HELLENIC ASTRONOMICAL SOCIETY

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IAASARS

EPSERVER

Solar Energetic Particle Events within the STEREO era: 2007-2012

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. Klassen[2], A. Nindos[5], R. Gomez-Herrero[6], N. Vilmer[3], A. Kouloumvakos[5], R. A. Mewaldt[7], K. Tziotziou[1], G. Tsiropoula[1]

[1] Institute of Astronomy, Astrophysics, Space Applications and Remote Sensing, National Observatory of Athens, Greece
[2] Christian-Albrechts-Universitaet zu Kiel, Leibnizstrasse 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] Department of Physics, University of Ioannina, Greece
[6] SRG, University of Alcalá, 28871, Alcalá de Henares, Spain
[7] California Institute of Technology, MC 220-47, Pasadena, CA 91125, USA
** also at the Nuclear and Particle Physics Section, Physics Department, University of Athens, Greece*

Outline

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STEREO (Solar Terrestrial Relations Observatory)

Instrumentation

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A View to Future Ongoing Work

Analysis of case studies: The example of March 2012 series events

Applying Velocity Dispersion Analysis for Space Weather related events

Assessment of the Data Analysis Methods Used in this Work

Summary

Motivation

Create comprehensive
Solar **E**nergetic **P**article Event lists
[Catalogues] based on **STEREO** recordings

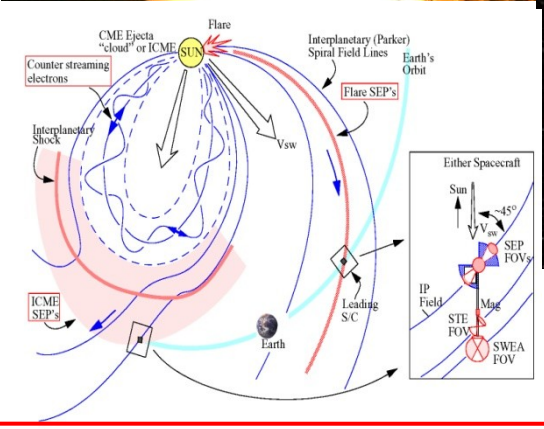
(Req#1) | SEP event catalogues (optimally) should provide:

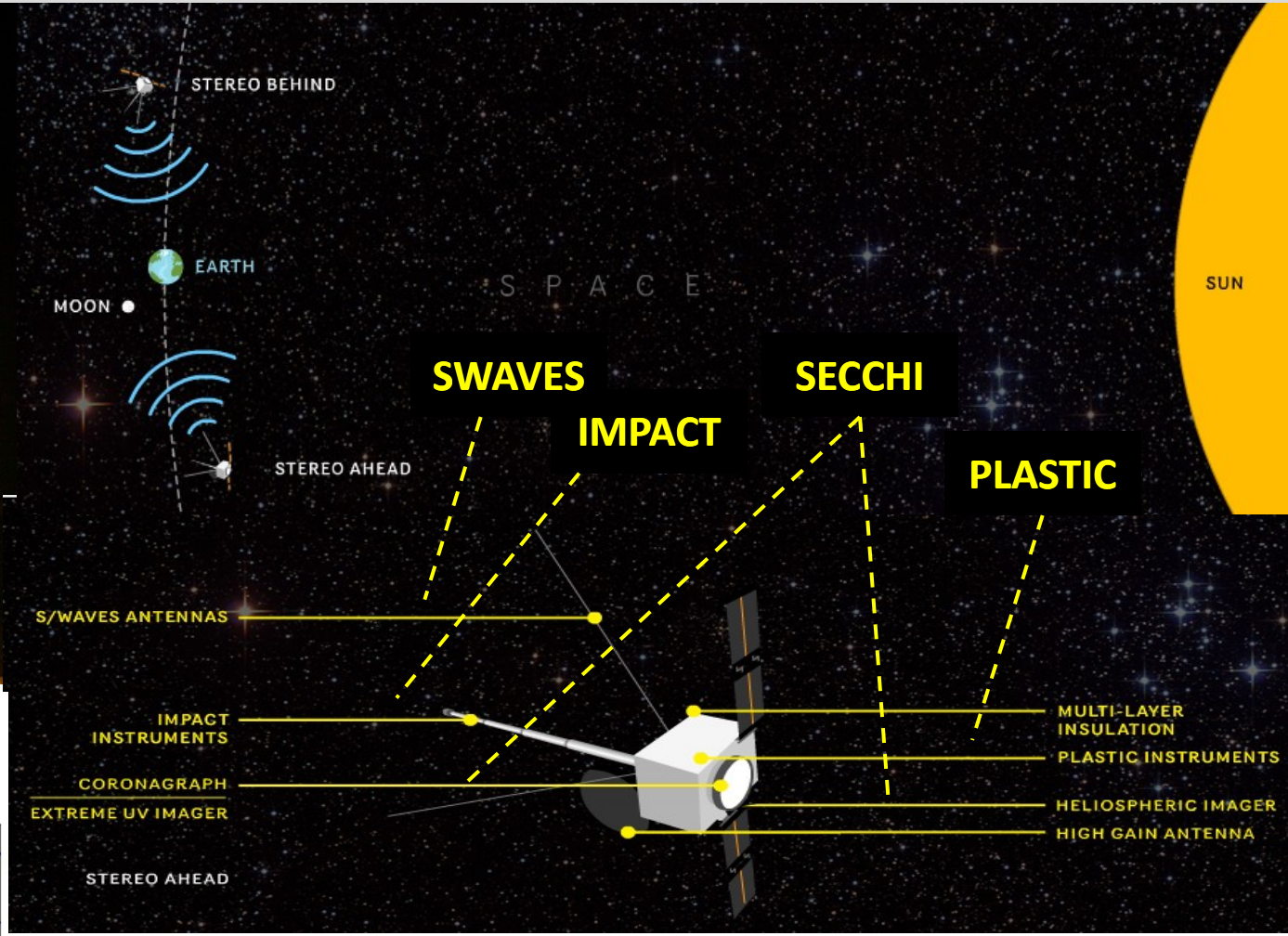
- the event characteristic parameters (year, month, day, onset and peak time)
- information on the s/c, the species and the energy channels used

(Req#2) | A complete description of an SEP requires:

- reports on parameters of the solar activity that can be associated with each SEP event
- the solar source associated with an SEP event
- observational data accompanying the source activity

Solar Terrestrial Relations Observatory-STEREO





http://stereo.gsfc.nasa.gov/launch.shtml

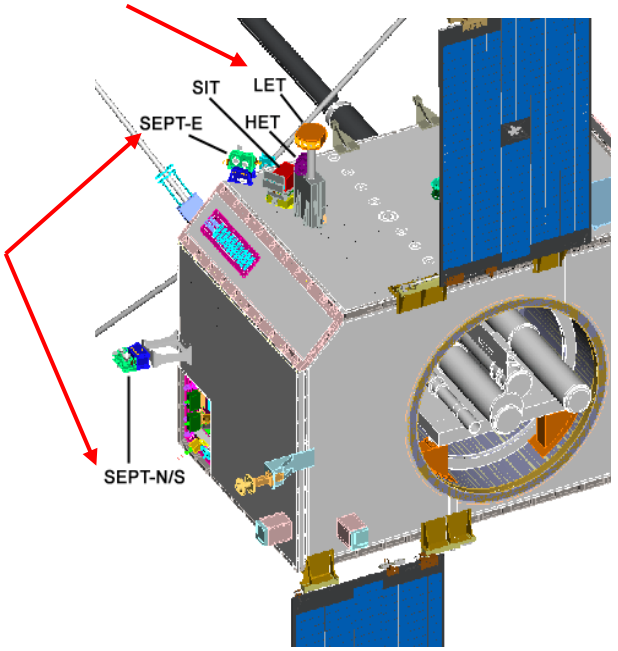
Luhman et al., 2008

http://www.solarstormwatch.com/mission_briefing/the_stereo_spacecraft

Instrumentation

stereo - impact

In-situ Measurements of Particles and CME Transients (IMPACT)



Low Energy Telescope (LET)

p: 1.8-10 (15) MeV

He: 4-10 (15) MeV/n

heavy ions

Two 133° x 29° view cones

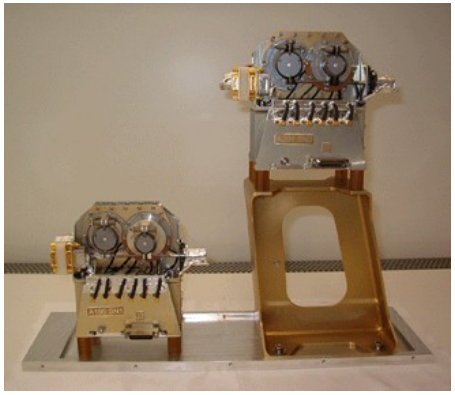
Solar Electron Proton Telescope (SEPT)

e-: 0.065-0.43 MeV

ions: 0.084-6.5 MeV

52° and 52.8° view cones; four directions

Mewaldt et al., 2008



Müeller-Mellin et al., 2008

Compilation of the STEREO catalogues

Criteria

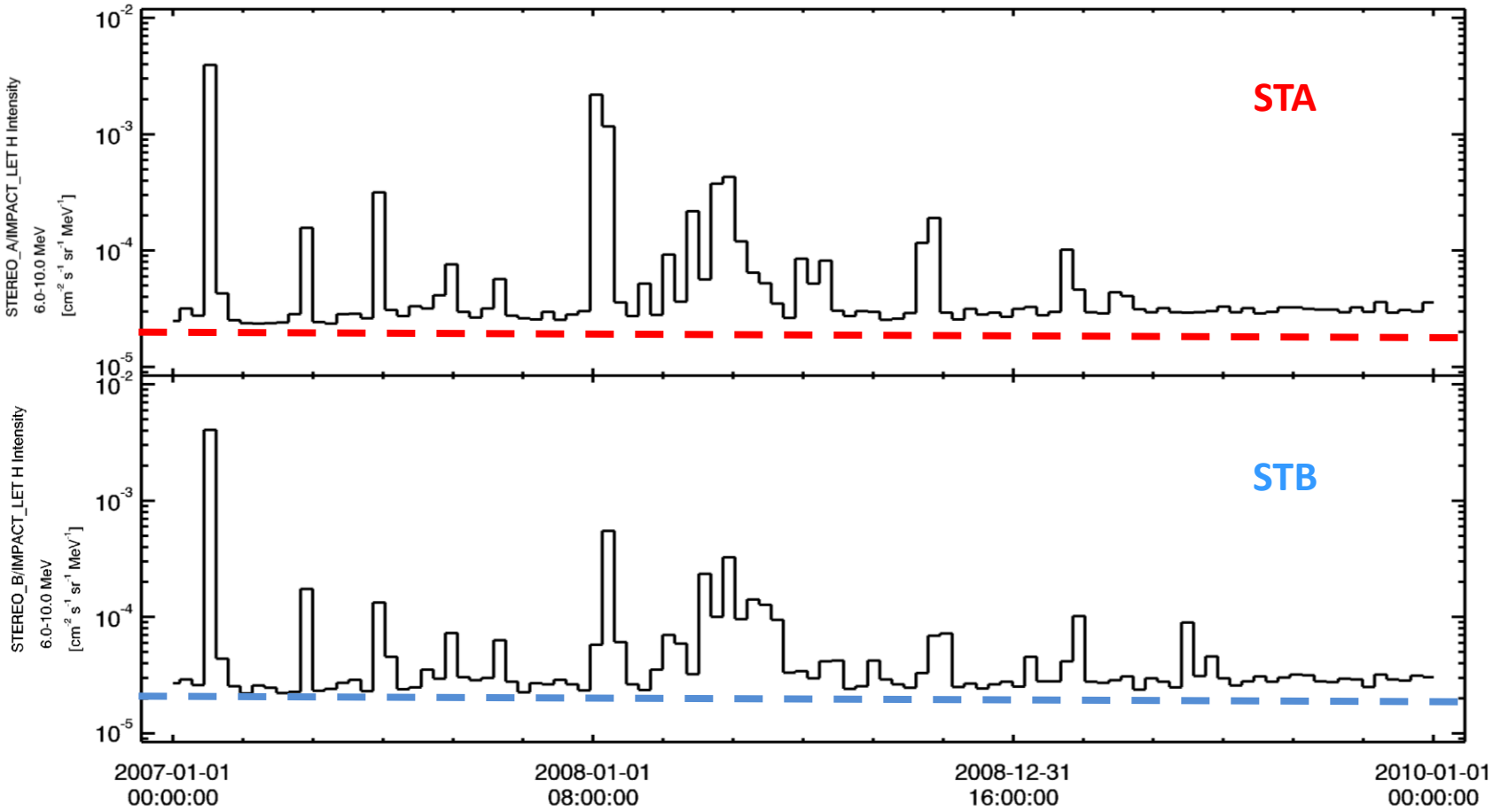
- Selection of events using **STEREO/LET protons** with 6 MeV < E <10 MeV:

  - Increases **above background**
  - No other **intensity threshold** applied
  - Cross-check with **CIRs & ICMEs**
  - Cross-check with **electrons** (SEPT)
  - Cross-check with **HET** recordings (40-100 MeV)

Papaioannou et al., in preparation, 2013

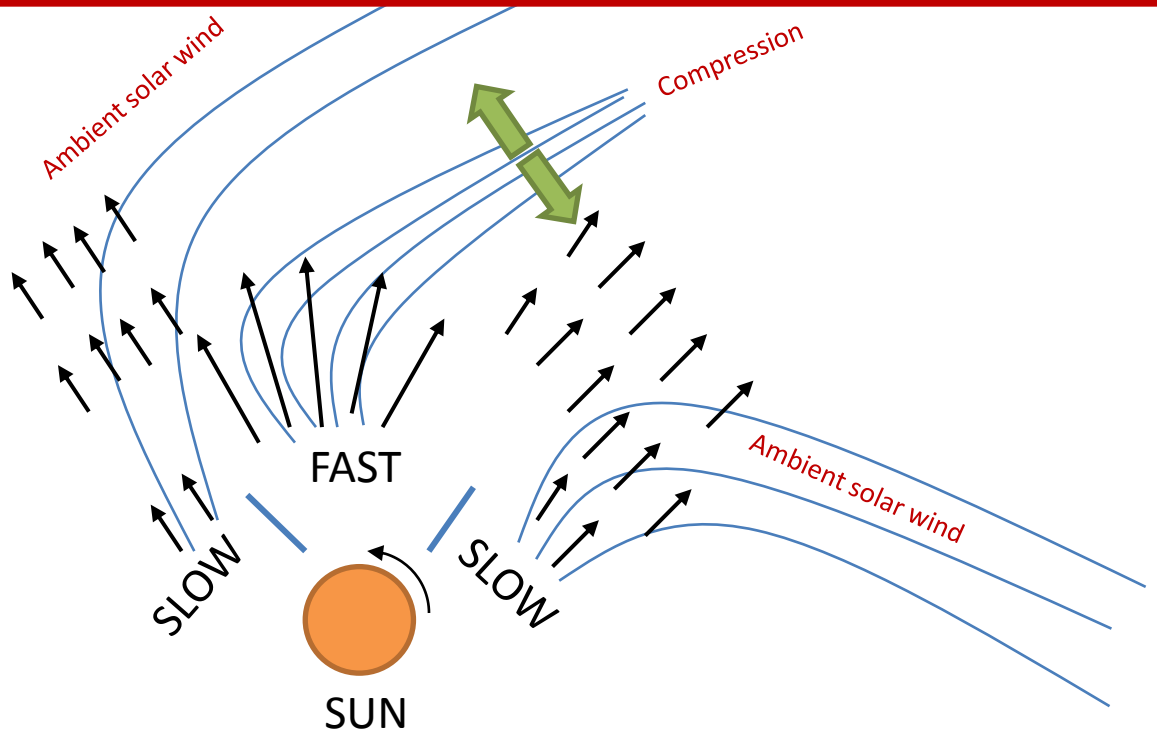
Compilation of the STEREO catalogues

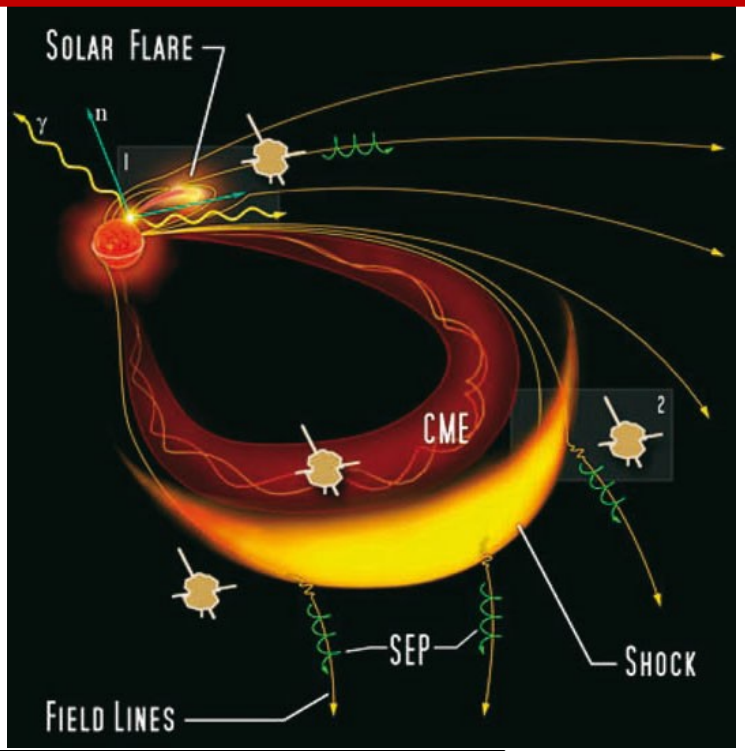
A. Increases above background



Compilation of the STEREO catalogues

B. Cross-check with CIRs/ICMEs





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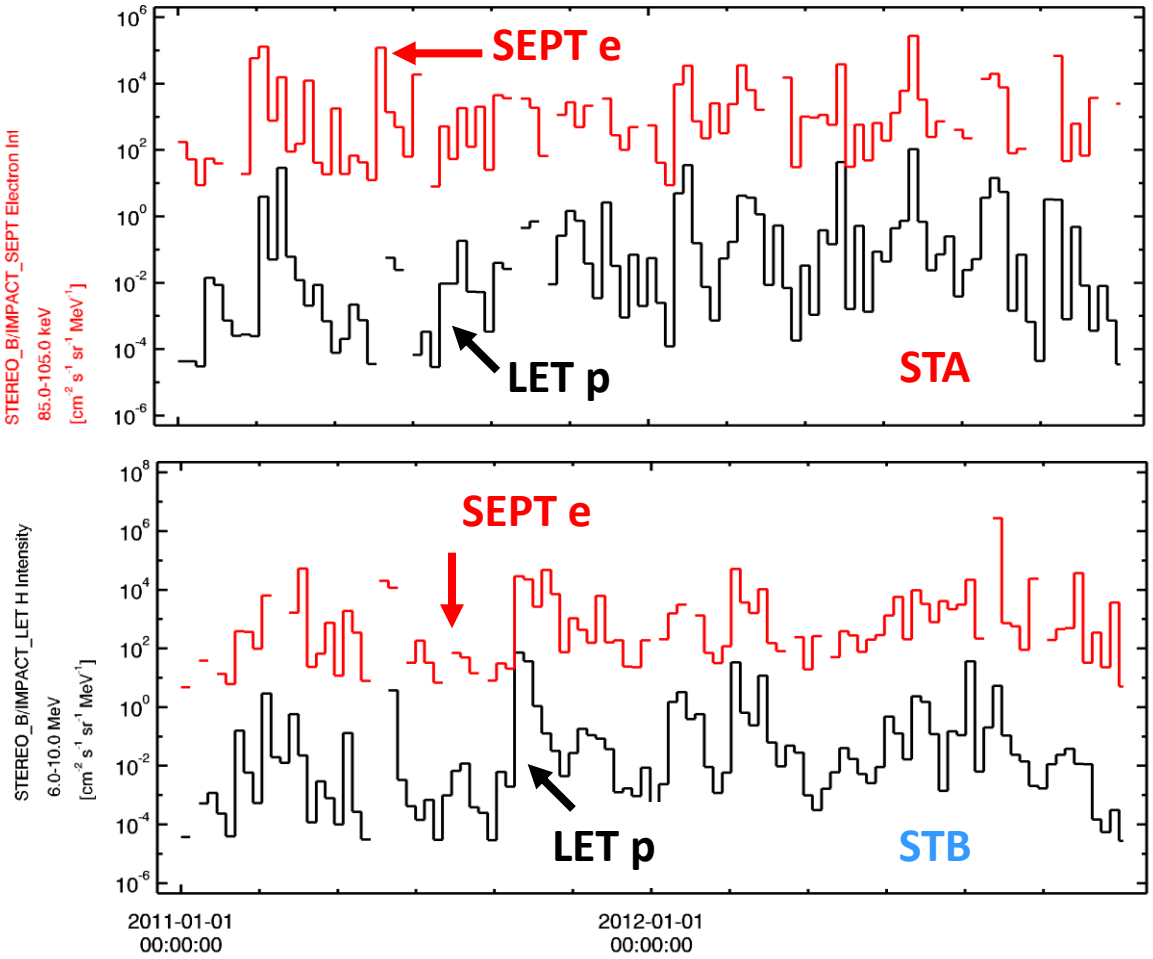
http://www-ssc.igpp.ucla.edu/~jlan/STEREO/Level3/STEREO_Level3_Shock.pdf
http://www-ssc.igpp.ucla.edu/~jlan/STEREO/Level3/STEREO_Level3_SIR.pdf
http://www-ssc.igpp.ucla.edu/~jlan/STEREO/Level3/STEREO_Level3_ICME.pdf

Compilation of the STEREO catalogues

C. Cross-check with electrons (SEPT)



Parallel scanning of NR electrons from 2007-2012

> 95 % of the STEREO/LET events present signatures in SEPT

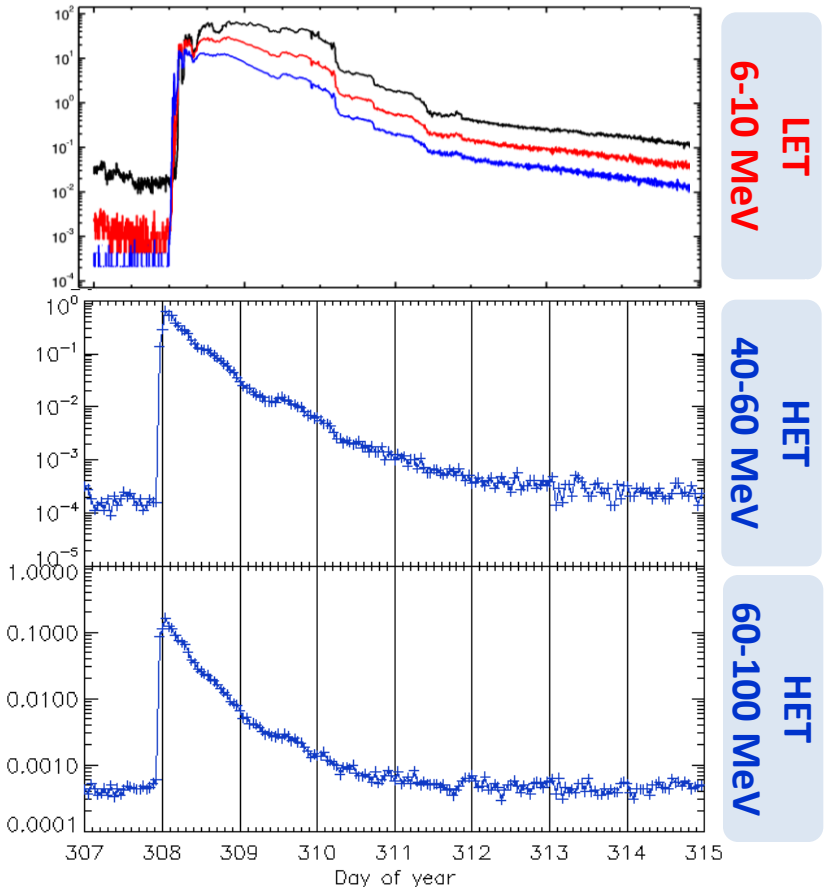
↓

Proton + Electron rich events

Compilation of the STEREO catalogues

D. Cross-check with HET recordings (40-100 MeV)

SEP Proton Event on 03.11.2011
recorded from 1.8-100 MeV



SEP events that extend to high energies

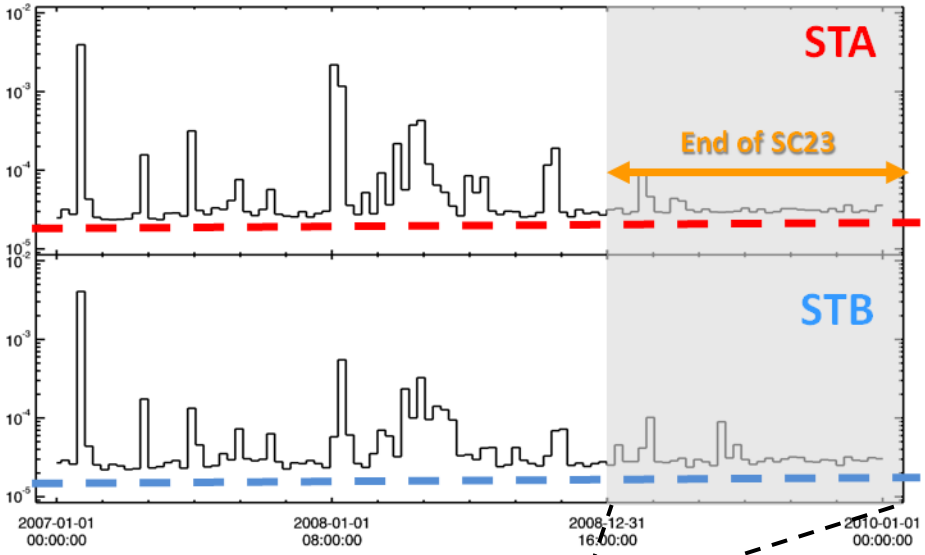
↓

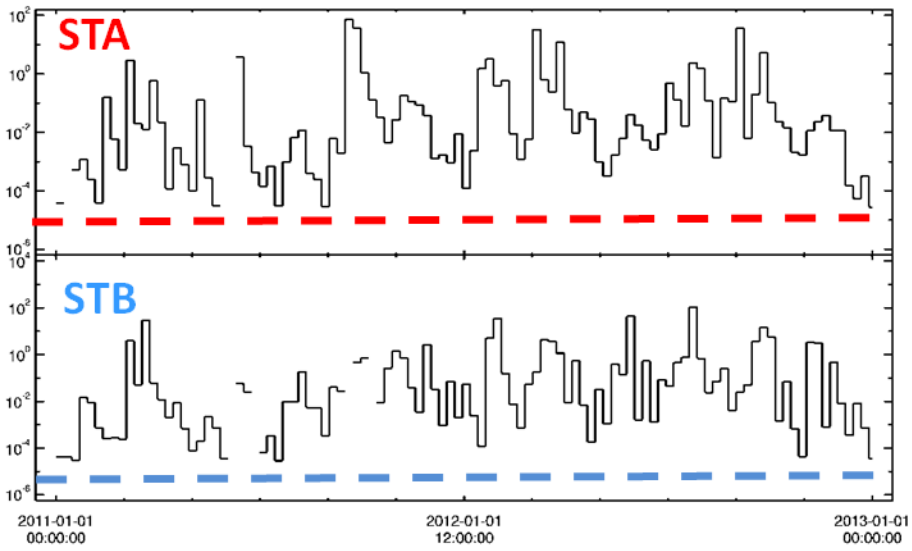
Space Weather relevant events

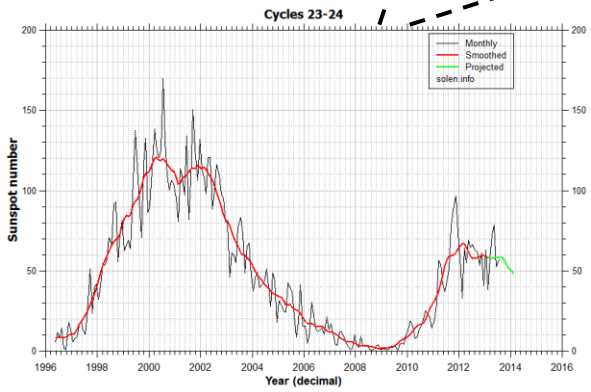
~ 30 % of the STEREO/LET events present signatures in HET energies (i.e. up to 100 MeV)

Compilation of the STEREO catalogues

Ride the wave of Solar Cycle 24



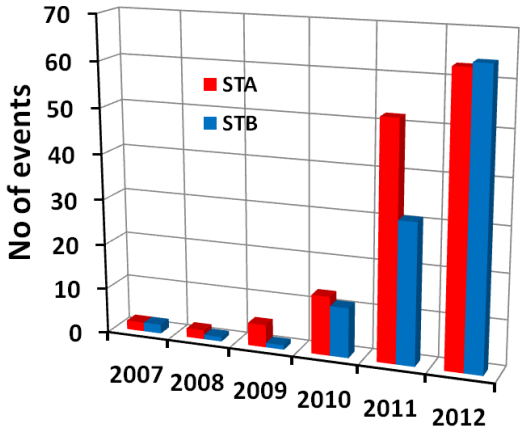




Total No of events

STA 139 events

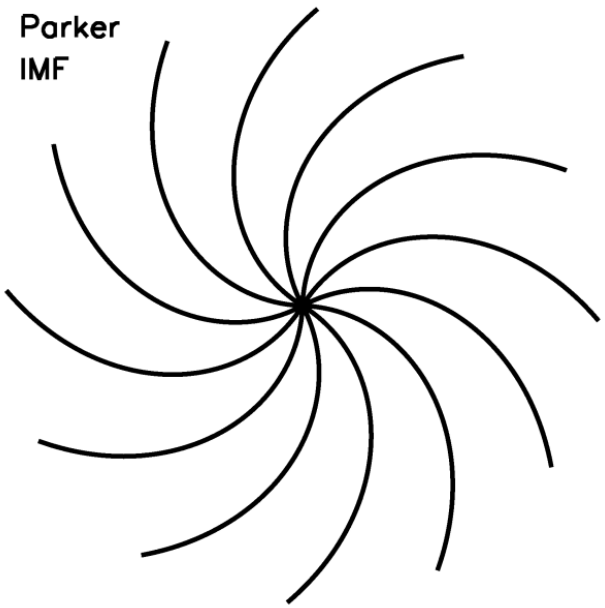
STB 113 events



Time-Shifting Analysis (TSA)

Calculating the path travelled by the particles

✓Calculation of the nominal Parker (or Archimedean) spiral



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

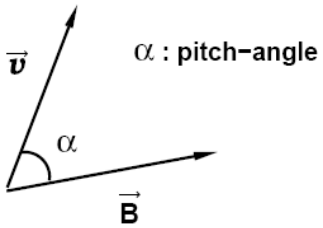
$$z(r) = \frac{a}{2}\left[\ln\left(\frac{r}{a} + \sqrt{1+\frac{r^2}{a^2}}\right) + \frac{r}{a}\sqrt{1+\frac{r^2}{a^2}}\right]$$

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

Vainio et al., 2013

Time-Shifting Analysis (TSA)

Propagation of the particles



- **Scatter-free propagation**

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

$$\mu = \cos\alpha$$

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

- **NR Electrons**

✓Onset time for **STEREO/SEPT** @ **65-105 keV**

✓Velocity of **SEPT electrons**, based on mean energy 82.6 keV: **0.53c**

Malandraki et al., 2012

STEREO/LET Catalogues *Sample*

2010

No	Date	Longitude (o)	Latitude (o)	Vsw (Km/s)	R (AU)	L(AU)	Travel time (sec)	Release Time (UT)
10	17.01.2010	64.68	-7.057	450	0.964979	1.1212	1192.766	5:06
11	08.02.2010	65.28	-5.695	490	0.963003	1.10352	1173.957	8:16
12	12.02.2010	65.388	-5.331	510	0.962602	1.09592	1165.872	11:16
13	14.02.2010	65.435	-5.161	470	0.962424	1.11233	1183.33	6:50
14	15.02.2010	65.457	-5.083	410	0.962344	1.14534	1218.447	2:41
15	02.03.2010	65.901	-3.395	360	0.960809	1.18519	1260.84	15:24
16	12.06.2010	73.473	7.717	460	0.956905	1.11592	1187.149	1:53
17	23.06.2010	74.741	7.345	530	0.95749	1.0883	1157.766	1:07
18	14.08.2010	79.955	4.112	390	0.962079	1.15981	1233.84	10:40

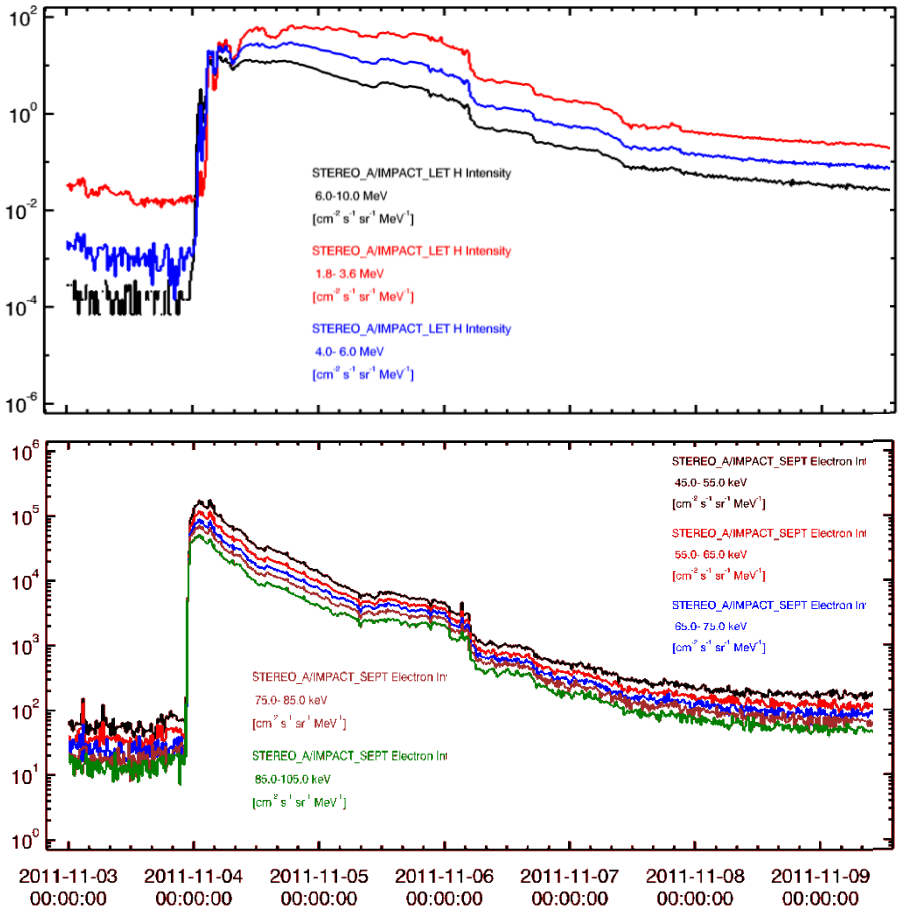
Event Characteristics

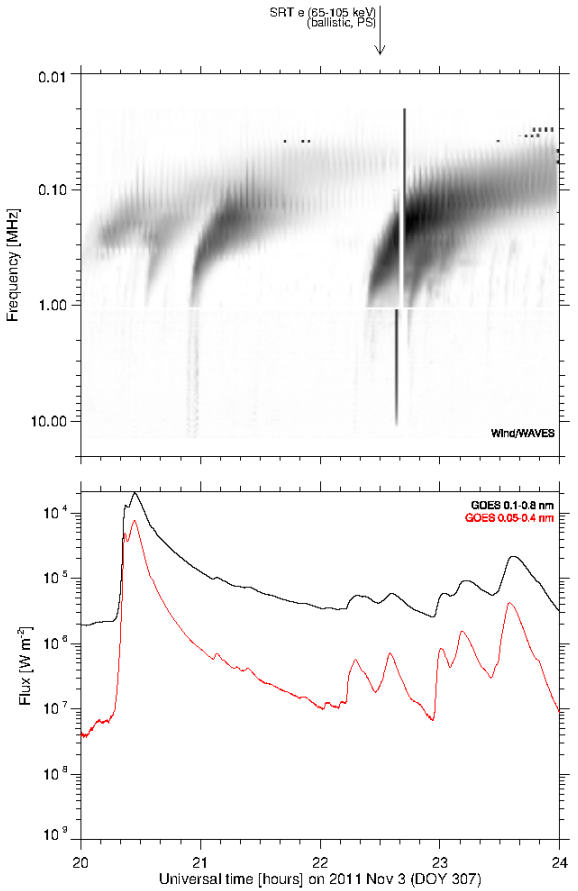
Parker Spiral

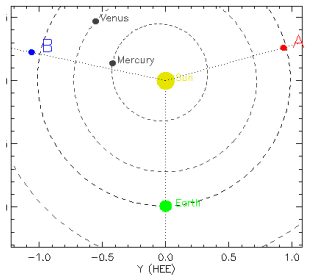
TSA (SEPT)

STEREO/LET Catalogues

Items presented in the Catalogues







Items

– **Position** plots

– **Onset** and **Peak time** for both Electrons and Protons

– Complementary **SEP plots**

– Relevant **solar EM** data

STEREO/LET Catalogues

Release of the Catalogues

Available through:
server.sepserver.eu

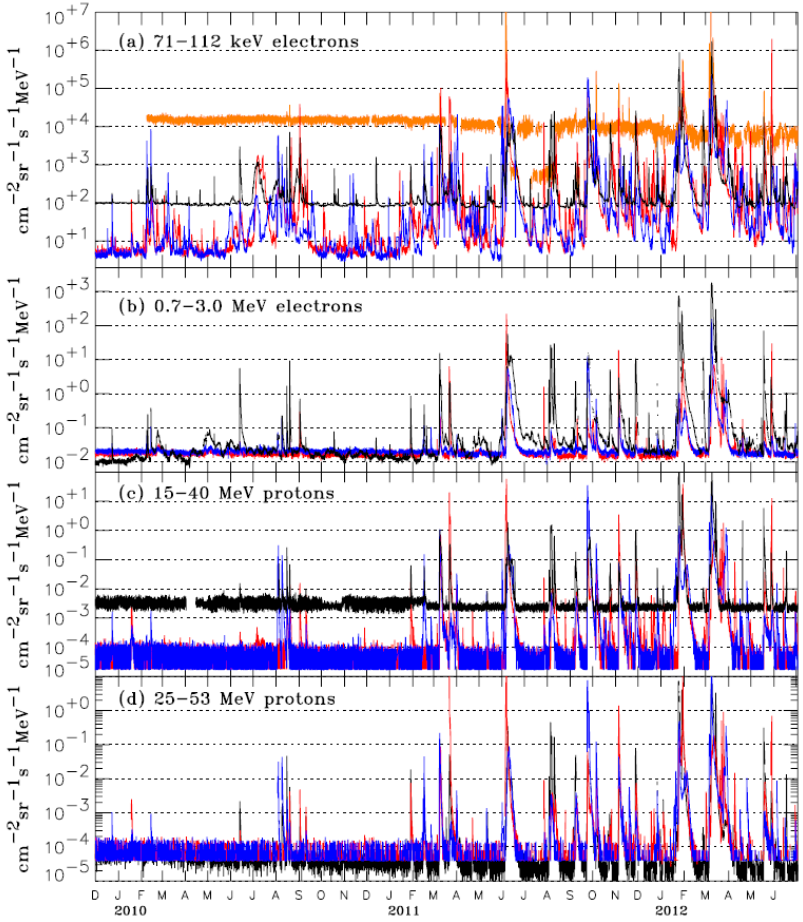
STEREO Catalogues will constitute the **5th** (**STA**) and **6th** (**STB**) Catalogues of the SEPServer Project

All of the **Items** of the **Catalogues** will be **tabulated** for easy access and will also be **linked** to the central ***SEPServer*** **database** for **direct exploitation** and further **scientific analysis** per event

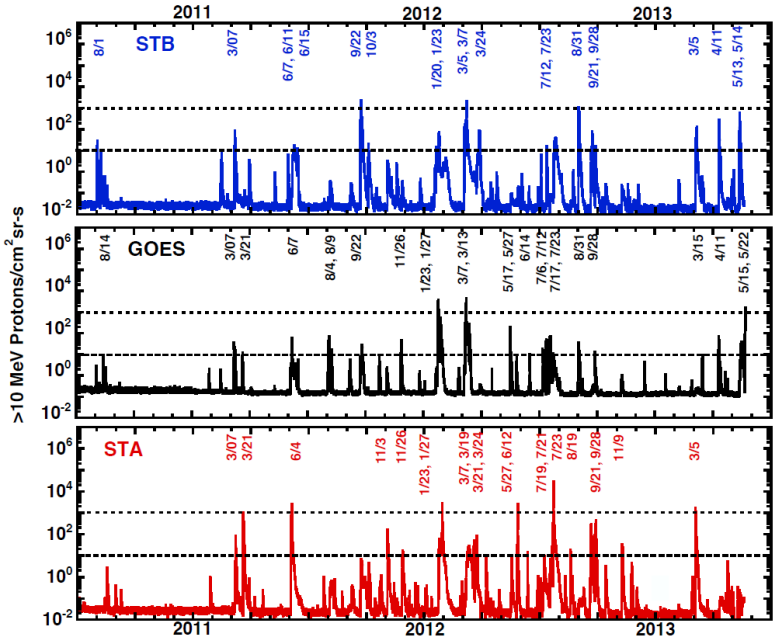
see Malandraki et al, 2013 this conference

STEREO/LET Catalogues

Validation



Lario et al., 2013



Mewaldt et al., 2013

Dresing et al., 2013

#	Event Date	Type III Onset (UT)	Long Sep Angle (°)			Electron Onset Time (UT)			Maximum Intensity of 65-105 keV e			acc. by	
			STB	ACE	STA	STB	ACE	STA	STB	ACE	STA	Type II	CME
1	2009-11-03	03:31	105	62	3	06:44	03:54	03:57	2.96e1	4.98e2	2.68e3	-	-
2	2010-01-17	03:54	-112	165	118	04:30	-	04:55	1.64e1	-	1.90e2	yes	yes
3	2010-02-07	02:29	7	-78	-121	03:04	03:00	05:32	7.31e3	6.34e2	6.36e1	-	yes
4	2010-02-08	04:20	8	-65	-116	04:32	05:45	06:00	1.79e3	1.41e3	6.19e1	-	yes
5	2010-02-12	11:23	-32	-87	-129	12:14	12:35	13:04	1.31e4	1.57e3	3.43e2	?	yes
6	2010-08-07	18:10	-40	-96	-160	19:07	19:20	-	2.42e3	3.09e2	-	yes	yes
7	2010-08-14	10:01	45	-5	-92	10:30	10:15	10:52	2.18e3	6.38e3	6.3e1	yes	yes
8	2010-08-18	05:32	92	36	-42	06:53	06:10	06:10	7.07e2	1.07e4	4.55e3	yes	yes
9	2010-08-31	20:48	133	72	17	22:07	21:35	21:21	3.61e1	6.24e3	8.95e4	yes	yes
10	2010-09-09	23:22	90	25	-50	-	00:04	01:00	3.12e1	3.42e2	1.77e2	yes	yes

A View to Future Ongoing Work

Exploitation of the Catalogues

Analysis of specific case studies [multi-spacecraft events]

Apply velocity dispersion analysis (VDA) in SW related events

Assess the data methods used in the analysis

Exploitation of the STEREO Catalogues *I.*

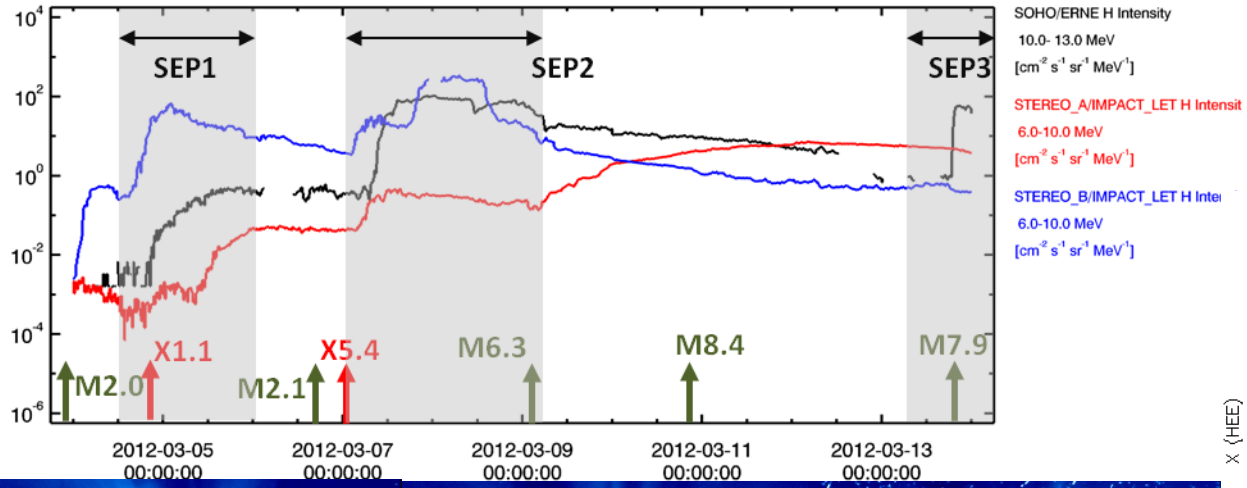
Analysis of case studies: March 2012 SEP Events

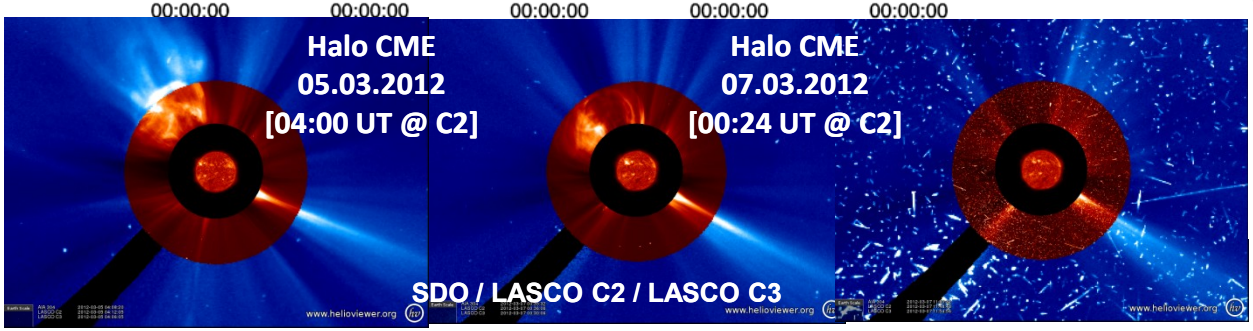
Tracking AR1429 from the E - W

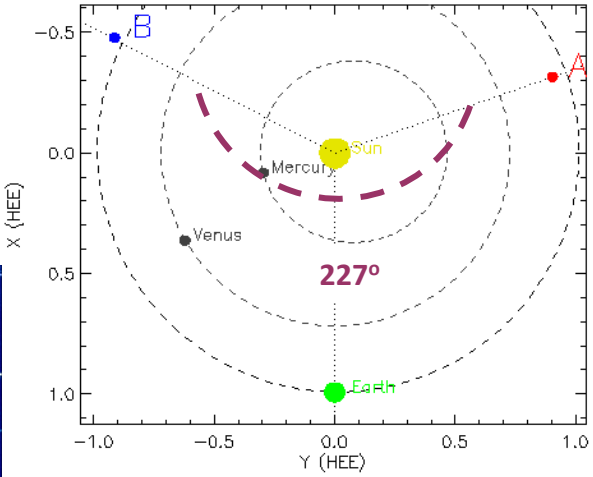
Longitudinal Separation – STA & STB = 133°

Longitudinal Separation – STA & SOHO = 109°

Longitudinal Separation – STB & SOHO = 118°







Klein et al, in preparation, 2013

Exploitation of the STEREO Catalogues *I.*

Multi-spacecraft - Wide Spread Event

Event Date	Ref.	Interpretation	Other events
03.04.2010	Rouillard et al., 2011	**Shock Evolution**	**21.03.2011** Rouillard et al., 2012
17.01.2010	Dresing et al., 2012	**Perpendicular Diffusion**	**17.05.2012** Heber et al., 2013
07.02.2010	Wiedenbeck et al., 2013 Wiedenbeck et al., 2011	**Cross-Field Transport**	Reames, 2013 Tan et al., 2013

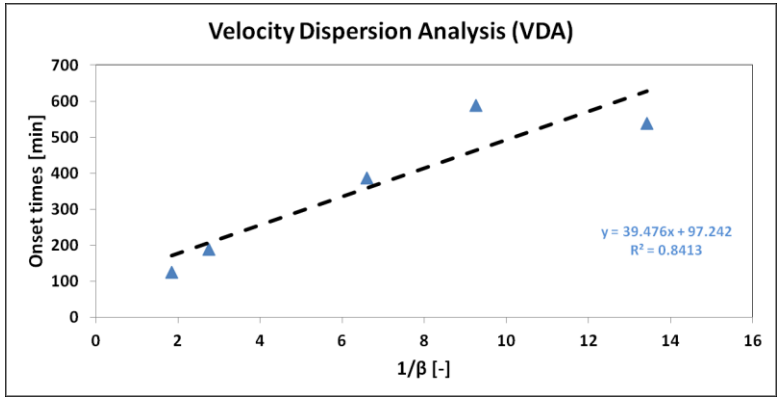
✓**A lot of new information leads to new knowledge and to new [old] questions on the source, acceleration and propagation of SEPs** ☺

✓ **Thorough examination of single case studies, in view of Multi-spacecraft measurements within STEREO era will hopefully shed light to these questions !**

Malandraki, 2013

Exploitation of the STEREO Catalogues *II.*

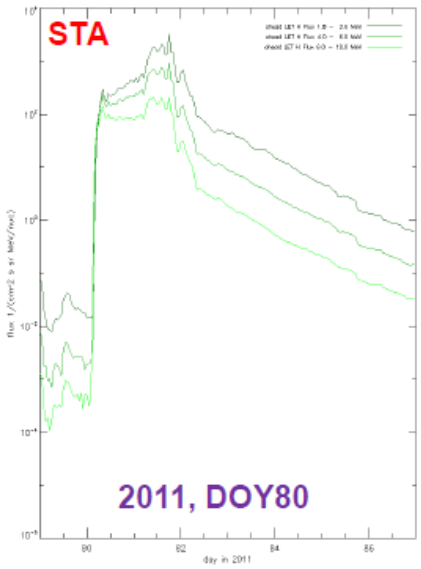
Applying Velocity Dispersion Analysis (VDA): Events of SW Interest

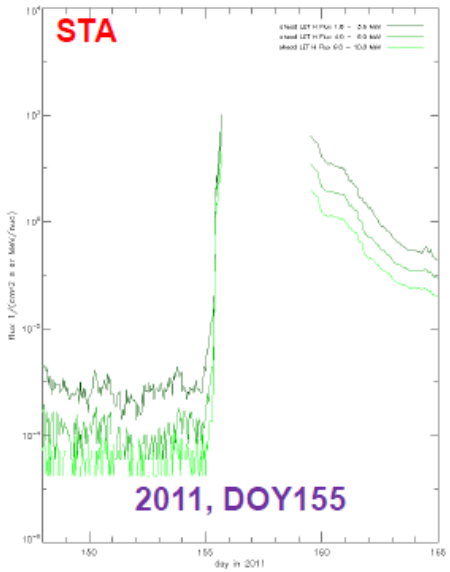


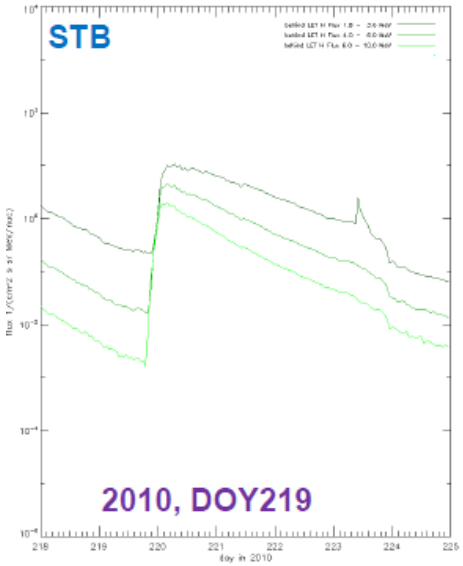
~ 30 % of the STEREO/LET events present signatures in HET energies (i.e. up to 100 MeV)

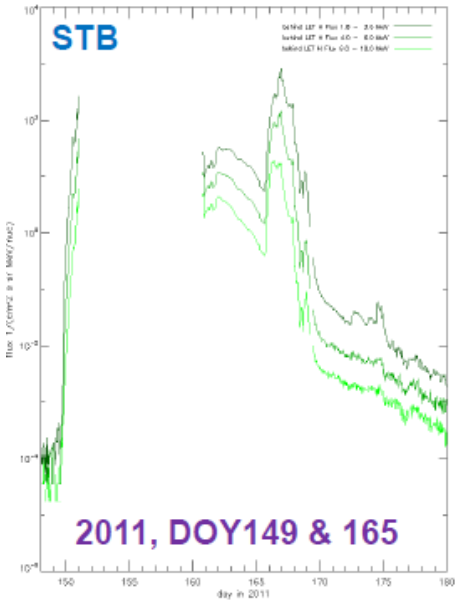
$$t_{\mathrm{onset}}(E) = t_0 + 8.33\,\frac{[\mathrm{min}]}{[\mathrm{AU}]} \cdot s \cdot \beta^{-1}(E)$$

A total of 20+ channels from the combined usage of LET and HET will lead to a detailed SRT range per event



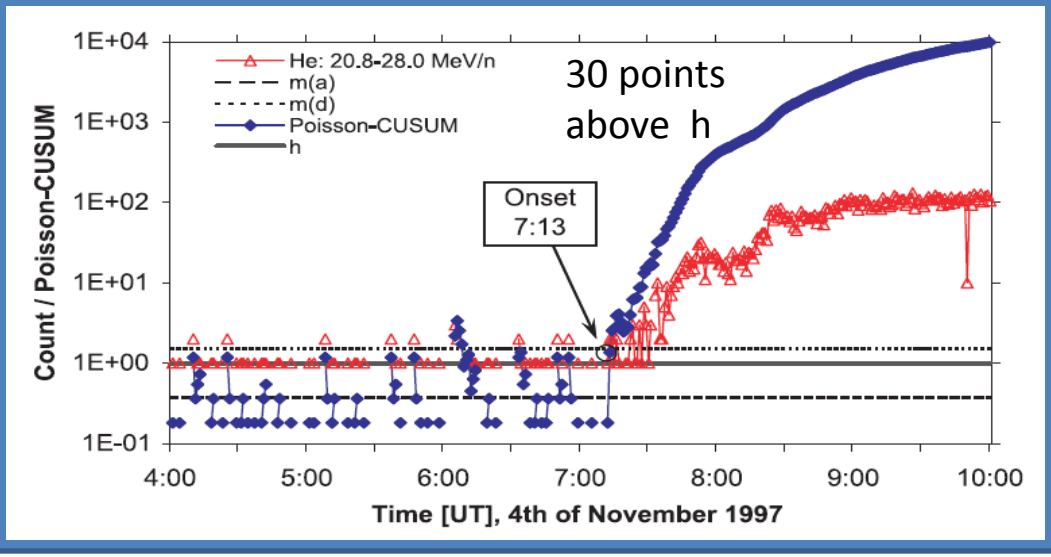






Exploitation of the STEREO Catalogues *III.*

Assessment of the Data Analysis Methods: Onset Time Determination



Method 1: Poisson-CUSUM

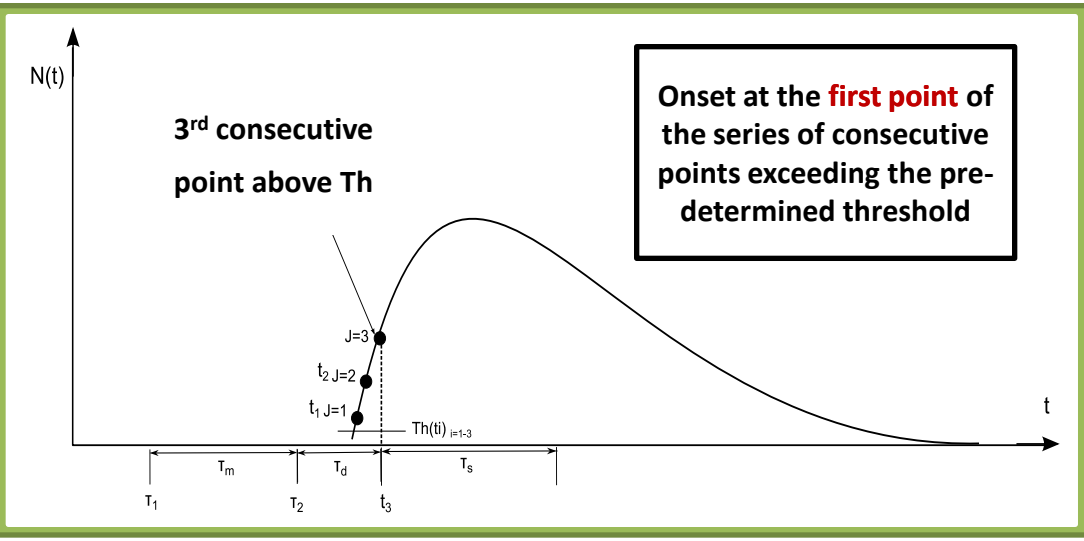
- Cumulation of the difference between an observed count Y_i in time $_i$ and a reference value k

$$S_o = 0$$

$$S_i = \max(0, Y_i - k + S_{i-1})$$

- Out-of-control signal (i.e. Onset) if S_i exceeds the decision interval **h**

Huttunen-Heikinmaa et al., 2005



Method 2: The σ method

$$I(t) = \frac{1}{\tau_m} \sum_{t=\tau-\tau 1-\tau 2}^{\tau-\tau 2} N(t)$$

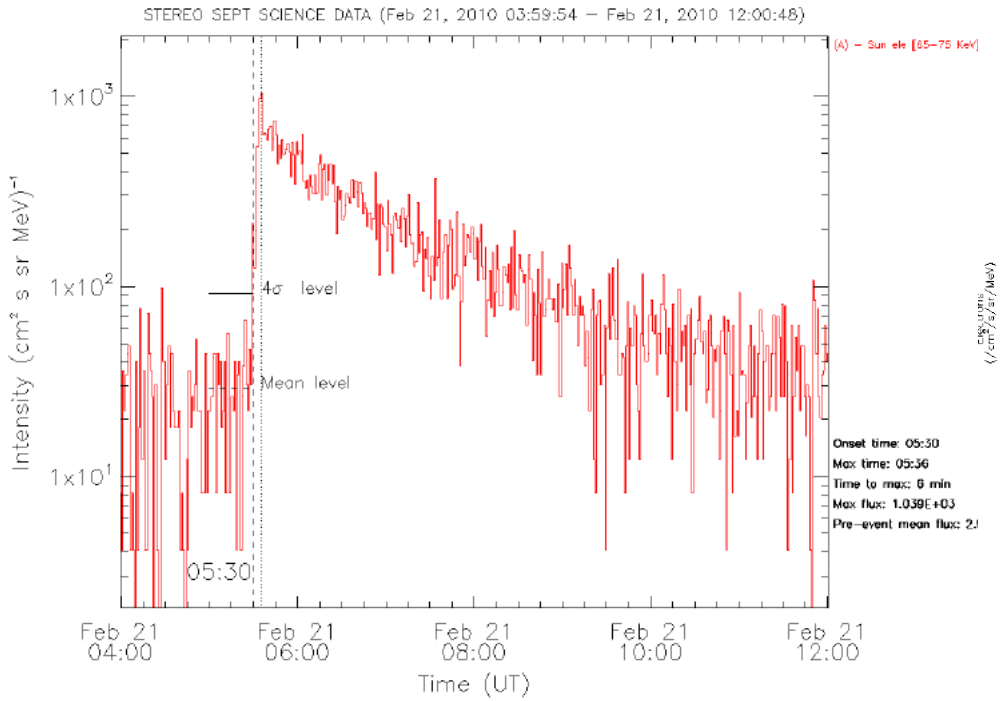
$$Th = \langle I \rangle + 3\sigma$$

$$m = 3$$

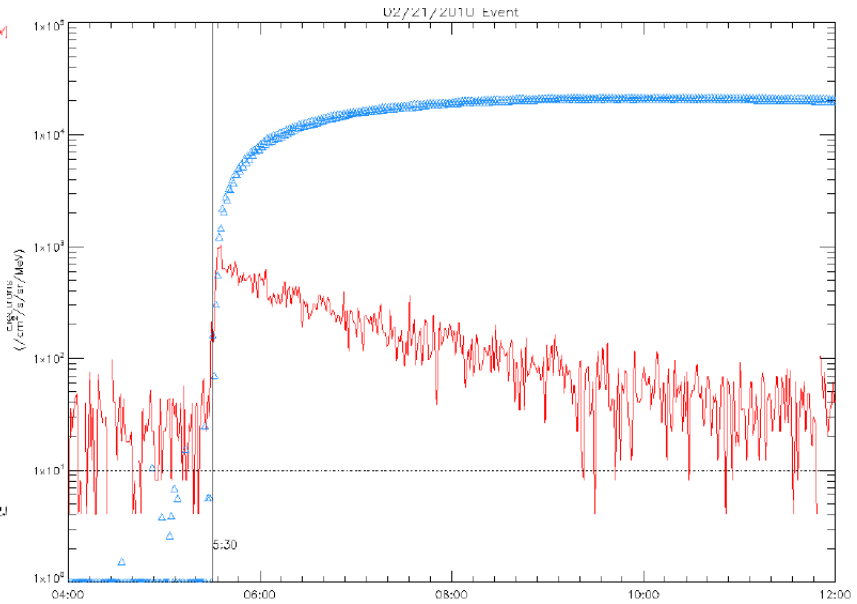
Malandraki et al., 2012

Exploitation of the STEREO Catalogues *III.*

Application / Example: STEREO SEPT



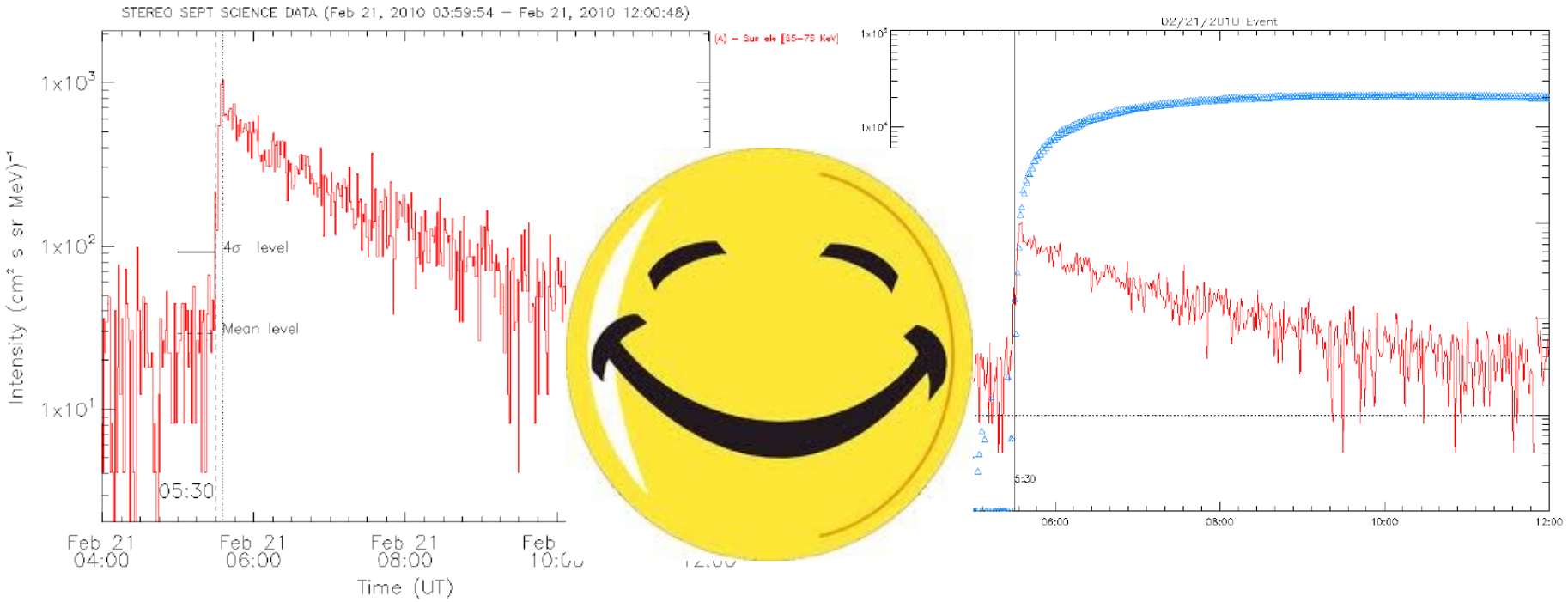
4 σ above bg @ 5:30 UT



30 points above h @ 5:30 UT

Exploitation of the STEREO Catalogues *III.*

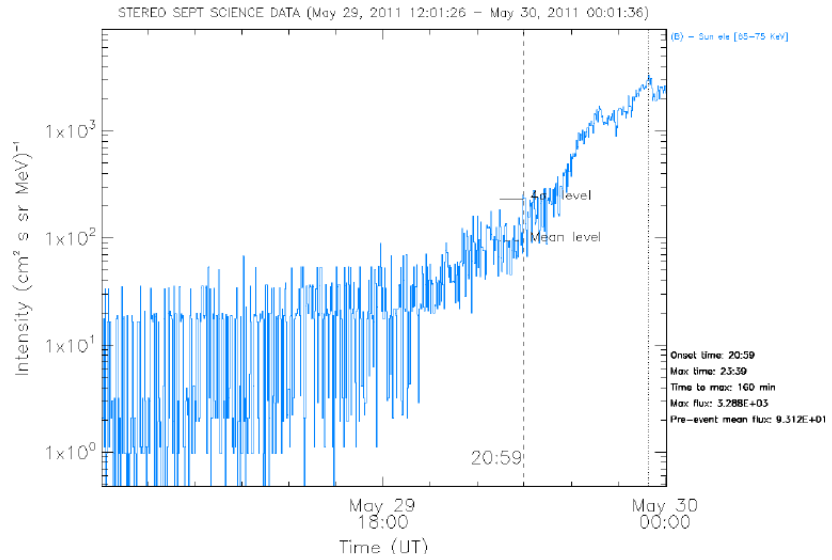
Application / Example: STEREO SEPT

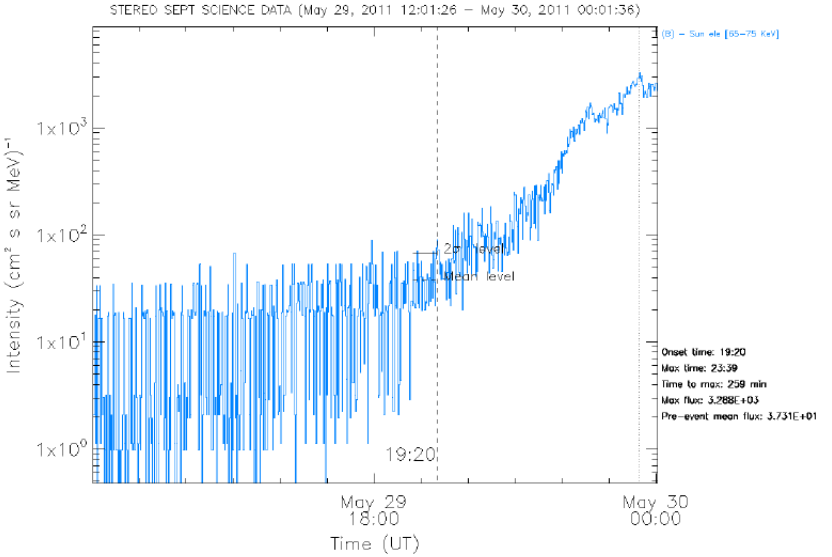


4 σ above bg @ 5:30 UT

30 points above h @ 5:30 UT

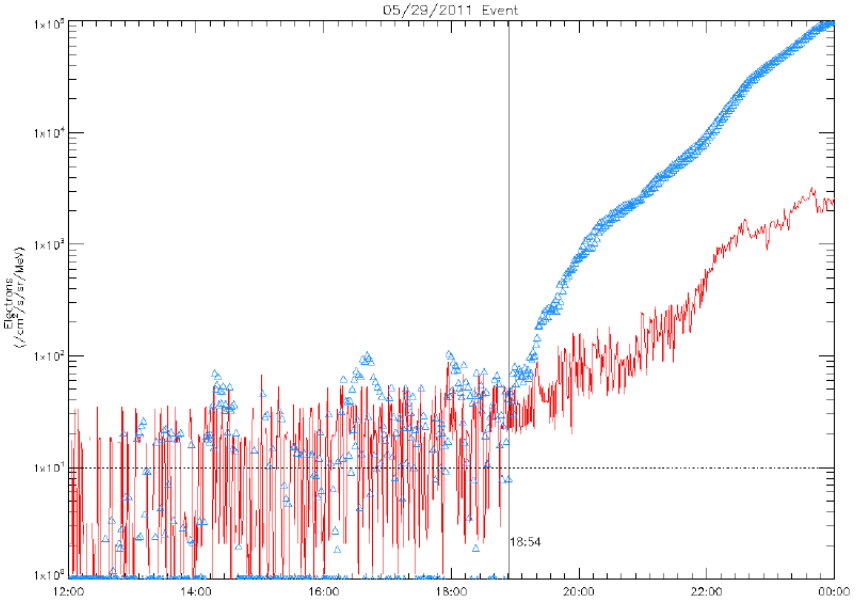
Exploitation of the STEREO Catalogues *III.*





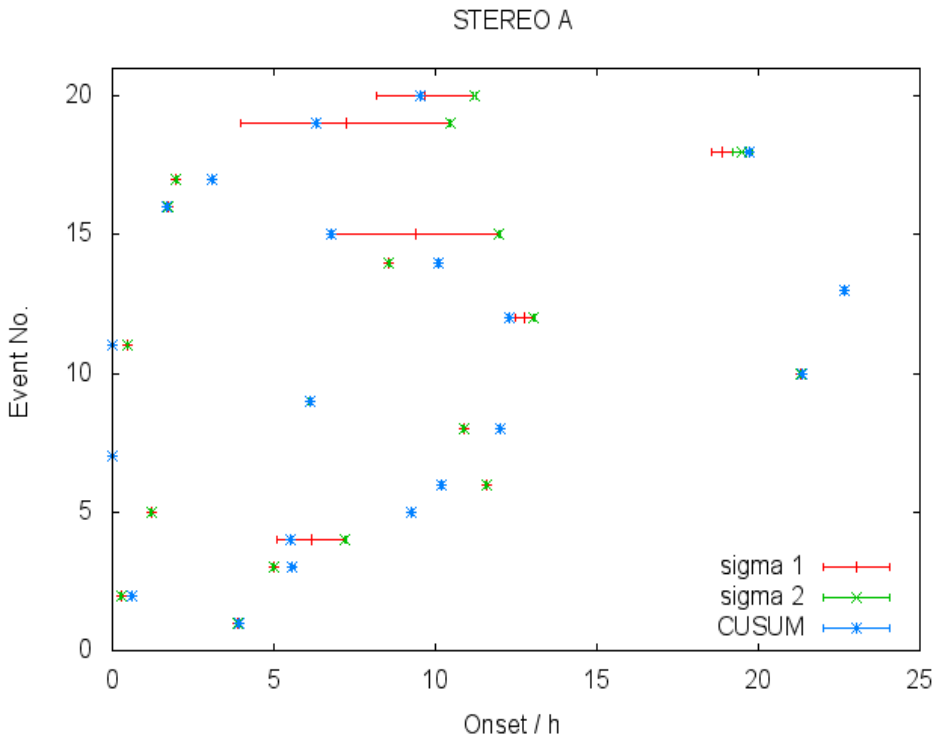
The everyday practice

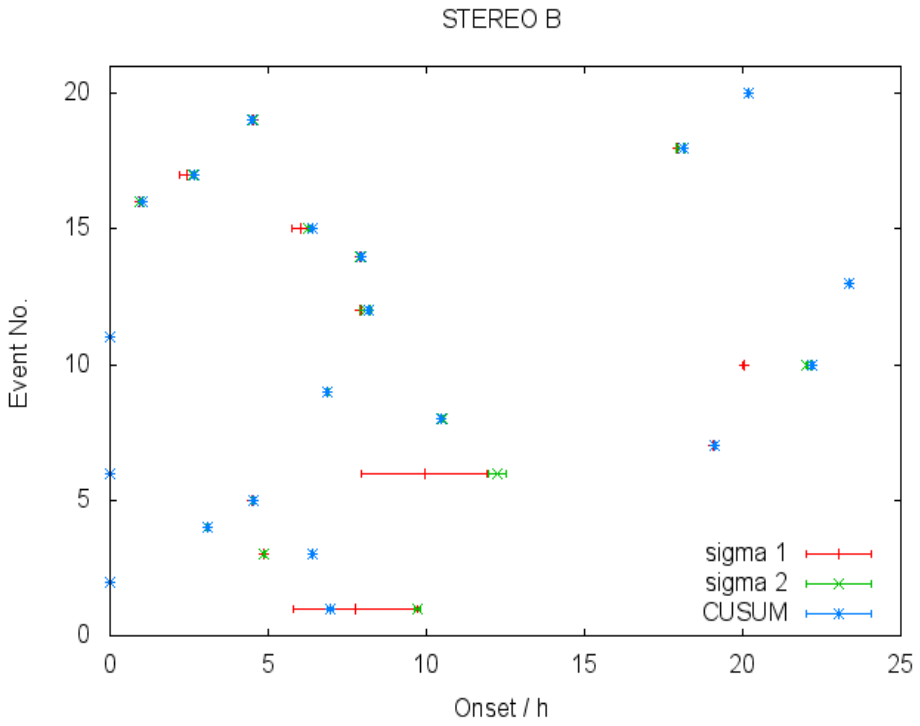
4 σ above bg @ 20:59 UT
2 σ above bg @ 19:20 UT
30 points above h @ 18:54 UT



Exploitation of the STEREO Catalogues *III.*

Comparison of the Poisson CUSUM to the σ method: STEREO SEPT





Preliminary results

Herbst et al, in preparation, 2013

Summary

Two SEP lists have been compiled

STEREO A / LET (SEPT)

STEREO B / LET (SEPT)

Time-shifting analysis (TSA)

STA & STB: SEPT electrons

Different methods of analysis have been applied

Poisson-CUSUM & n σ: STEREO/SEPT / STEREO/LET

Solar Associations

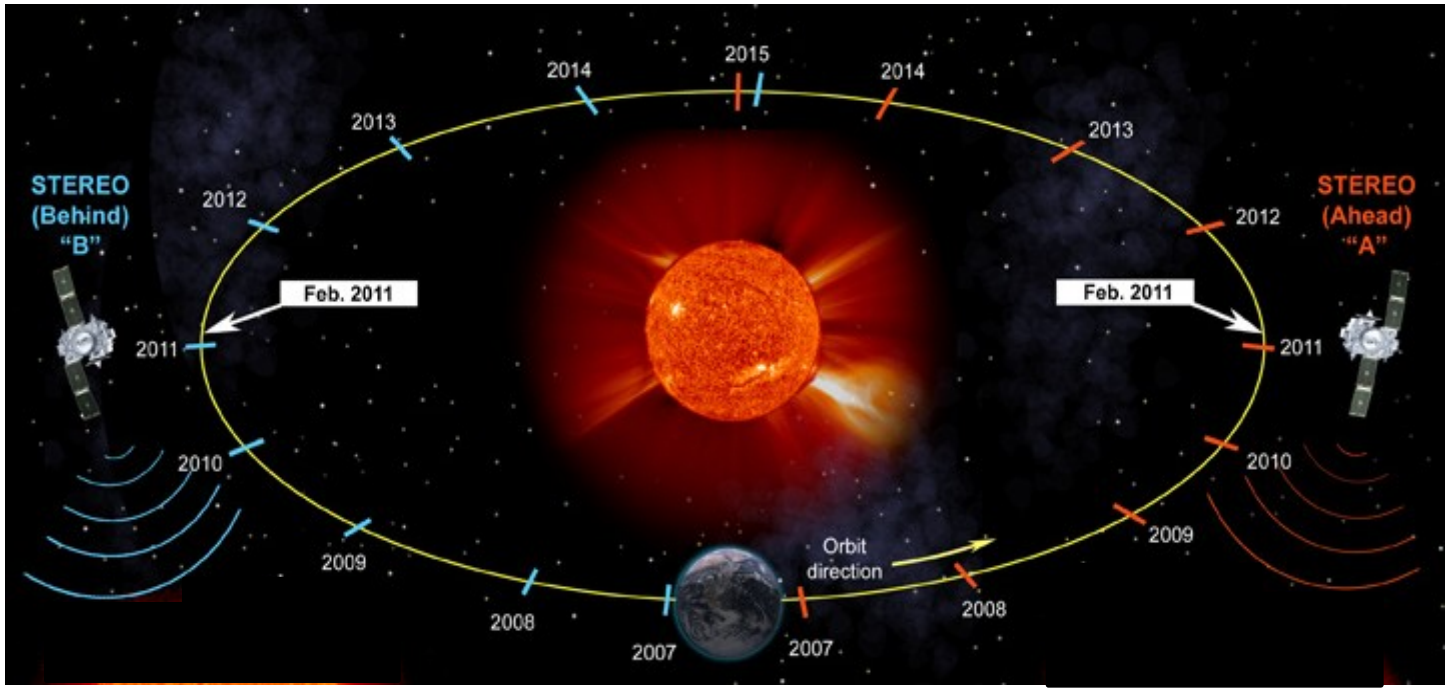
Wind/WAVES, STEREO/WAVES, ARTEMIS, NRH, CMEs (LASCO and STEREO), SXRs, HXRs

Multi-spacecraft studies

Series of March 2012 SEP events

Further Exploitation of the results through SEPServer project is in progress (i.e. VDA analysis for SW related events / Assessment of Data Methods**)**

Thank you ☺



Acknowledgments The research leading to these results has received funding from the European Union's Seventh Framework Programme (FP7/2007-2013) under grant agreement n◦ 262773 (SEPServer)

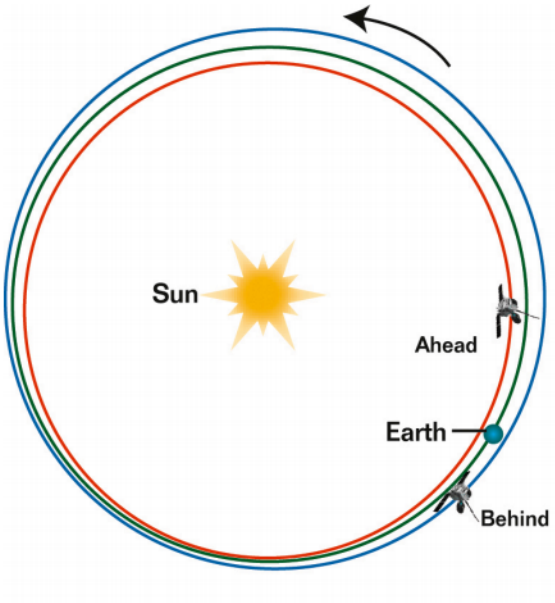
Backup slides

STEREO Orbit

(B) 1.00–1.08 AU

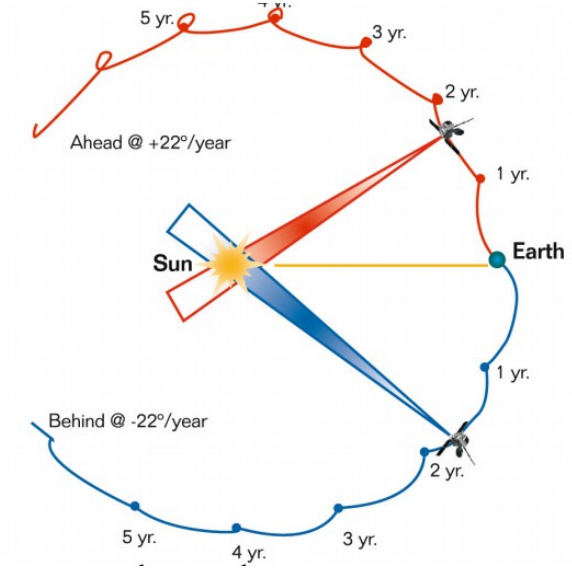
(E) 0.98–1.02 AU

(A) 0.94–0.98 AU



Heliocentric Inertial Coordinates
(Ecliptic Plane Projection)

Kaiser et al., 2008

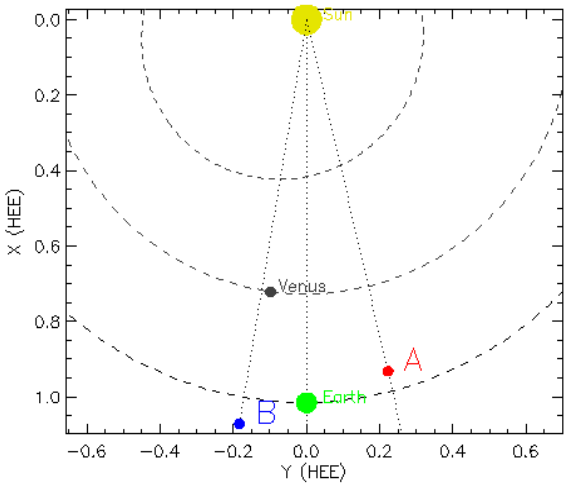


Geocentric Solar Ecliptic Coordinates
Fixed Earth-Sun Line
(Ecliptic Plane Projection)

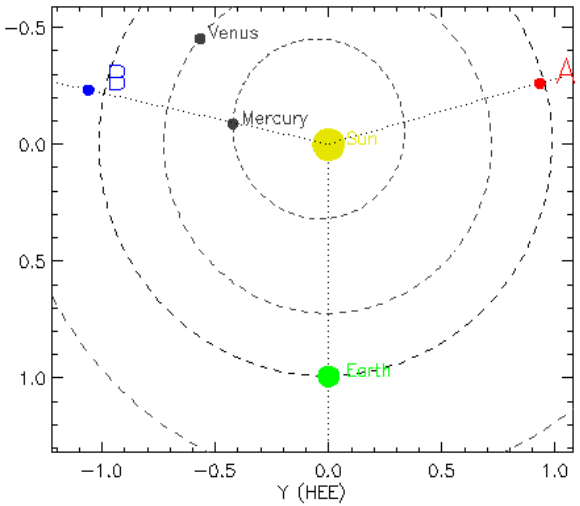
Bucik et al., 2013

STEREO Orbit

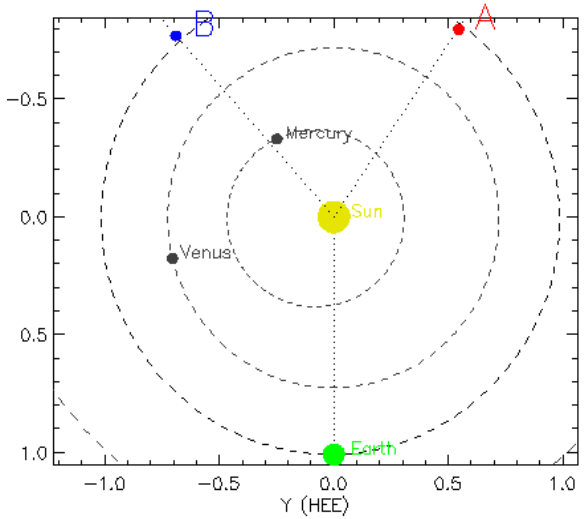
STA, EARTH & STB in 2007
(Beginning of the Mission)



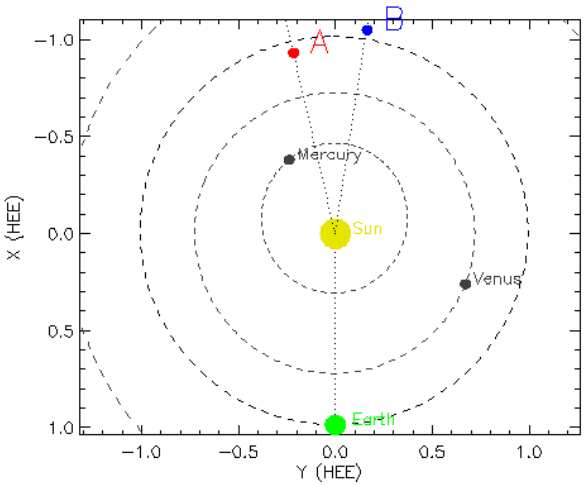
STA, EARTH & STB in 2011
(Beyond the Visible Sun !)



STA, EARTH & STB in 2013
(Today September 2013)



Multiple recordings within the Heliosphere

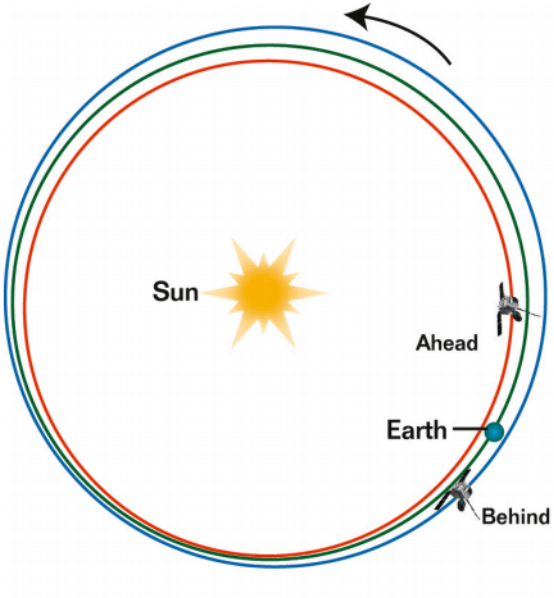


STA, EARTH & STB in 2015
(Full 3D Vision of the Sun !)

http://stereo-ssc.nascom.nasa.gov/

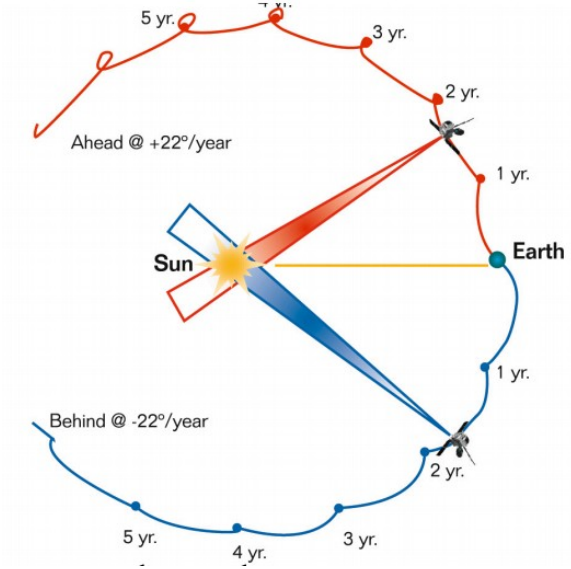
STEREO Orbit

(B) 1.00–1.08 AU
(E) 0.98–1.02 AU
(A) 0.94–0.98 AU



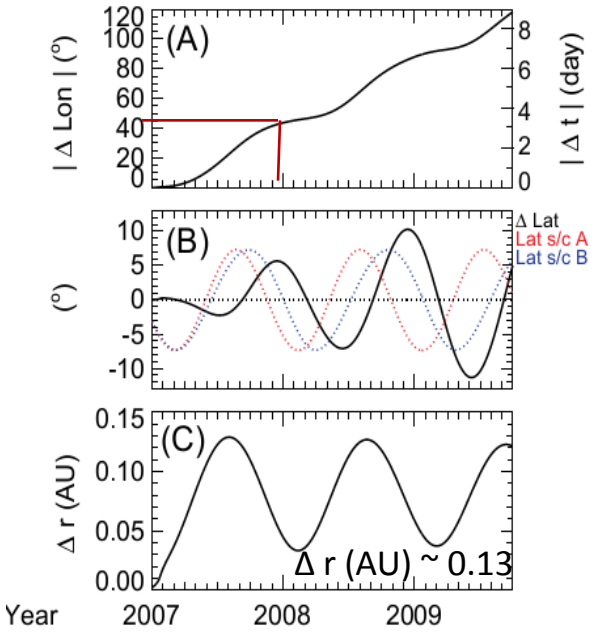
Heliocentric Inertial Coordinates
(Ecliptic Plane Projection)

Kaiser et al., 2008



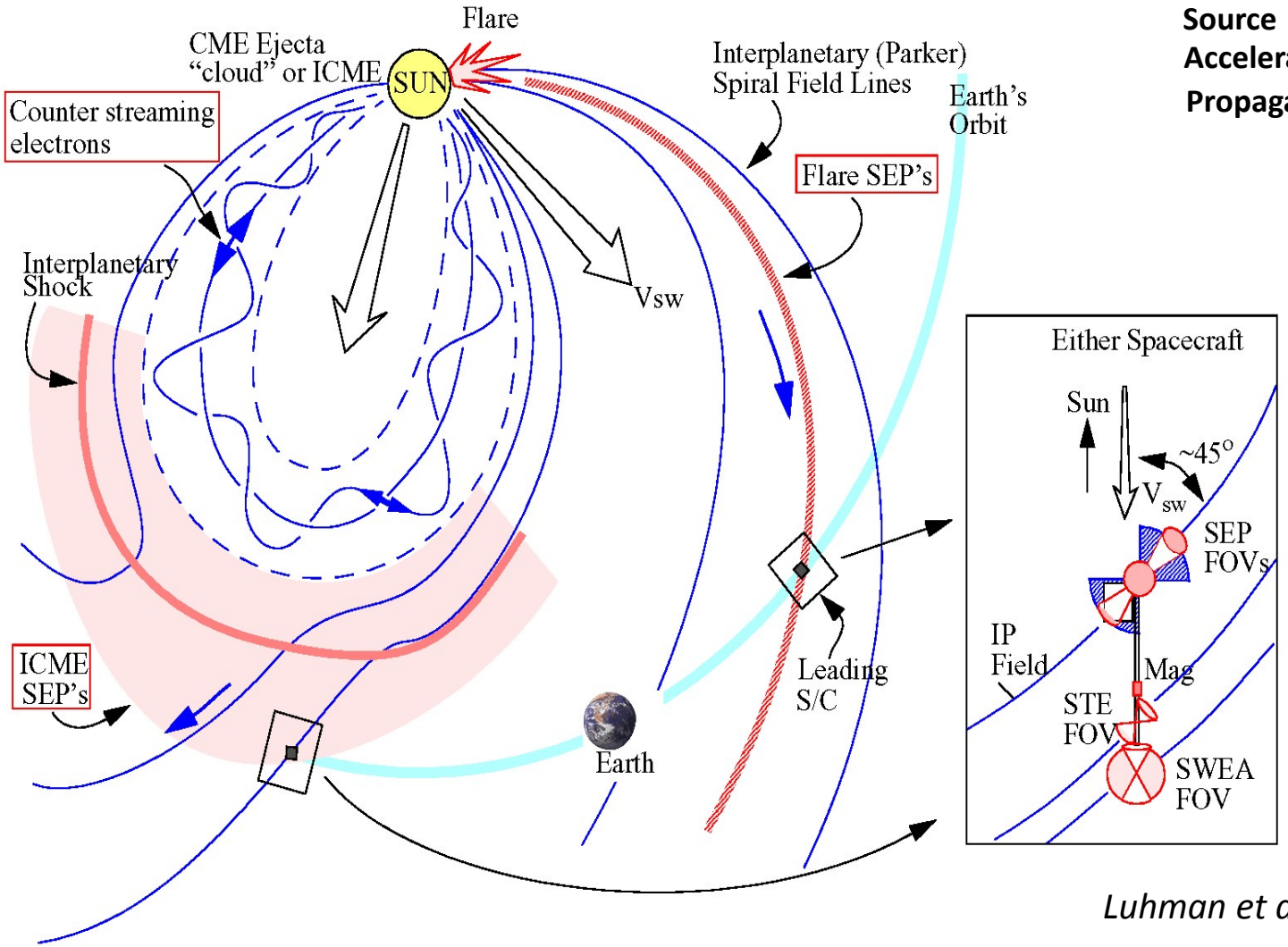
Geocentric Solar Ecliptic Coordinates
Fixed Earth-Sun Line
(Ecliptic Plane Projection)

Δ Lon ~44°/year



Bucik et al., 2013

The Multi-spacecraft Approach – STEREO era

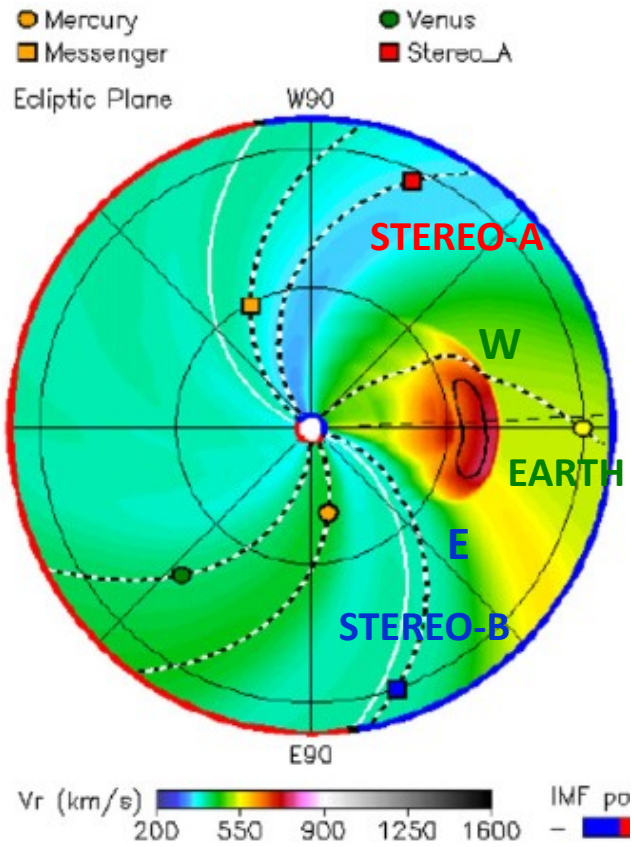


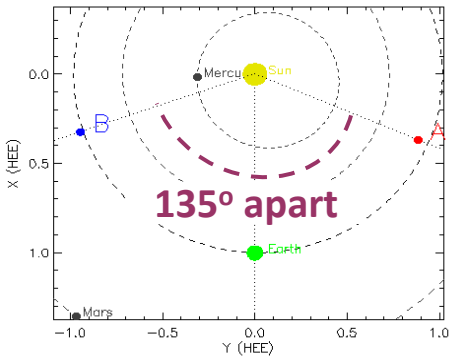
Source
Acceleration
Propagation

Luhman et al., 2008

The Multi-spacecraft Approach – STEREO era

03 April 2010 | Multi-spacecraft Wide Spread Event *I*

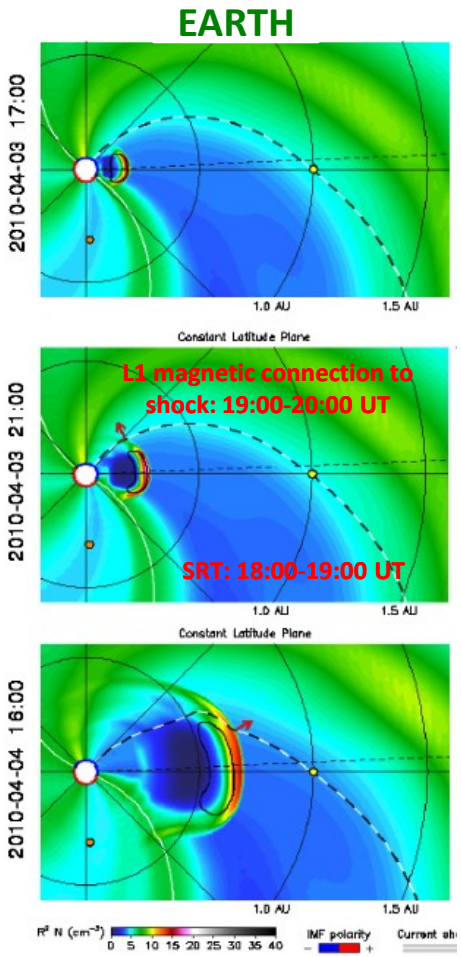




STB & EARTH recorded an SEP / STA did not

EARTH is connected to the W edge of the shock

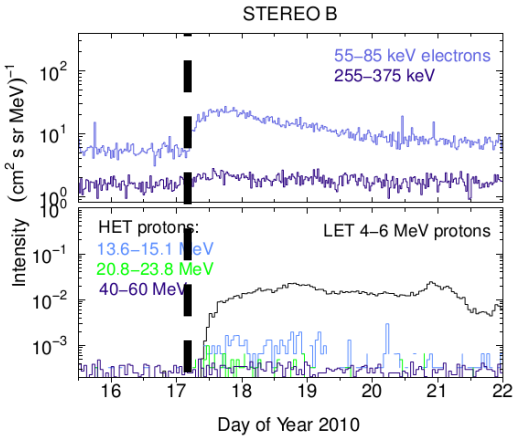
STB is connected to the E edge of the shock

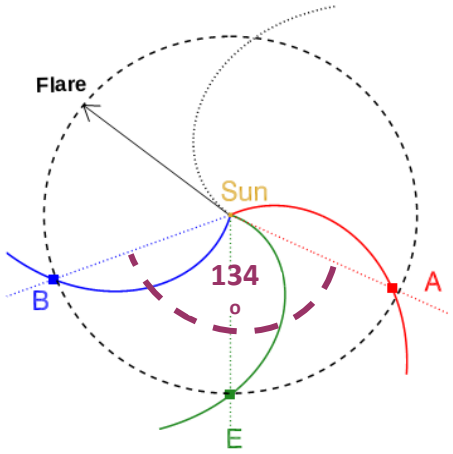


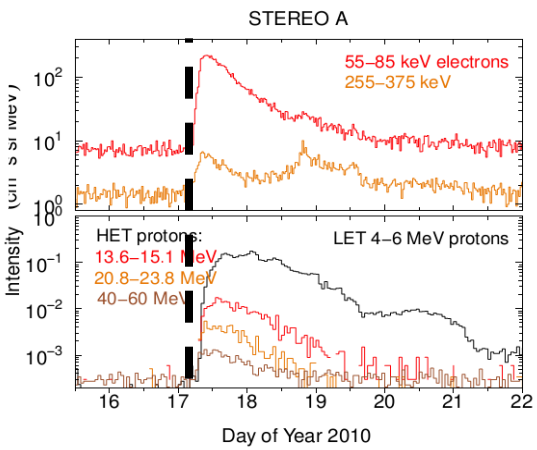
Rouillard et al., 2011

The Multi-spacecraft Approach – STEREO era

17 January 2010 | Multi-spacecraft Wide Spread Event *II*

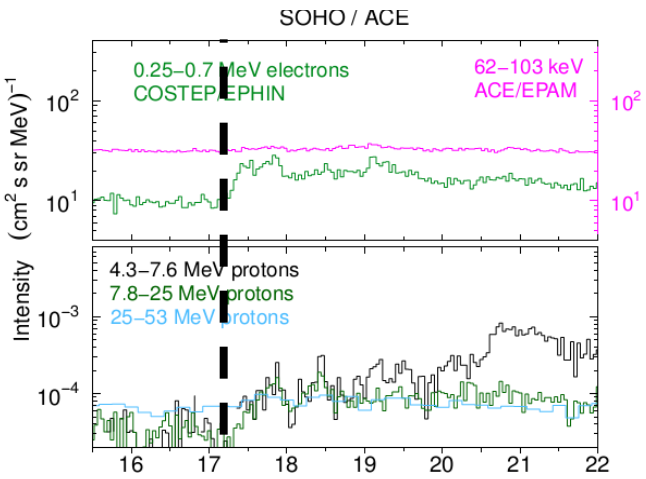






STB – Onset time: 4:30±24 min

STA – Onset time: 4:55±24 min



Longitudinal Separation – Flare & STB foot point 113°

Longitudinal Separation – Flare & SOHO foot point 161°

Longitudinal Separation – Flare & STA foot point 117°

Flare onset time – SEP @ STB *49min*

Flare onset time – SEP @ EARTH ~*2.5h*

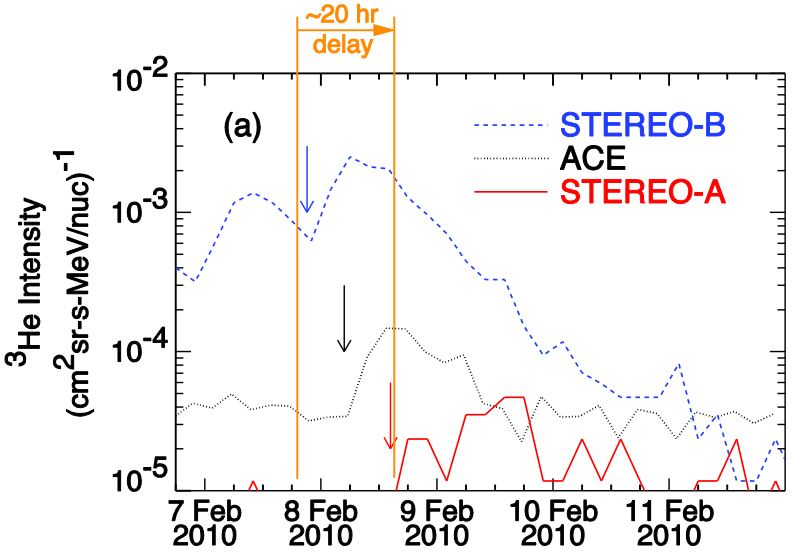
Flare onset time – SEP @ STA *74min*

Dresing et al., 2012

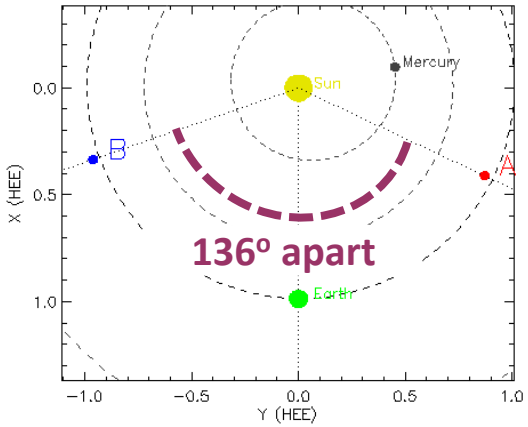
EARTH – Onset time: 6:16±57 min

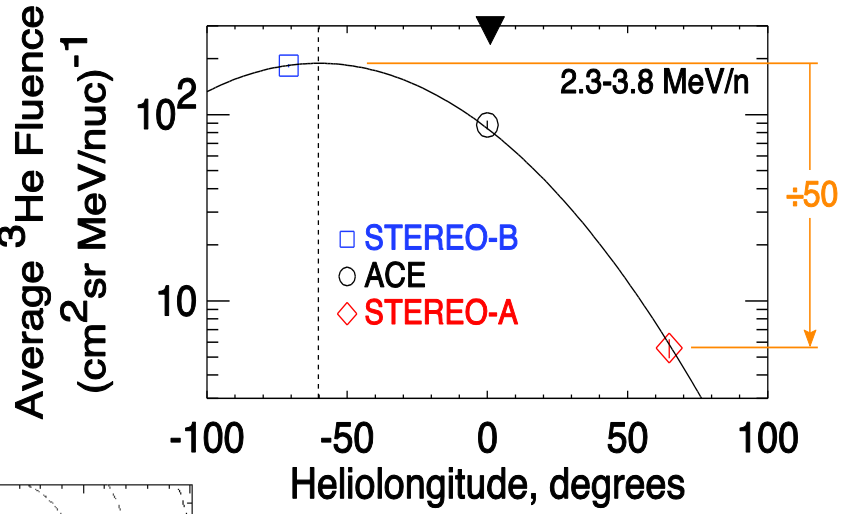
The Multi-spacecraft Approach – STEREO era

7 February 2010 | Multi-spacecraft Wide Spread Event *III*



✓ ***~20 hr delay*** was observed between the ***onset*** at ***STB*** and ***STA***.





✓ The ***peak intensity*** at ***STA*** was smaller by a factor of ~50 from that observed at ***STB***.

Wiedenbeck et al., 2011, 2013

Reames, 2013