Lists of Solar Energetic Particle (SEP) events based on STEREO recordings: 2007-2012

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A. Papaioannou[1], O.E. Malandraki[1], B.Heber[2], N. Dresing[2], K.-L. Klein[3], R. Vainio[4], R. Rodriguez-Gasen[3] , A. Pönni[4], M. Alho[4,5] , D. Heynderickx[6], N. Agueda[7]

[1] Institute of Astronomy, Astrophysics, Space Applications and Remote Sensing, National Observatory of Athens, Greece
[2] Christian-Albrechts-Universitaet zu Kiel, Leibnistrasse 11, Kiel, D-24118, Germany
[3] Observatoire de Paris, Meudon, LESIA-CNRS UMR 8109, 92195, France
[4] Department of Physics, POB64, 00014, University of Helsinki, Finland
[5] Finnish Meteorological Institute, Helsinki, Finland
[6] DHC Consultancy, Leuven, Belgium
[7] Universitat de Barcelona, Barcelona, Spain

Abstract: The STEREO (Solar TErrestrial RElations Observatory) mission employs two nearly identical space-based observatories – one ahead of Earth in its orbit (STEREO-A: STA), the other trailing behind (STEREO-B: STB) aiming at providing the first-ever stereoscopic measurements of the Sun. The intensities of SEP events are strongly affected by the properties of the interplanetary magnetic field that control the acceleration and propagation of particles throughout the heliosphere. The study of SEP events provides useful information on the physics of solar particle genesis, propagation and acceleration. Therefore the usage of STEREO recordings provides an unprecedented opportunity to identify the evolution of such events at different observing points within the heliosphere. In this work, two instruments onboard STEREO have been used in order to identify all SEP events observed within the rising phase of solar cycle 24 from 2007 to 2012, namely: the Low Energy Telescope (LET) and the Solar Electron Proton Telescope (SEPT). A scan over STEREO/LET protons within the energy range 6-10 MeV has been performed for each of the two STEREO spacecraft (i.e. STA & STB). We have tracked all enhancements that have been observed above the background level of this particular channel and cross checked with available lists on STEREO/ICMEs, SIRs and shocks as well as with the reported events via literature. Furthermore, parallel scanning of the STEREO/SEPT electrons in order to pin point the presence (or not) of an electron event has been performed in the energy range of 55-85 keV, for all of the aforementioned proton events, included in our lists. Simulation based analysis has also been performed for two events of this catalog using the inversion methods that were developed within SEPServer.

STEREO mission:

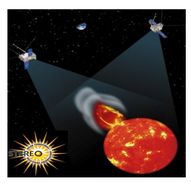


Figure 1. An artistic representation of the STEREO satellites

✓ Launched in October 2006, the NASA *STEREO* mission was set out to to explore the causes and mechanisms of coronal mass ejections (CMEs) and to discover the mechanisms and sites of solar energetic particle (SEP) events. During its operational lifetime up-to-now, STEREO spacecrafts have provided valuable information while providing 3-D recordings of both CMEs and SEP events.

✓ Energetic particle data from the **Low Energy Telescope (LET)** (*Mewaldt et al. 2008*) and the **Solar Electron and Proton Telescope (SEPT)** (*Müller-Mellin et al. 2008*) onboard ***STEREO*** *satellites* both of which are part of the ***IMPACT*** suite (*Luhmann et al. 2008*), have been used in our analysis.

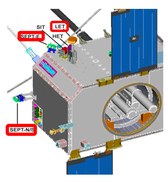


Figure 2. Schematic representation of the STEREO IMPACT SEP package – including the positions of the instruments on-board the satellite - in the outline red boxes LET and SEPT are indicated.

Compiling the STEREO Event Lists:

○ An overall scanning in the recordings of the low energy protons (***P: Energy range: 6-10 MeV***) of **STEREO/LET** and in the electrons (***E: Energy range: 55-85 keV***) of **STEREO/SEPT** was performed on the basis of the current analysis. The goal was to identify clear intensity increases, optimally, in both protons of STEREO/LET and electrons of STEREO/SEPT.

○ The scanning resulted into the identification of a total of **138 events** for **STEREO A** and **132** for **STEREO B** from **2007 to 2012 .**

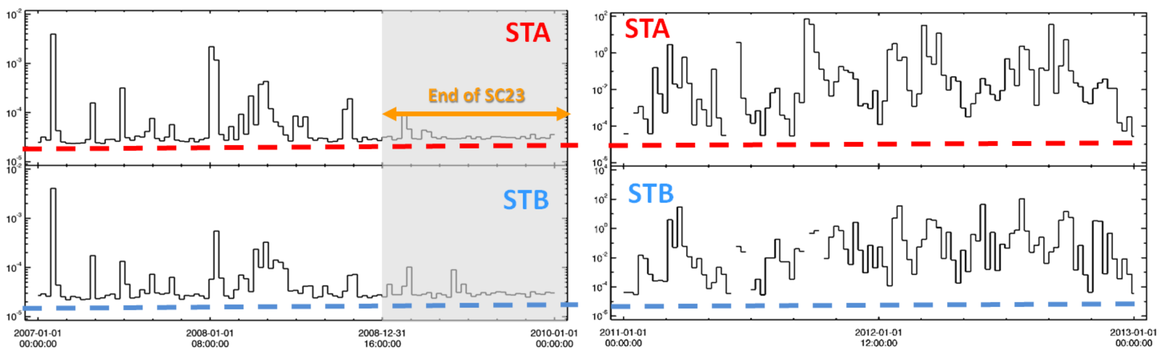
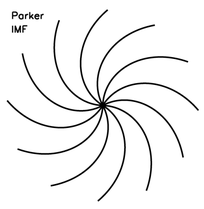


Figure 3. Illustration of the scanning on STEREO/LET data that led to the compilation of the SEPServer STEREO Catalogues. The background of the 6-10 MeV channel [2 x 10^{-5} particles/cm^2 sr s MeV] is presented in each diagram (red dashed line for STA and blue dashed line for STB)

○ Furthermore, we have compared our **event lists** with the available ones of *interplanetary coronal mass ejections* (***ICMEs***), *stream interaction regions* (***SIRs***) and ***interplanetary shocks*** that are being maintained the Space Physics Center at UCLA (***http://www-ssc.igpp.ucla.edu/forms/stereo/stereo_level_3.html***), as well as with the reported events via literature.

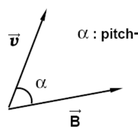
○ ***Time shifting analysis (TSA)*** (*Malandraki et al. 2012; Vainio et al., 2013*) has been performed for all of the events in our lists aiming at the identification of the relevant solar events. We have calculated the length of the ***nominal Parker spiral*** and assumed ***scatter-free*** propagation of the ***near relativistic electrons***, as an outcome we tabulated the ***relevant solar events*** that are associated with the recorded particle enhancements.



$$L(u_{sw}) = z(r_{S/C}) - z(R_\odot)$$

$$z(r) = \frac{a}{2}\left[\ln\left(\frac{r}{a} + \sqrt{1+\frac{r^2}{a^2}}\right) + \frac{r}{a}\sqrt{1+\frac{r^2}{a^2}}\right]$$

$$a = u_{sw}/\Omega_\odot \qquad 2\pi\Omega_\odot^{-1} = 24.47\ \mathrm{d}$$



$$\mu = \cos\alpha = \frac{V_\parallel}{V}$$

$$t_{rel}(E) = t_{onset}(E) - 8.33\,\frac{\mathrm{min}}{\mathrm{AU}}\,L\beta^{-1}(E)$$

✓For the ***first arriving particles*** we assume **α=0°** and **μ=1**.

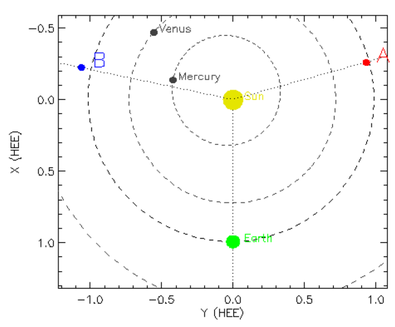
SEP events Catalogues| STEREO A & STEREO B:

*The results from TSA for the **SEP events recorded on STEREO A & STEREO B** are presented online at **http://server.sepserver.eu**. **We** provide: the characteristics of each event (i.e. number of the event, date, onset and peak time for both electrons (E_{min}~0.47c) and protons (E_{min}~0.12c)), start and end times of the associated solar data, position of each spacecraft (in HEQQ Coordinates), distance from the Sun (in AU). Multiple levels of information including the calculated Parker spiral in (AU) and the SRT calculated via TSA (**Papaioannou et al. 2013**)*

References:

> Agueda et al., Ap. J., 675, 1601, 2008 > Agueda et al., Adv. Space Res., 44, 794, 2009 > Dresing et al., Sol. Phys., 281, 281, 2012 > Luhtmann al., SSRv, 136, 117, 2008 > Malandraki et al., Sol. Phys., 281, 333, 2012 > Mewaldt et al., SSRv, 136, 285, 2008 > Papaioannou et al., A & A , *submitted, 2013* > Müller–Mellin et al., SSRv, 136, 363, 2008 > Vainio et al., JSWSC, 3, A12, 2013

Multi-spacecraft SEP events presented in SEPServer's Catalogues



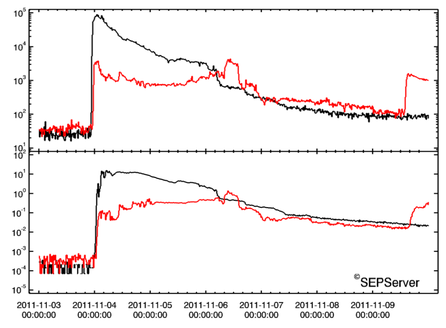


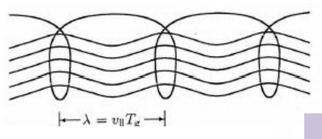
*Figure 4. The multi-spacecraft SEP event on **3 November 2011** as this was recorded from both **STA** & **STB** electrons (SEPT) (**upper right figure**) and protons (LET) (**lower right figure**), when the angular separation of the STEREO spacecraft was **> 200° (left figure)***

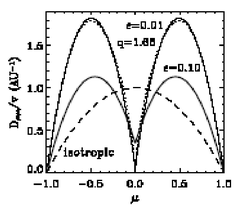
○ Tabulated results of the **multi-spacecraft events of 2012** including the relevant **solar associations**, i.e. **AR** and **flare site**, **type II** radio bursts and **CME** from COR1 list

○ The implementation of ***a complete up-to-date list of SEPs recorded by STEREO*** will enhance the multi-spacecraft investigations on SEP events (***Dresing et al., 2012***), shedding light on many open physical questions concerning the genesis and propagation of energetic particles

Date	AR	Flare Site	Type II	CME at COR1 STEREO
12.01.2012	11402	N30E115	15:00-15:45	8:25 (STB), 8:05 (STA)
19.01.2012	11402	N32E22	15:00-2:45 (next day)	14:45 (STB) & 14:25 (STA)
23.01.2012	11402	N28W21	4:00-15:00 (next day)	1:25
27.01.2012	11402	N22W71	18:30-4:45(next day)	?
29.02.2012	11420	N12W140	-	9:05
07.03.2012	-	-	1:00-19:00(next day)	0:15
24.03.2012	11451	N18E165	0:40-10:40	0:10
15.04.2012	11461	N15E100	2:30-2:50(next day)	1:25
17.05.2012	11476	N11W76	1:40-6:20	1:45
26.05.2012	11482	N16W122	20:50-23:20	20:45
14.06.2012	11504	S17E06	-	-
31.08.2012	-	-	20:00-23:45	19:49

Modeling SEP events with SEPServer's SEPinversion software:





○ Interplanetary transport simulations can be used to unfold the interplanetary transport effects from in-situ observations and infer the SEP injection profile close to the Sun and the transport conditions in the heliosphere (see ***Agueda et al. 2008; 2009***)

Assumptions:

- Gyration around and streaming along the IMF
- Focusing and mirroring: **$1-\mu^2/B$=const**.
- Pitch-angle scattering ⇒ **diffusion**
- Solar wind **convection**

Advantages:

- Use of the *measurements to infer the best fit injection profile*. **Deductive**.
- *Systematic exploration of the parameters space*. **Reproducible**.
- *No a priori parametrization* about the injection profile

Application to the 7 February 2010 event (STB):

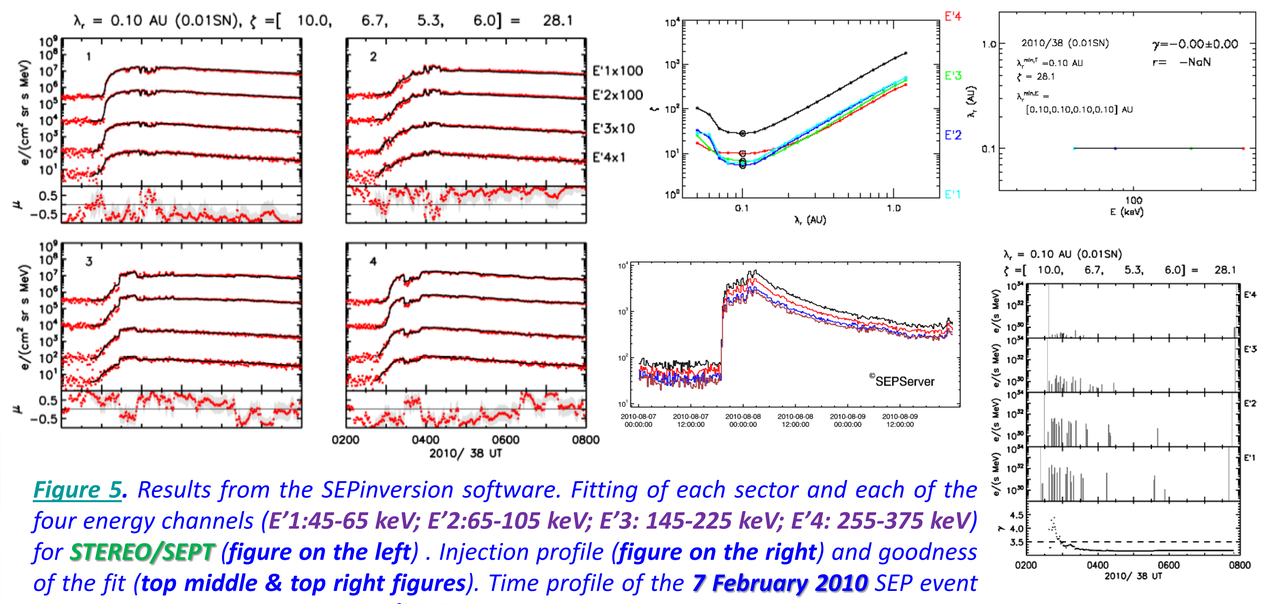


*Figure 5. Results from the SEPinversion software. Fitting of each sector and each of the four energy channels (**E'1:45-65 keV; E'2:65-105 keV; E'3: 145-225 keV; E'4: 255-375 keV**) for **STEREO/SEPT** (**figure on the left**) . Injection profile (**figure on the right**) and goodness of the fit (**top middle & top right figures**). Time profile of the **7 February 2010** SEP event as this was recorded onboard **STB/SEPT** (**middle bottom figure**)*

Conclusions:

○ We have presented ***Complete Catalogues*** of **SEP events** recorded by **STA** & **STB** from **2007 to 2012**.

○ We have also presented a list of multi-spacecraft SEP events for the same time period, which includes the ***relevant solar events*** of each **SEP event** as recorded by ***GOES soft X-rays***, ***SOHO/LASCO*** and ***STEREO*** coronographs, as well as the associated electromagnetic emission data.

○ We have utilized the SEPServer **SEPinversion** software [available through: ***http://server.sepserver.eu***] and have produced a fitting of the **7 February 2010** SEP event. This latter result demonstrates the capabilities offered by SEPServer when utilizing the already available SEP event Catalogues.

Contact: atpapaio@astro.noa.gr

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