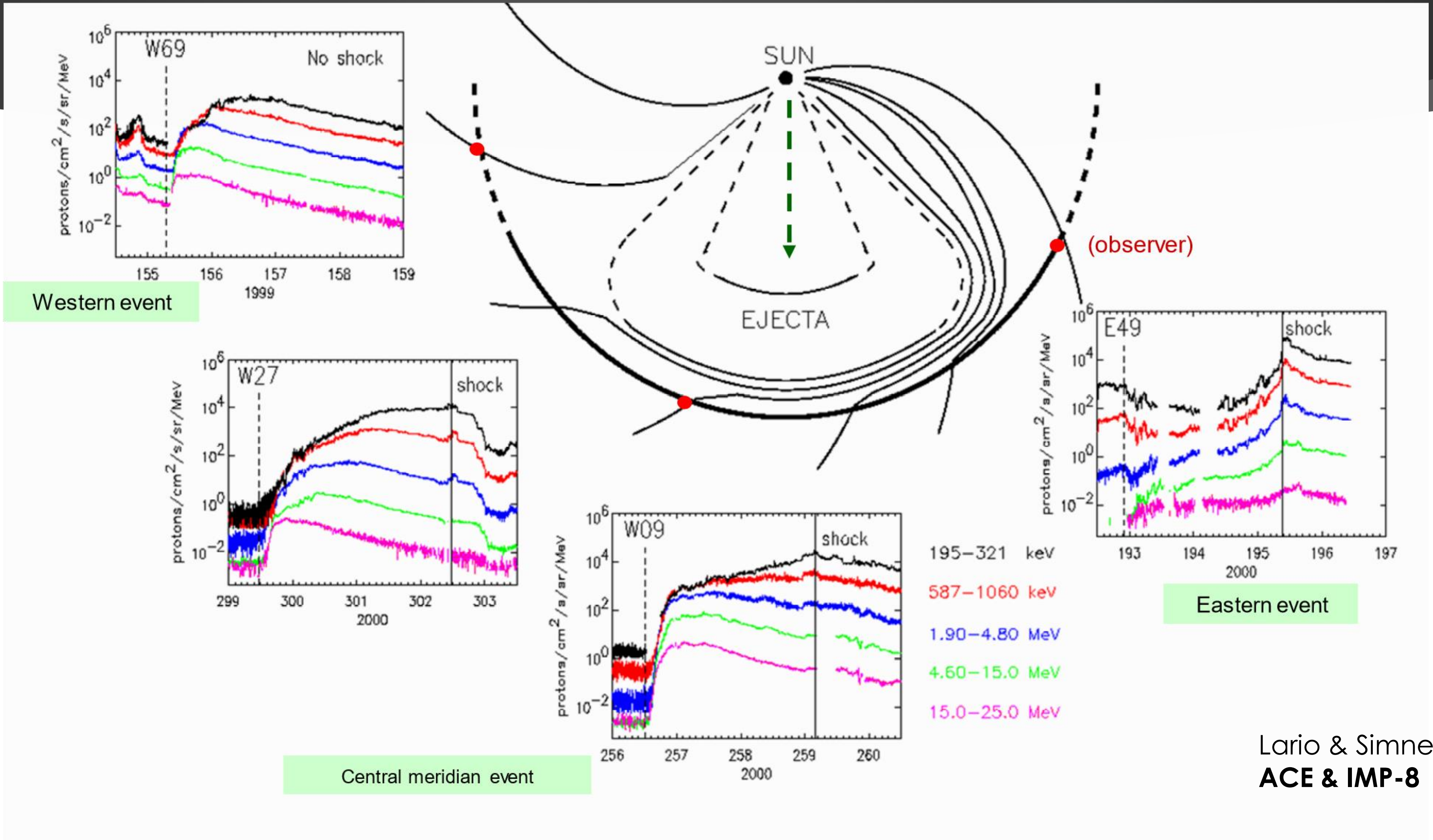
Information on the column contents is made visible when hovering the mouse pointer over the column headers in the last row of the table header (e.g. 'Date'). Clicking on the icons will open a

http://server.sepserver.eu/

SEPs: Catalogs (Earth's perspective): online and papers

Online catalogs	Published catalogs
NOAA preliminary listing (1976–present), p>10 MeV https://umbra.nascom.nasa.gov/SEP/	Cane et al. (2010): p>25 MeV, IMP-8, 1996–2006 Miteva et al. (2013): GOES, SOHO, ACE, 1996–2006
SEPEM reference list (1973–2013), p~7.23–10.45 MeV http://dev.sepem.oma.be/help/event_ref.html	Dierckxsens et al. (2015), p>10, 60 MeV, GOES, 1997–2006 Papaioannou et al. (2016), p>10, 30, 60, 100 MeV, GOES, 1984–2013
ERNE major proton events (1996–1999), 12–100 MeV https://srl.utu.fi/erne_data/events/proton/HED/eventlist.html SOHO/ERNE particles events (1996–2007) https://srl.utu.fi/SEPCatalog/index.php	
SEPServer event catalogs (misc) p, e http://server.sepserver.eu/	Vainio et al. (2013), misc lists Paassilta et al. (2017), p~68 MeV, SOHO/ERNE, 1997–2016
Solar proton events (1980–2008), misc http://www.wdcb.ru/stp/online_data.en.html#ref113	Kühl et al. (2017), >500 MeV, SOHO/EPHIN, 1997–2016
Proton event catalogs at SRTI-BAS (1996–2018) http://newserver.stil.bas.bg/SEPcatalog/	Miteva et al. (2018), p~25, 50 MeV, Wind/EPACT, 1996–2016 Miteva et al. (preliminary results on SOHO/ERNE)

SEPs: Longitudinal effects (ecliptic, near-Earth)



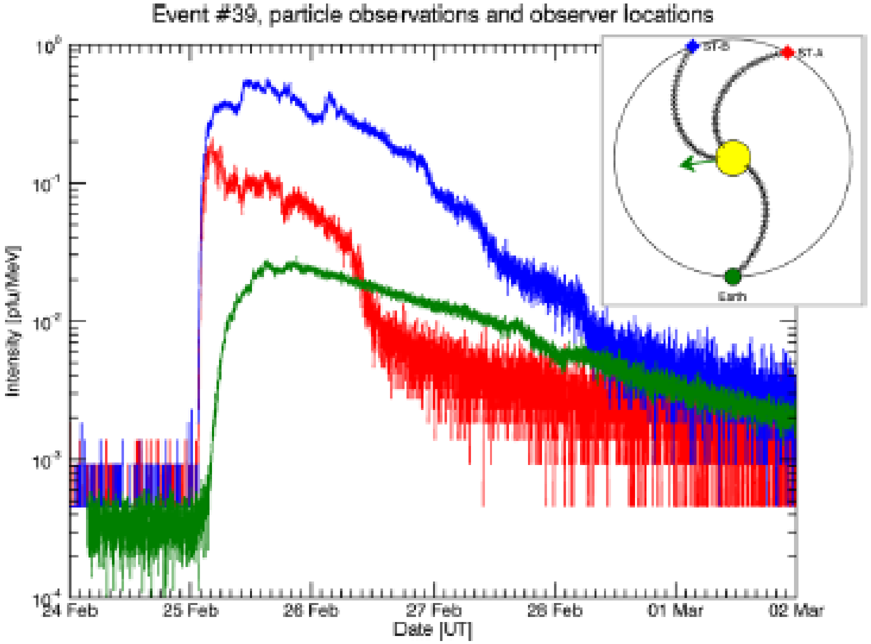
Lario & Simnett (2004)

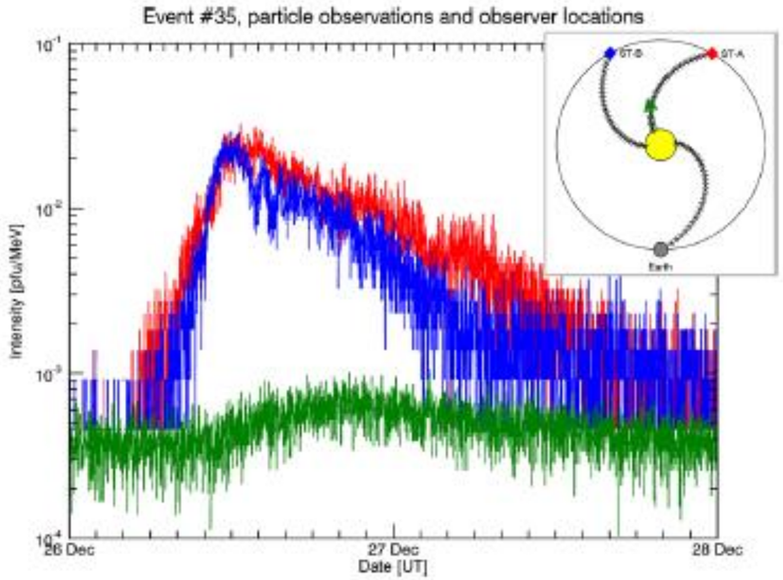
ACE & IMP-8

SEPs: Multi-spacecraft observations

e.g. Paassilta et al. (2018): 2009–2016 (SOHO/ERNE, ACE/EPAM, STEREO/SEPT)

Figure 1 Detected proton intensities (*red* = STEREO-A/HET, *blue* = STEREO-B/HET, *green* = SOHO/ERNE) during event 39 (25 February 2014). *Inset*: relative locations of the STEREO spacecraft and the Earth during the event. The *arrow* pointing out from the Sun shows the location of the event-related flare (at E82), and the *asterisks* mark the nominal Parker spiral magnetic field lines connecting each observer to the Sun.





- 55% of near-Earth events are seen also by STEREO
- max-intensity for western events
- rise times and release delays are not a simple function of connection longitude

Figure 4 Detected proton intensities (*red* = STEREO-A/HET, *blue* = STEREO-B/HET, *green* = SOHO/ERNE) during event 35 (26 December 2013). ERNE data show a weak enhancement that does not qualify as an event according to our selection criterion. *Inset*: relative locations of the STEREO spacecraft and the Earth during the event. The *arrow* pointing out from the Sun shows the location of the event-related flare (at E164), and the *asterisks* mark the nominal Parker spiral magnetic field lines connecting each observer to the Sun.

SEPs: Catalogs (STEREO; Ulysses)

http://server.sepserver.eu/

- ✓ STEREO: 2007 – 2012

Papaioannou et al. (2014): 2007–2012 (SEPServer STEREO catalog)

- ✓ Paassilta et al. (2018): 2009–2016 (SOHO/ERNE, ACE/EPAM, STEREO/SEPT)

- ✓ Ulysses: 1998 – 2006

http://server.sepserver.eu/

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Event catalogue: SEPServer STEREO-A Catalogue

SEPServer STEREO-A Catalogue		SEP Observations						Solar observations		Spacecraft Location			Comments
		LET Protons (6-10 MeV)			SEPT Electrons (55-85 keV)								
Event #	Date	p^- onset	p^- peak time	p^- peak value	e^- onset	e^- peak time	e^- peak value	Start time	Stop time	*R* (AU)	Helio Long. (deg)	Helio Lat. (deg)	
0	19.05.2007	16:45	23:45	2.25E-02	13:50	18:05	7.28E+02	12:30	15:00	0.959666	5.672	-1.434	
1	23.05.2007	10:25	3:45 (DOY 144)	1.32E-02	6:30	10:25	5.56E+02	7:00	10:00	0.959303	6.017	-0.903	
2	05.04.2008	20:20	21:00	1.50E-03	16:32	16:45	4.56E+02	12:00	24:00	0.951614	24.119	-4.192	
3	11.12.2008	11:50	13:30	1.90E-03	9:58	10:36	2.46E+01	8:00	11:00	0.967227	42.068	-5.346	
4	02.05.2009	-	-	-	20:02	20:46	8.21E+02	18:00	22:00	0.957439	47.472	1.849	
5	05.05.2009	10:30	13:30	7.40E-03	8:44	9:25	5.03E+02	8:00	11:00	0.957262	47.719	2.243	
6	03.11.2009	5:20	8:20	2.60E-03	3:57	4:25	2.78E+03	3:00	6:00	0.966748	62.382	-3.489	
7	05.11.2009	8:00	13:00	8.00E-04	0:16	3:06	4.29E+02	23:00 (DOY 309)	2:00	0.966819	62.439	-3.701	
8	22.12.2009	8:20	15:50	4.20E-03	6:26	7:26	3.40E+01	4:00	7:00	0.966624	63.904	-0.108	

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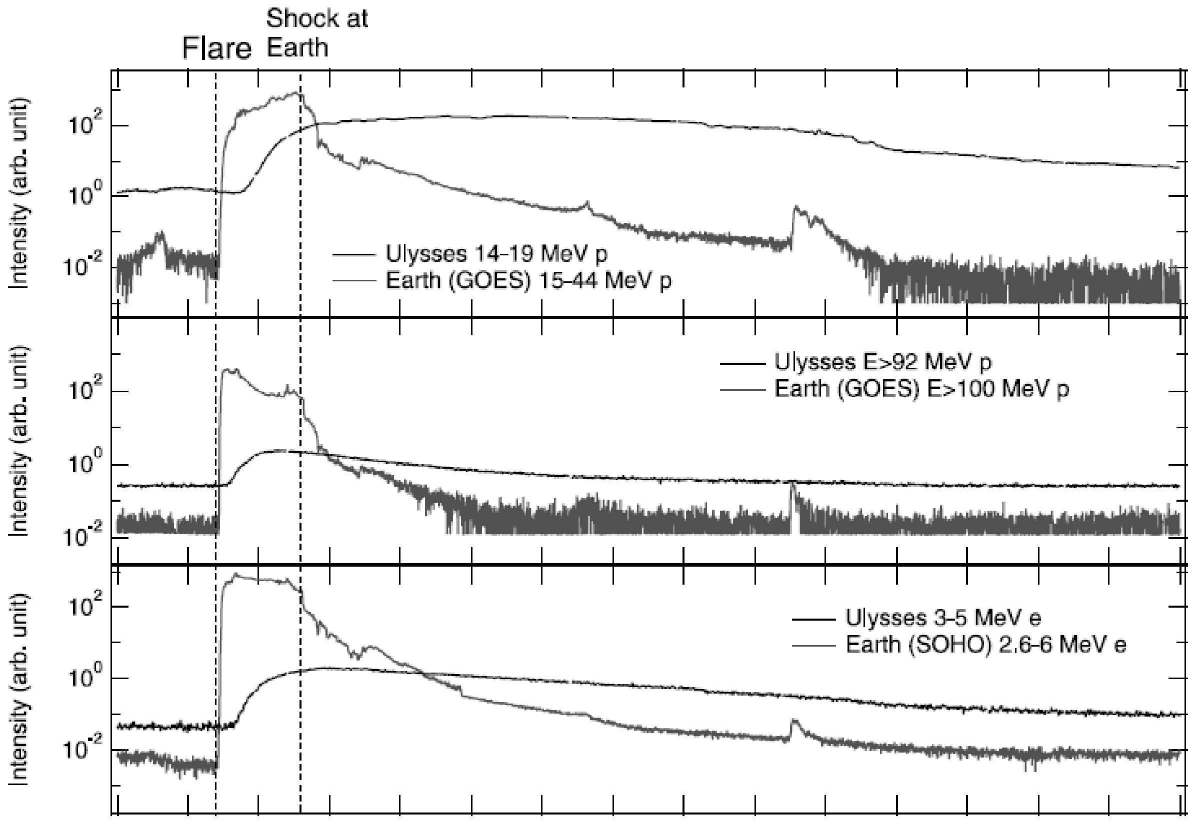
SEPs: Latitudinal effects (historical remark)

Zhang et al. (2003): 14 July 2000 Bastille event



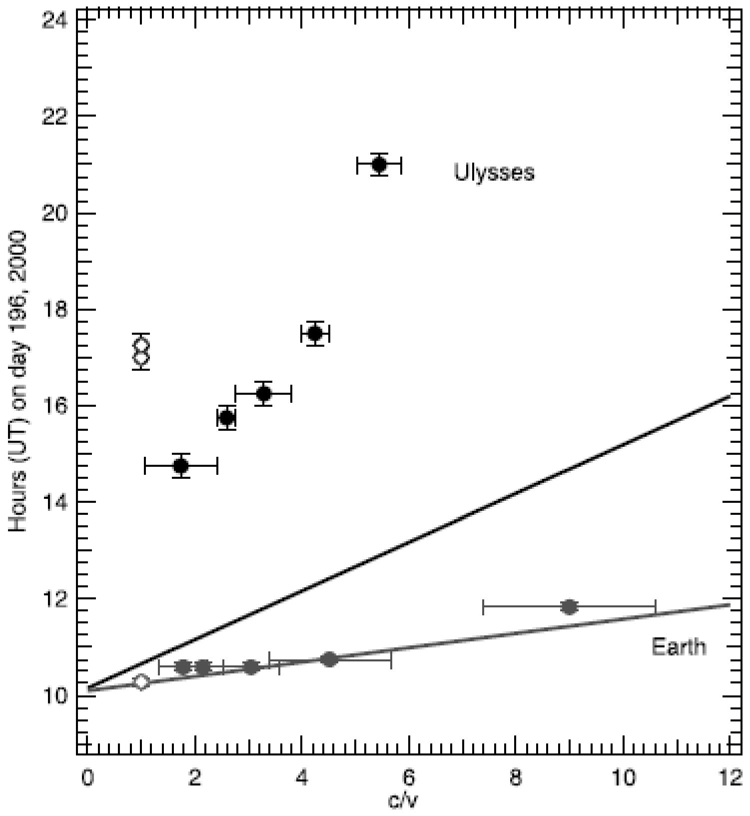


Figure 5. Onset times of energetic particle increases observed at Ulysses (dark) and the Earth (gray) as functions of particle velocity. The open symbols are for relativistic electrons and filled ones are for protons. The lines are derived from prediction by assuming that particles stream along magnetic field lines from the Sun to the spacecraft.

high-latitudes vs. ecliptic:

- ➢ Later onsets
- ➢ Lower intensities
- ➢ Cross-field diffusion?
- ➢ Inner heliosphere particle reservoir during solar max: Maclennan and Lanzerottii (2003)

SEPs: Latitudinal effects (historical remark)

Dalla et al. (2003)

- No correlation with longitude – Φ
- Correlation with latitude – θ

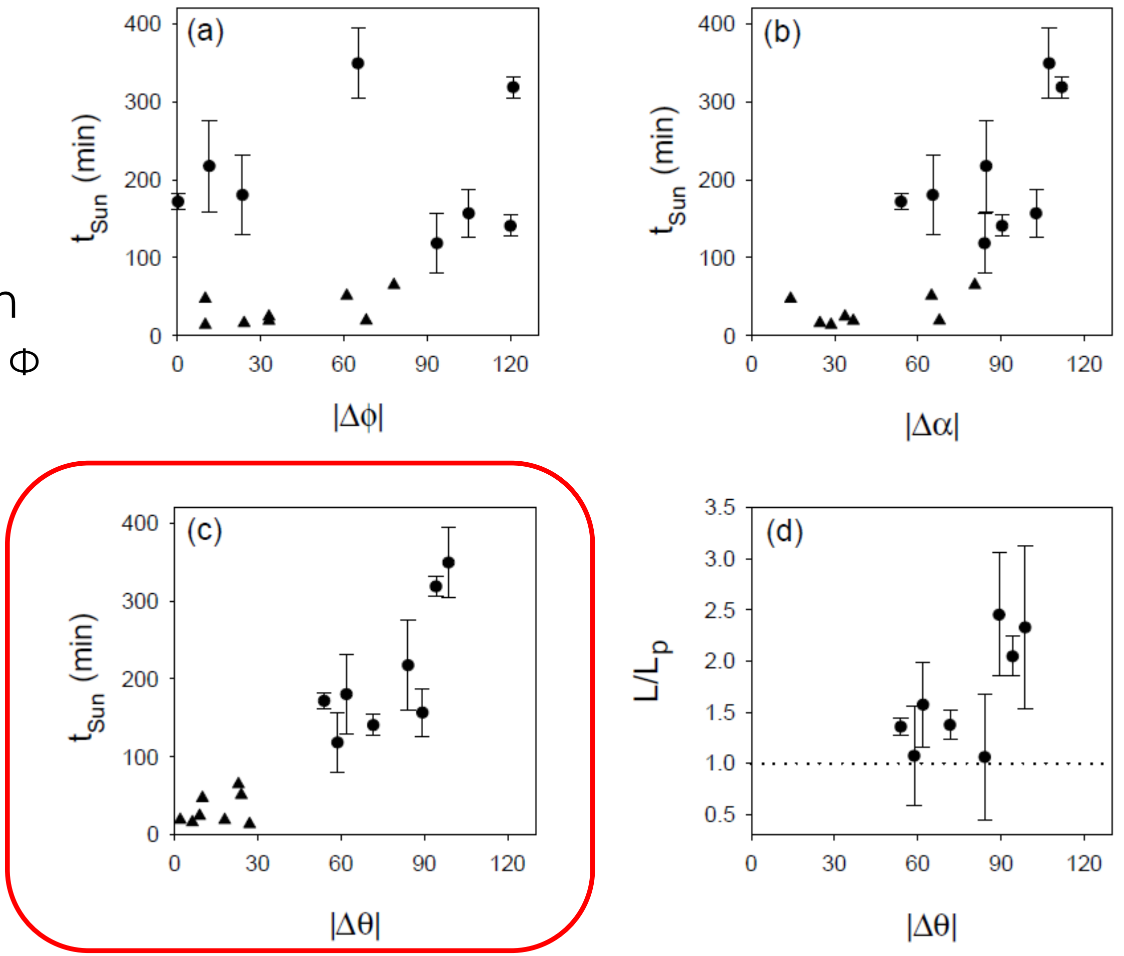


Fig. 6. Release time t_{Sun} versus angular separations between the spacecraft footpoint and the flare locations. Circles are Ulysses data points and triangles are Wind data points. **(a)** t_{Sun} versus difference in longitudes $|\Delta\phi| = |\phi_{\rm footpt} - \phi_{\rm flare}|$; **(b)** versus great circle angular separation $|\Delta\alpha|$ between footpoint and flare; **(c)** versus difference in latitude $|\Delta\theta| = |\theta_{\rm footpt} - \theta_{\rm flare}|$. Also given in panel **(d)** is the ratio L/L_p versus $|\Delta\theta|$. Plots are given for only 8 SEP events because the flare location was not known for 1 event.

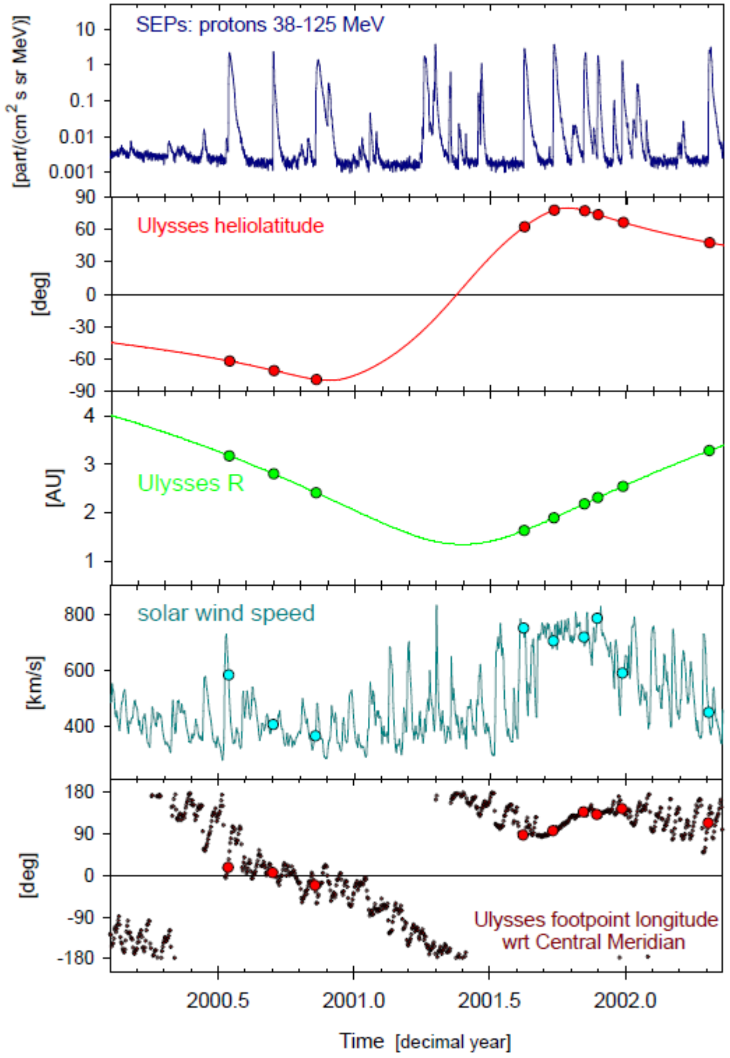
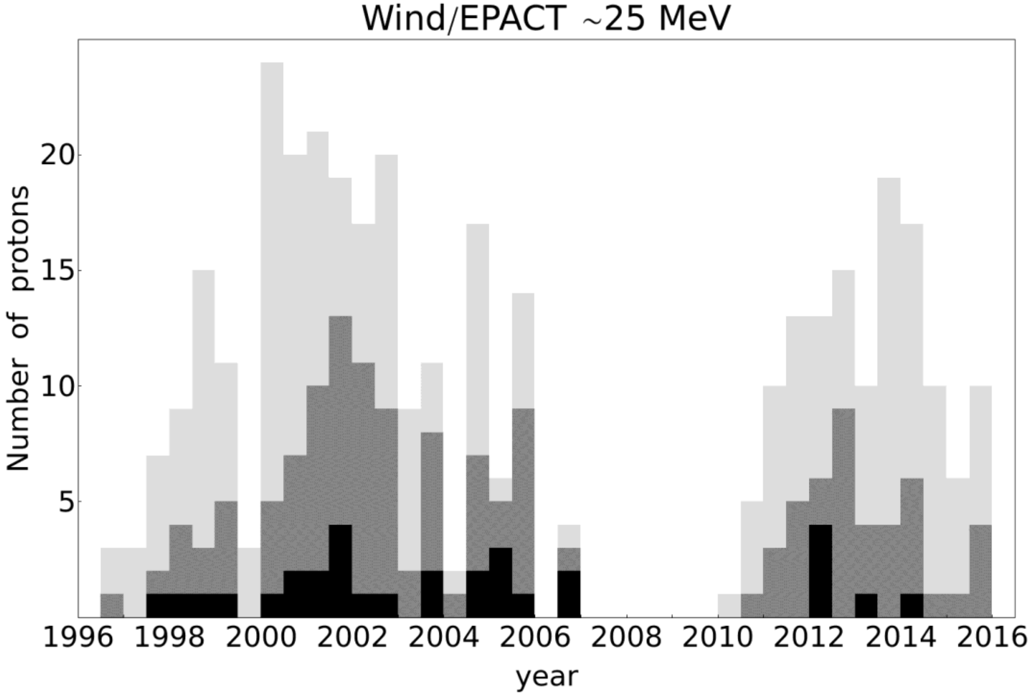
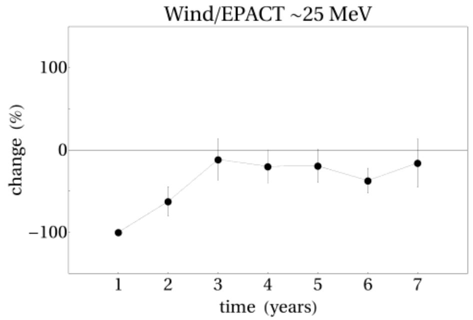
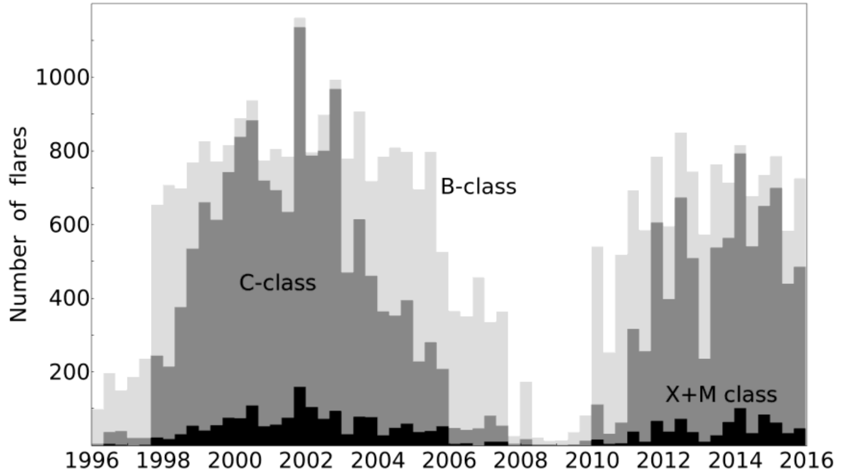


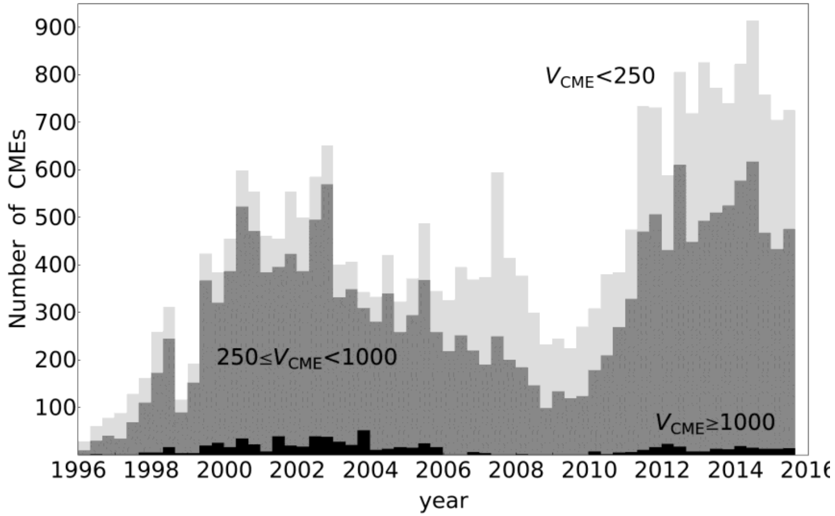
Fig. 1. Overview of Ulysses SEP high-latitude measurements. From top to bottom panels: SEP fluxes for protons 32–125 MeV (COSPIN/KET); Ulysses heliographic latitude; Ulysses distance from the Sun; solar wind speed (SWOOPS); longitude of the nominal footpoint of a Parker spiral field line through Ulysses, with respect to Central Meridian (the footpoint position is calculated by using the measured solar wind speed). The dots on the plot are at the start time of the 9 large SEP events considered in the onset time analysis.

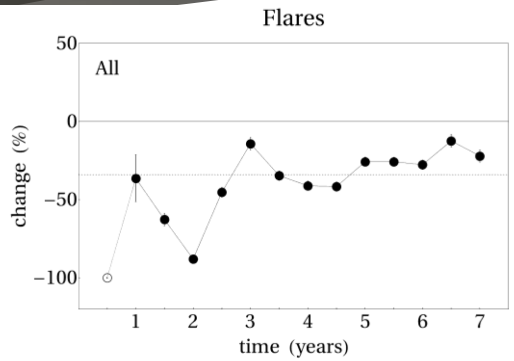
SEPs: Solar cycle effects

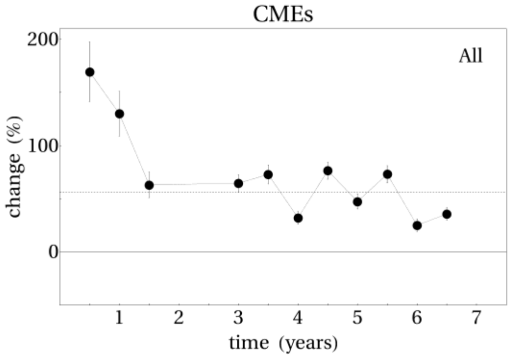












Miteva et al. (Sun&Geosphere 2017), http://newserver.stil.bas.bg/SUNGEO/

SEPs: Instrumental effects

- Data gaps – instrument black-out, safe mode, data transfer, etc.

ex. SOHO loss

- Sensitivity – background level at quiet times

ex. changing background level during solar cycles

- Pile up, contamination – counting two particles as one or at different energy

- Saturation → to use multi-instrument cross-correlation proxies?

ex. 11% (12/112) of SEPServer proton events

Miteva et al. (JASTP in press)

SEPs: (failed) Classification

Table I: Two-class Paradigm for SEP Events

	IMPULSIVE	GRADU/
Particles:	Electron-Rich	Proton-Ri
$^3He/^4He$	~1	~0.000!
Fe/O	~1	~0.1
H/He	~10	~100
Q_{Fe}	~20	~14
Duration	Hours	Days
Longitude Cone	< 30°	~ 180°
Radio Type	III,V (II)	II, IV
X-Rays	Impulsive	Gradua
Coronograph	—	CME
Solar Wind	—	IP Shoc
Events/Year	~1000	~10

Reames (1999, 2013) & Cliver (2009)

Table II: Revised SEP Event Classification[a]

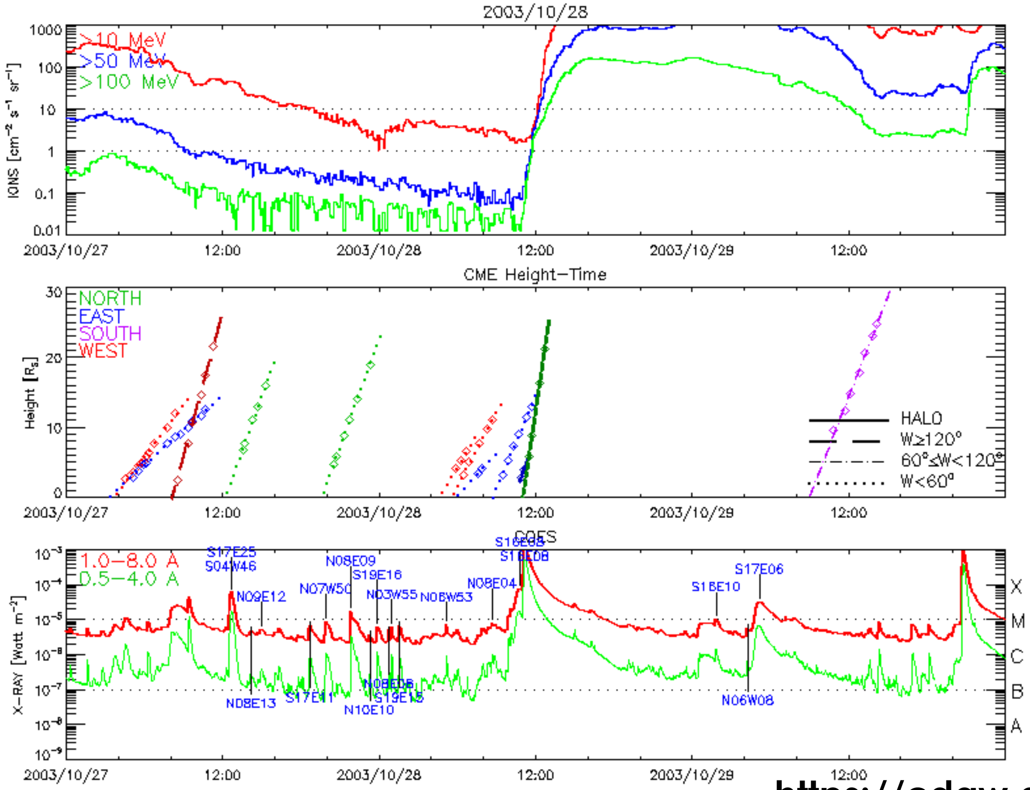
	Flare	Shock	
		Quasi-Perp	Quasi-Par
H Upper Limit[b]	~3 pr	~10^3 pr	~10^4 pr
e/p[b]	~10^2-10^4	~100	~50
$^3He/^4He$[c]	~10^3-10^4	~10^1-10^2	~1
Fe/O[d,e]	~8	~3	<1
Z(>50)/O[d,f]	~10^2-10^3	~10^{-1}-10^1	~10^{-1}-10^1
Ion Spectra[g]	—	Power-law	Exp. Rollover
QFe[h]	~20	~20	~11
SEP Duration	<1-20 hr	~1-3 days	~1-3 days
Longitude Cone[i]	<30-70°	~100°	~180°
Seed Particles	N/A	Flare STs	Coronal STs
Radio Type[j]	III	II (III)	II (III)
X-ray Duration	10-60 min	~1 hr	>1 hr
Coronagraph[k]	*	CME	CME
Solar Wind	—	IP Shock	IP Shock

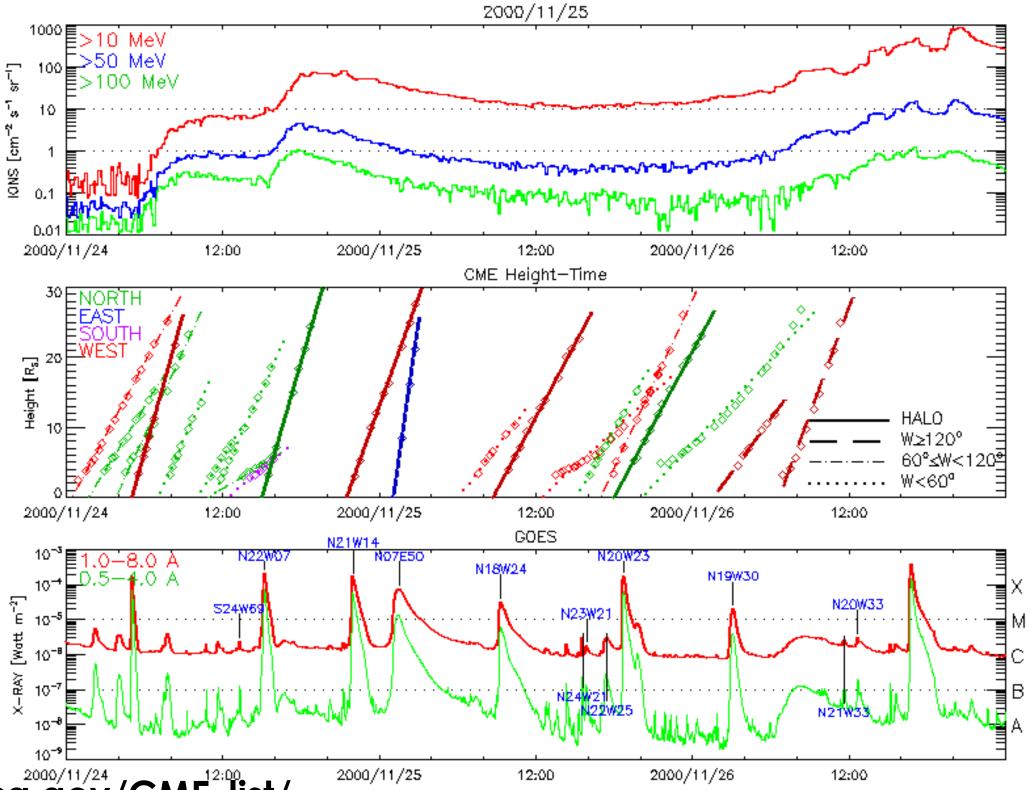
Plateau-like distribution of SEPs

Cane et al. (2010)

SEPs: Solar origin – flares and CMEs (procedure)

- Subjectivity issues (observer’s issue): set of criteria for temporal and spatial association of the eruption
- Multiple eruptive phenomena (physics issue)





https://cdaw.gsfc.nasa.gov/CME_list/

SEPs: Solar origin – Bulgarian–Russian project

http://newserver.stil.bas.bg/SEPorigin/

SEP origin project

Research collaboration and network

HOME | WORK PACKAGES | TEAM | RESULTS | OUTREACH

Project title:

The origin of solar energetic particles:

solar flares vs. coronal mass ejections

Call for proposals

Competition for financial support for bilateral projects 2016 – Bulgaria – Russia

Duration: **2 years** | **PI (Bulgaria):** ***Rositsa Miteva***

Start date: **23 June 2017** | **PI (Russia):** ***Larisa Kashapova***

Objectives

The goal of the project is to identify the individual contribution of flares vs. CMEs to the resultant flux of solar energetic particles by means of observations.

Different working hypotheses will be tested: there is one primary particle accelerator for the entire SEP population; there is a mixed contribution from flares and CMEs that vary from event to event; the injection and transport processes are the dominant factors compared to acceleration.

Large statistical studies will be complemented with detailed event analysis (using also data from the Russian satellites Vernov and CORONAS-F SONG and from the ground-based Rozhen observatory in Bulgaria).

Team members

Bulgaria

R. Miteva, D. Danov

Space Research and Technology Institute, Bulgarian Academy of Sciences

N. Petrov, Ts. Tsvetkov

Institute of Astronomy and National Astronomical Observatory, Bulgarian Academy of Sciences

Russia

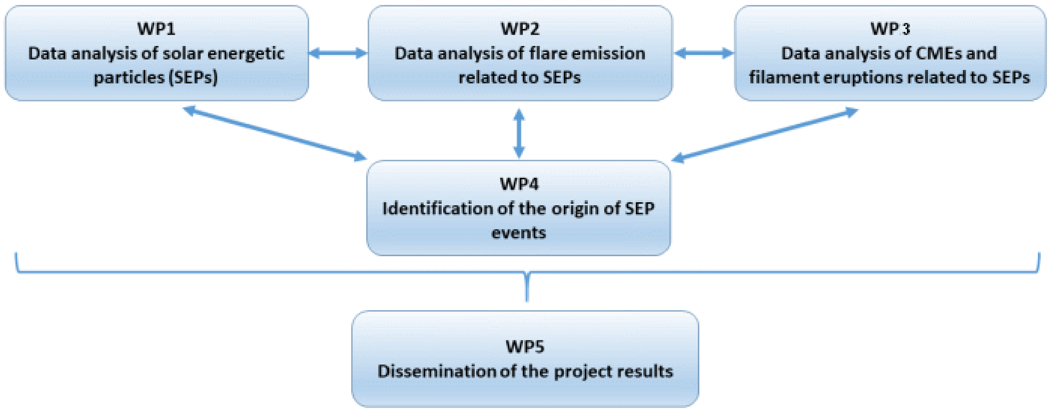
L. Kashapova, N. Meshalkina, I. Myshyakov, D. Zhdanov

Institute of Solar Terrestrial Physics - SB Russian Academy of Sciences

I. Myagkova, A. Bogomolov

Skobeltsyn Institute of Nuclear Physics, Lomonosov Moscow State University

Work organization



The project is supported by:

the National Science Fund of Bulgaria

ФОНД НАУЧНИ ИЗСЛЕДВАНИЯ

МИНИСТЕРСТВО НА ОБРАЗОВАНИЕТО И НАУКАТА

with contract No. ДНТС/Russia 01/6 (23-Jun-2017)

the Russian Foundation for Basic Research

РОССИЙСКИЙ ФОНД ФУНДАМЕНТАЛЬНЫХ ИССЛЕДОВАНИЙ

Project No.17-52-18050

SEPs: Statistical studies – Pearson correlations

List of SEPs: peak flux

List of solar flares: class

List of CMEs: speed

@ given energy channel!

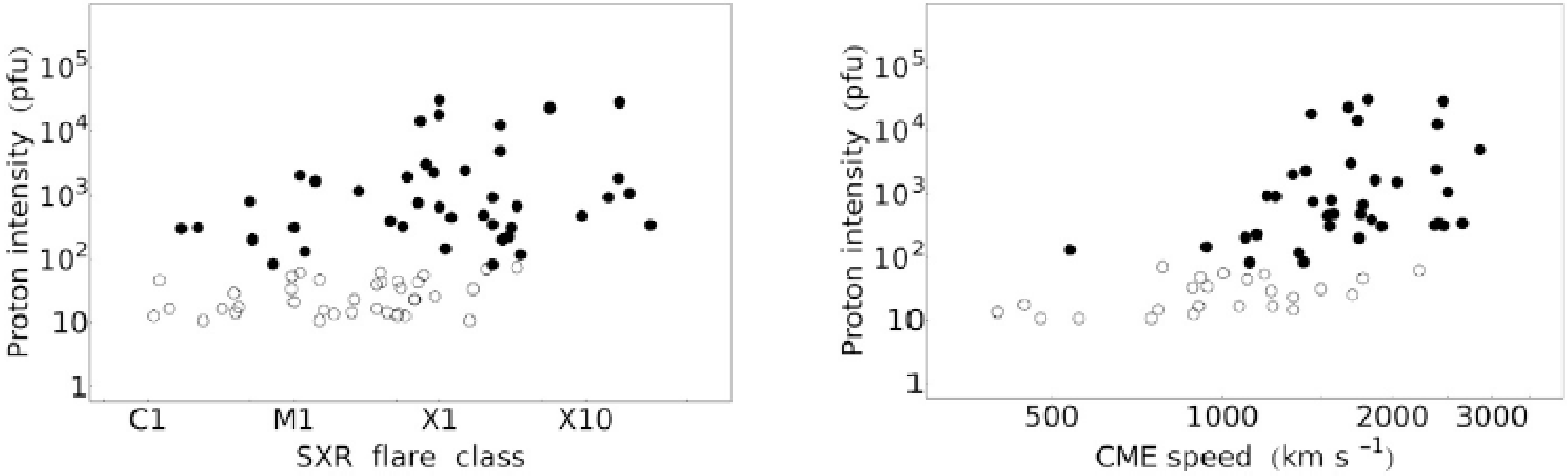


Fig. 5. Correlation plots (log–log) between the peak proton intensity from GOES-NOAA catalog and the flare class (left plot) and CME speed (right). Open/filled circles are for small/large protons with respect to the median intensity.

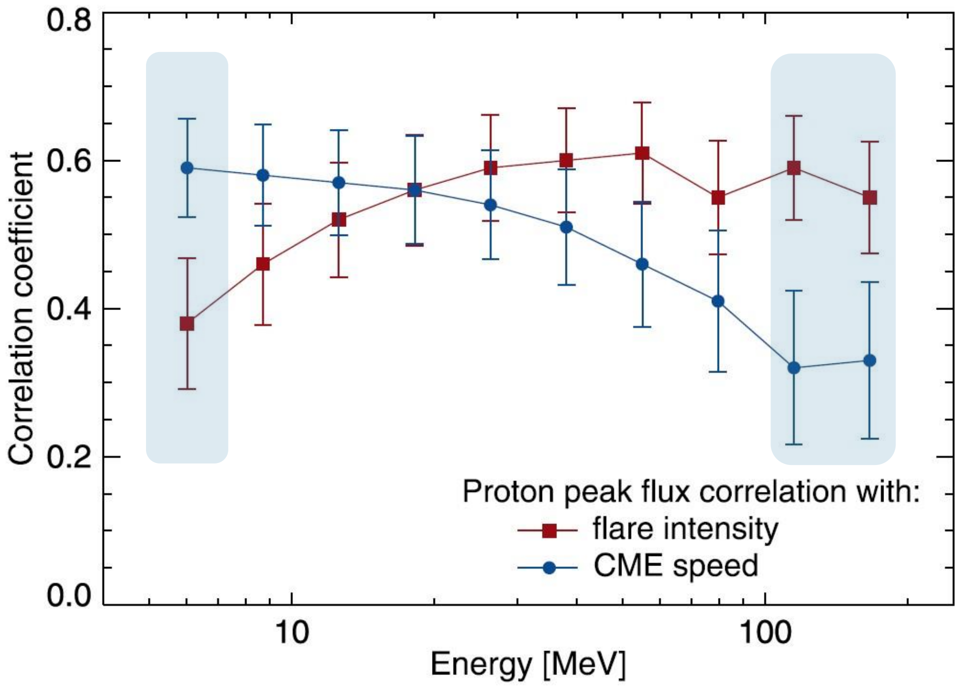
SEPs: Statistical studies – Pearson correlations

List of SEPs: peak flux

List of solar flares: class

List of CMEs: speed

Dierckxsens et al. (2015) **as function of energy!**



SEPs: Solar origin – flares and CMEs

- Subjectivity issues (observer's issue): set of criteria for temporal and spatial association of the eruption

Comparative analysis between solar origin associations: **Differences**

- SOHO/ERNE study vs. NOAA proton listing: 13% - for flares, 15% - for CMEs
- SOHO/ERNE study vs. Papaioannou et al. (2016): 11% - for flares, 15% - for CMEs

→ ***leads to statistical significant differences: lower correlations with flares compared to CMEs***

- SOHO/ERNE study vs. Paassilta et al. (2016): 1% - for flares, 4% - for CMEs
- SOHO/ERNE study vs. Miteva et al. (2018): 3% - for flares, 4% - for CMEs

→ ***no significant differences for larger event samples and instruments other than GOES***

Miteva (2018, preprint)

SEPs: Statistical studies – new approaches

Trottet et al. (Sol. Phys. 2015)

Partial correlation analysis

correlation between two variables (e.g. SEP flux and SXF class/CME speed) after removing the influence of control variable (CME speed/SXR class, respectively)

→ values always smaller than Pearson correlation coefficients

→ CME speed and SXR fluence (not SXR class) are the independent variables

→ microwave fluence has negligible effect

→ analysis extended in Miteva et al. (2018)

Papaioannou et al. (Sol. Phys. 2018)

(weighted) Principal component analysis

Technique to reduce the number of variables – transforms input parameters (width of CMEs, velocity of CMEs, log flare class, flare longitude, flare duration, flare rise time) into a set of orthogonal components

PC1: velocity of CMEs, width of CMEs, log flare class

PC2: flare duration, flare rise time

SEPs: relationship to other solar phenomena

- **EUV waves**

- Prominences

Eruptive prominences

- Radio burst types II, III, IV

(1996–2016)

- Flares

Radio emission flux
Hard X-ray flare flux
EUV flare flux

- CME

Speed and energy

- Catalog of EUV waves in relationship to SEP origin phenomena (1997–2006)

87% of SEPs are accompanied by EUV waves
10% of EUV waves have SEP signatures

- Detailed analysis of eastern EUV waves as origin of SEP events

→ Arrival of protons could be due to EUV wave acceleration reaching the footpoints of the connection line

→ Arrival of electrons is earlier and not related to EUV wave arrival; electron distributions are isotropic or weakly anisotropic

- SEP-related EUV waves and other solar phenomena

88% are related to signatures of shock wave (type II radio burst)

Miteva et al. (Sol. Phys. 2014)

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Project title:

The origin of solar energetic particles:
solar flares vs. coronal mass ejections

Work package 3: **Data analysis of CMEs and filament eruptions related to SEP events**
Task 3.2 **Eruptive prominences and their relations to SEP events**

Deliverable Report [Month 21]

Summary of results until June 2018

Statistical relationship between filaments and solar energetic particle fluxes (above 10 MeV) has not been previously reported. We investigate the association rate using the largest reported event sample, based on observations by the Atmospheric Imaging Assembly (AIA) aboard the Solar Dynamics Observatory (SDO), EUVI (Extreme Ultraviolet Imager) onboard STEREO (Solar TErrestrial RElations Observatory) A & B and Hα data archive from Big Bear Solar Observatory or Kanzelhöhe Observatory. We inspected 156 proton events in the time period between 2010 and 2016 since the most detailed observations of prominences with SDO started.

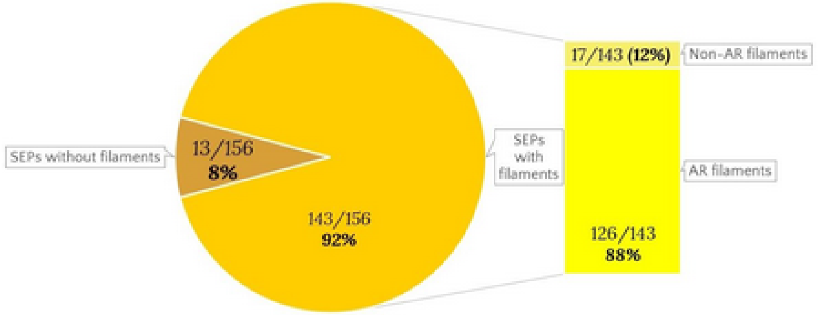
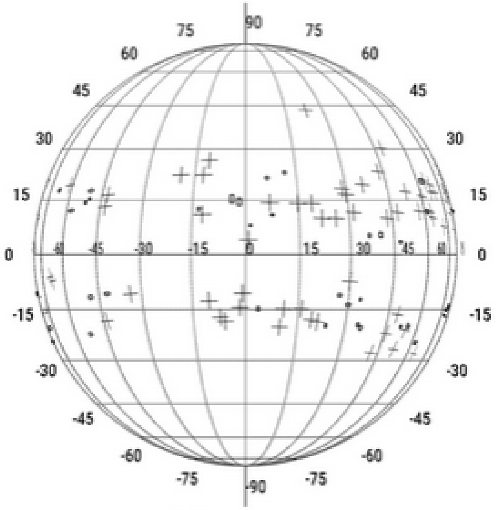


Figure 1. The association rate between SEPs and filaments (pie chart on the left) & SEP-related filaments link with active regions (bar plot on the right).

From our list, 143/156 SEP events were accompanied by prominences (92%), while in the remaining 13/156 cases (8%) could not be associated with any filaments (Figure 1). The association rate between SEP-related filaments and active regions (ARs) is 88%. Only 17 (about 12%) of the 143 SEP-related prominences are not connected with ARs.

SEP events tend to appear in an area $\pm 30^0$ around the solar equator, preferring latitudes around $\pm 15^0$ (Figure 2). The maximum of solar cycle 24 (as defined by sunspot number) reached in April 2014 coincides well with the maximum of registered proton events.



+ before the SC24 max
□ after the SC24 max
* SC24 max – 2014 April

Figure 2. Heliographic locations of the origin of SEP events. Cases observed before and after the maximum of solar cycle 24 (SC24) are noted with different symbols.

http://www.newserver.stil.bas.bg/SEPorigin/

Tsvetkov et al. (JSWSC 2018)

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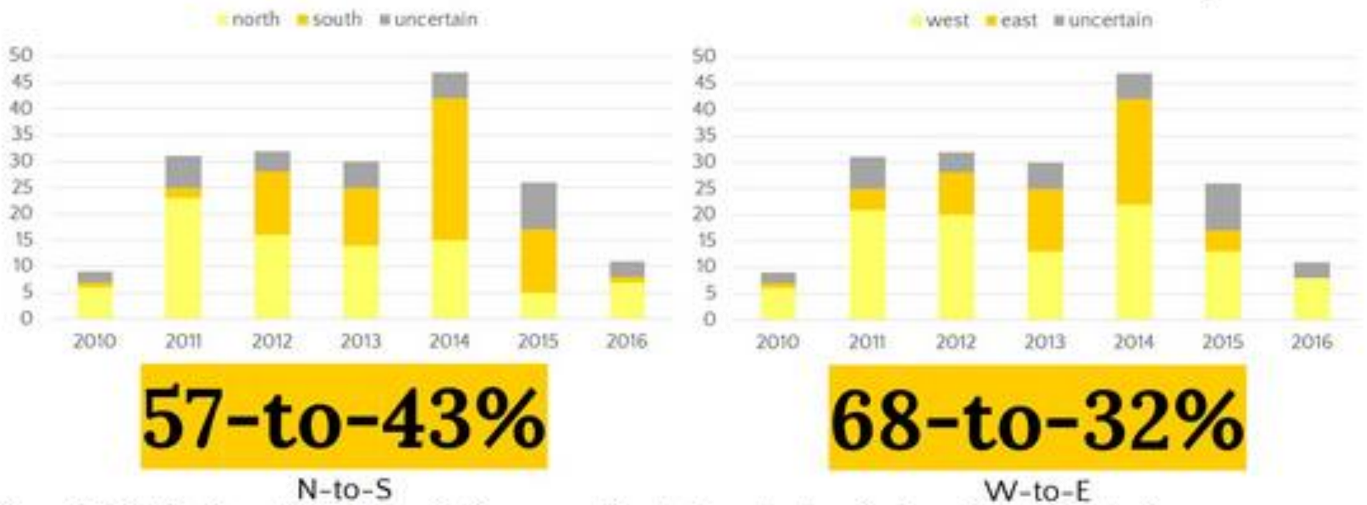

Figure 3. Distribution of SEP fluxes in time according to the solar hemisphere they originate from.

SEPs appear mostly in northern hemisphere before the maximum of solar cycle 24 and prefer southern hemisphere after the solar maximum (Figure 3 left plot). Moreover, we obtain that nearly 68% (103/152) of the proton sample originate from the western heliolongitudes, whereas the remaining 32% (49/152) are from the eastern (Figure 3 right plot). These percentages confirm the well-known observation for the preferential western origin of in situ observed particles.

http://www.newserver.stil.bas.bg/SEPorigin/

Tsvetkov et al. (JSWSC 2018)

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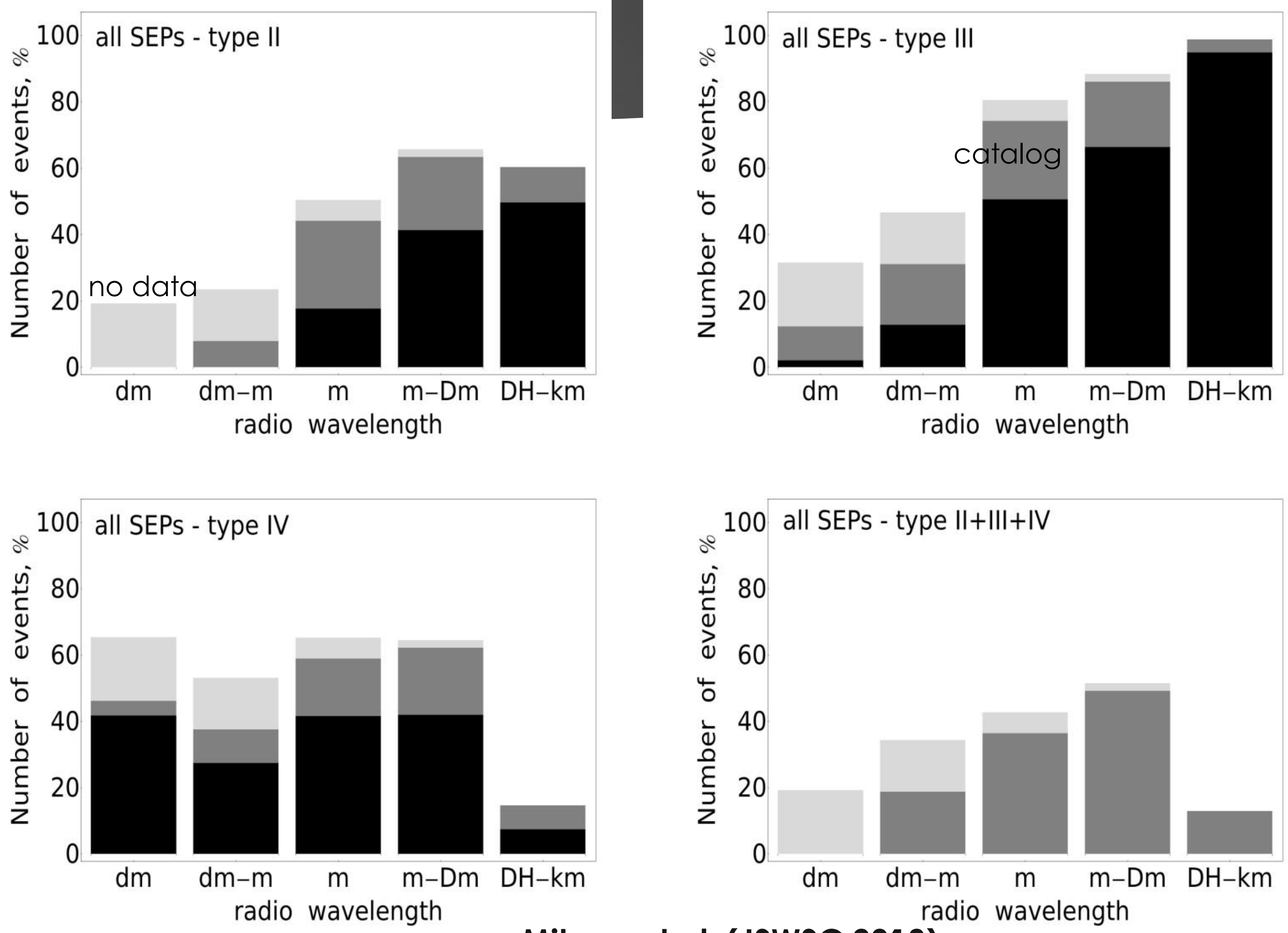
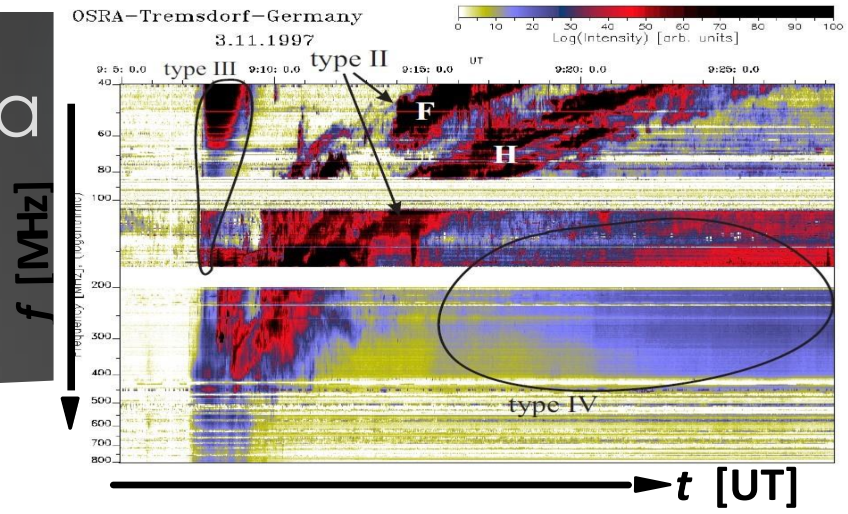


Miteva et al. (JSWSC 2018)

SEPs: relationship to other solar phenomena



- ➢ EUV waves

- ➢ Prominences

Eruptive prominences

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Speed and energy

Solar flare contribution to SEPs

- type III dm & dm−m ↔ DH, ~~type II~~: **3%** (13/431)
  m-type III, ~~type II~~: **13%** (58/431)
- Upper limit: **~16%**

CME contribution to SEPs

- DH−km type II, ~~dm & dm−m type III~~: **9%** (38/431)
  m-type II, ~~dm-m type III~~: **26%** (111/431)
- Upper limit: **~35%**

Mixed contribution to SEPs

~32% (139/431)

No data in m–km: **~17%** (72/431)

Miteva et al. (Sun&Geosphere 2018)

Upcoming results from:
Kashapova, Zhdanov and Meshalkina under the SEP origin project

SEPs: relationship to other solar phenomena

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- **Flares (emission from γ to radio waves)**
Radio emission flux
Hard X-ray flare flux
EUV flare flux

- CME
Speed and energy

Miteva et al. (Proceeding, in press)

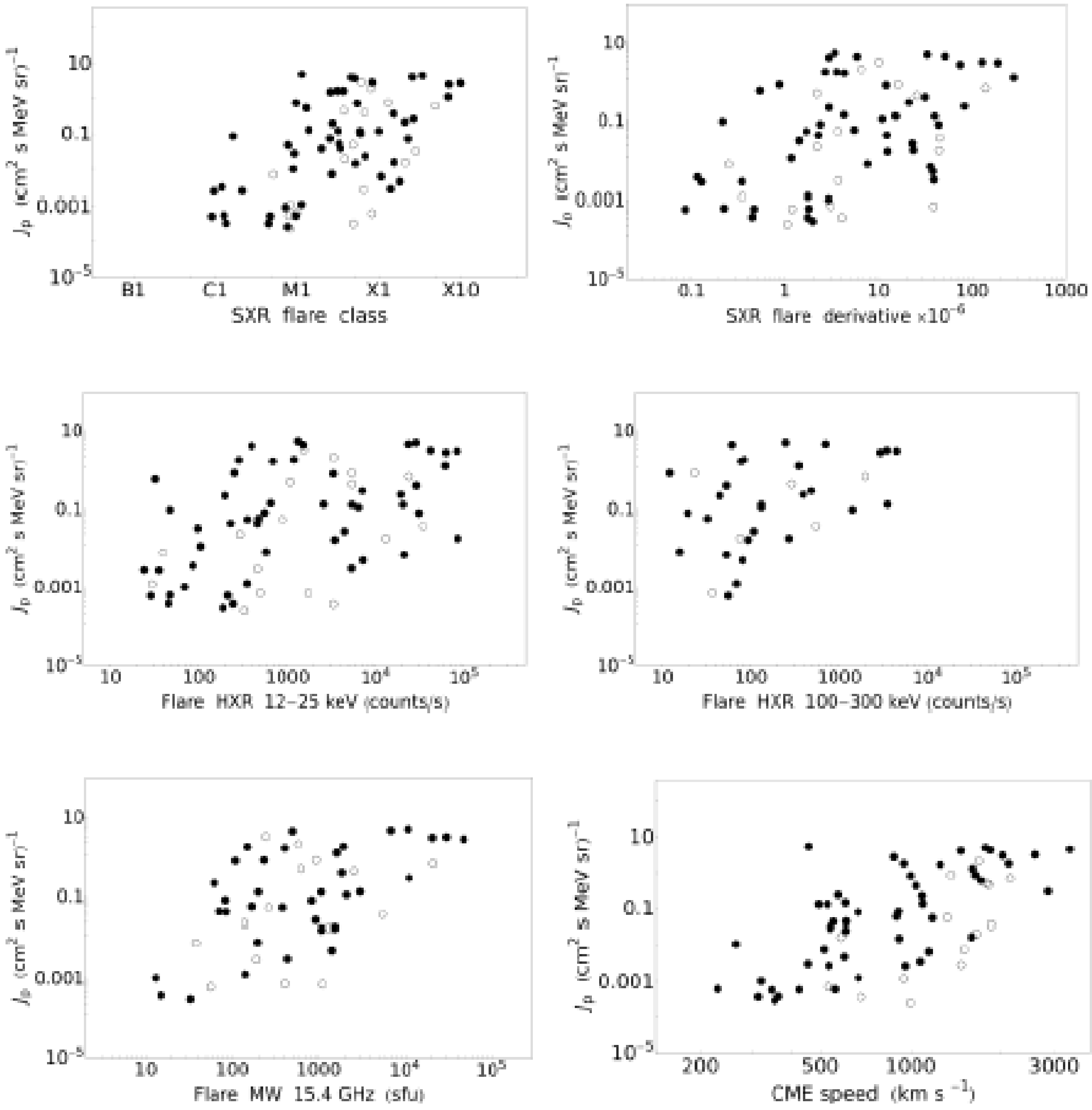

Figure 4. Selected scatter plots of the ~20 MeV peak proton intensity (J_p) and the properties of flare EM emission and/or CME speed. Open circles denote events originating from eastern helio-longitudes, filled circles – western origin events.

SEPs: relationship to other solar phenomena

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Table 1. Correlation coefficients between the ~20 MeV SOHO/ERNE peak proton intensity and the properties of flare EM emission and CME speed. The number of events used in each calculation is given in brackets. See text for abbreviations used.

Solar origin properties	**Correlation coefficients**	
	All events	*Well-connected events*
Flare EM emission		
SXR 1–8 Å, W/m^2	0.56±0.09 (70)	0.61±0.09 (52)
SXR derivative, W/(m^2 s)	0.48±0.09 (69)	0.50±0.10 (52)
HXR 12–25 keV, counts/s	0.48±0.08 (70)	0.50±0.10 (51)
HXR 25–50 keV, counts/s	0.50±0.09 (64)	0.50±0.11 (47)
HXR 50–100 keV, counts/s	0.44±0.11 (55)	0.38±0.13 (41)
HXR 100–300 keV, counts/s	0.41±0.12 (34)	0.42±0.13 (28)
MW 15.4 GHz, sfu	0.55±0.10 (50)	0.62±0.11 (35)
UV 1600 Å, relative units	0.50±0.15 (22)	0.43±0.20 (15)
CME speed, km/s	**0.64±0.08 (65)**	**0.72±0.07 (50)**

Miteva et al. (Proceeding, in press)

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Speed and energy

SOHO/LASCO CME catalog: https://cdaw.gsfc.nasa.gov/CME_list/
projected speeds

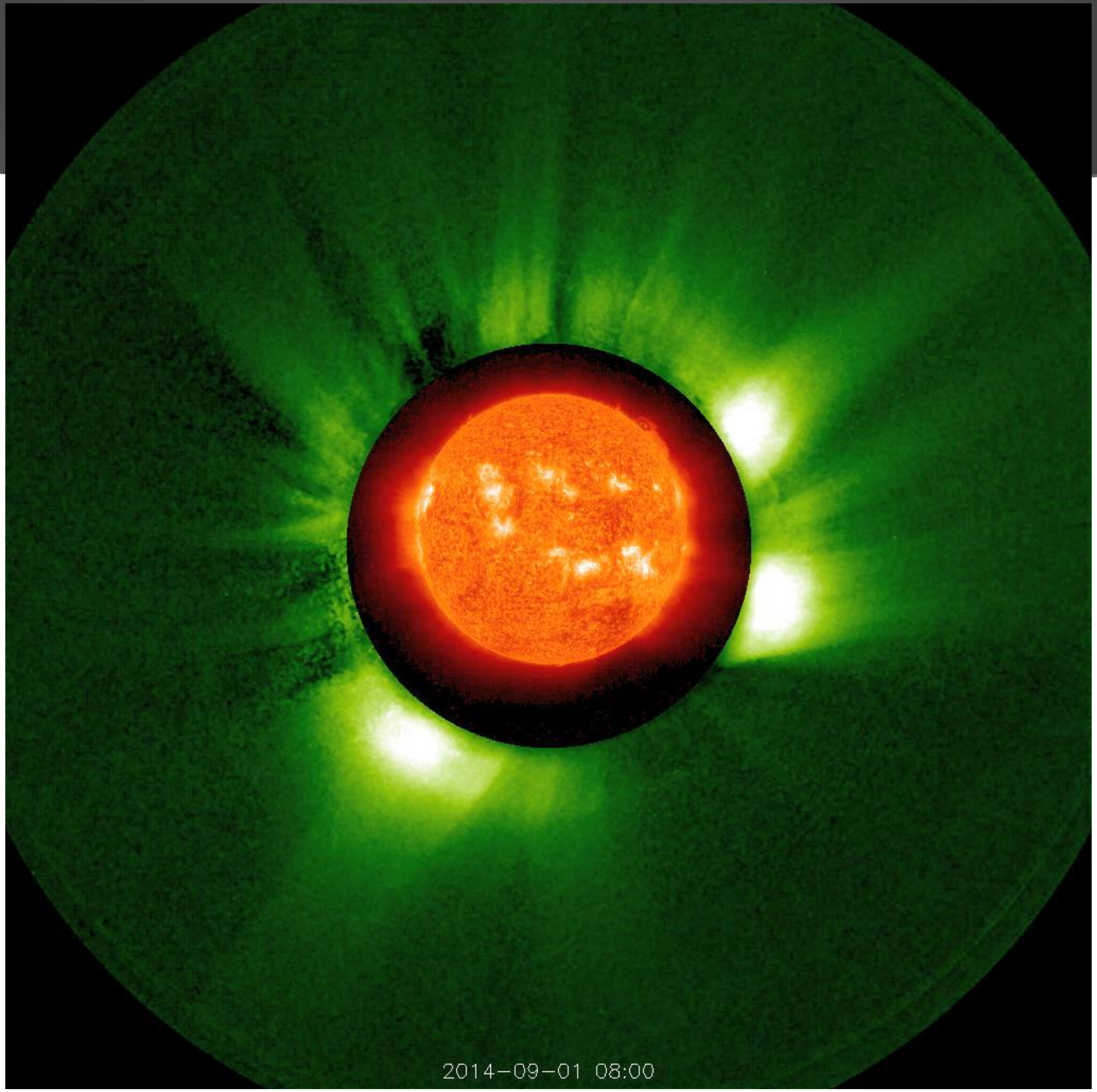
Richardson et al. (2015)
using CME projected speeds from different catalogs: consistent statistical results

De-projected speeds
e.g. HELCATS (part of solar cycle 24)

New CME parameters
e.g. CME energy: consistent results as for projected speeds
Miteva et al. (2018, preprint)

SEPs: Space weather

- stability of spacecraft
- snow-effect on CCD
- solar cell degradation
- sensor background noise, ionizations
- single event effects in Electronics
- airline operation effects: GPS navigation and communications
- increased radiation doses



e.g.
DiGregorio et al. (2008)
Kress et al. (2010)
Jones et al. (2005)

SEPs: Forecasting tools (user's perspective)

- **Empirical models**

REleASE (Posner 2007)

PPS (Kahler et al. 2007)

PROTONS (Balch 2008)

Laurenza et al. (2009); ESPERTA

UMASEP (Nunez et al. 2011–2018)

FORSPEF (Papaioannou et al. 2018)

Zucca et al. (2018)

- **Physics based models**

SOLPENCO (Aran et al. 2006)

EMMREM (Schwadron et al. 2010)

SEPMOD (Luhmann et al. 2010)

PREDICCS (Schwadron et al. 2012)

SOLPENCO2 (Crosby et al. 2015)

- **Mixed models**

COMESEP (Crosby et al. 2015)

- **Recycled models**

e.g. HESPERIA project

- **Neural network models**

e.g. Irina Myagkova's talk

Validation

Probability **O**f **D**etection = Hits/(Hits + Missed) (aim: ↗↗)
False **A**larm **R**ate = False hits/(Hits + False hits) (↘↘)

Percent **C**orrect = (Hits + True negatives)/Total number of forecasts (↗↗)
Heidke **S**kill **S**core, **W**arning **T**ime…

SEPs: Future missions – Parker Solar Probe (launched 12-Aug-2018)

http://parkersolarprobe.jhuapl.edu
https://www.nasa.gov/content/goddard/parker-solar-probe
→close-up (~9 sol. radii) observations

SWEAP
The Solar Wind Electrons Alphas and Protons investigation gathers observations using two complementary instruments: the Solar Probe Cup, or **SPC**, and the Solar Probe Analyzers, or **SPAN**.

The instruments count the most abundant particles in the solar wind – electrons, protons and helium ions – and measure such properties as velocity, density, and temperature to improve our understanding of the solar wind and coronal plasma.

Image credit: NASA
https://www.youtube.com/watch?v=UQ-E1icMpVw

SEPs: Future missions – Solar orbiter (scheduled Feb-2020)

http://sci.esa.int/solar-orbiter/
→close-up (0.28 AU) and high-latitude (33°/sol. eq.) observations

EPD: Energetic Particle Detector
Principal Investigator: Javier Rodríguez-Pacheco, University of Alcala, Spain
Collaborating countries (hardware): Spain, Germany, USA, ESA

EPD will measure the composition, timing and distribution functions of suprathermal and energetic particles.
Scientific topics:
sources, acceleration mechanisms, and transport processes of these particles.

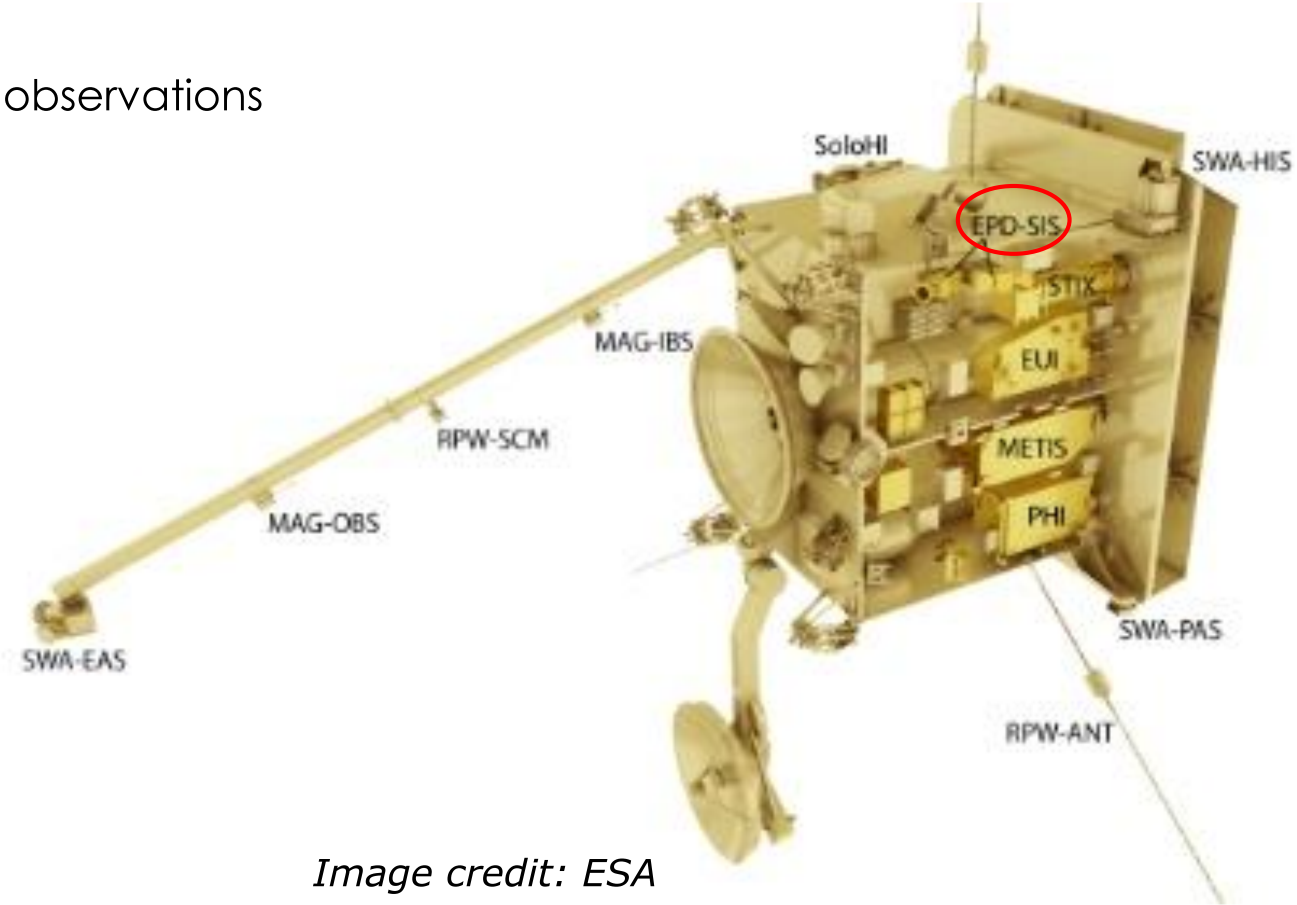


Image credit: ESA

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(II) Russian Foundation for Basic Research:
Project № 17-52-19050

http://newserver.stil.bas.bg/SEPorigin/

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