The Effects of the interplanetary Shocks on Energetic Storm Particle Events

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ISEST Mexico City 2015

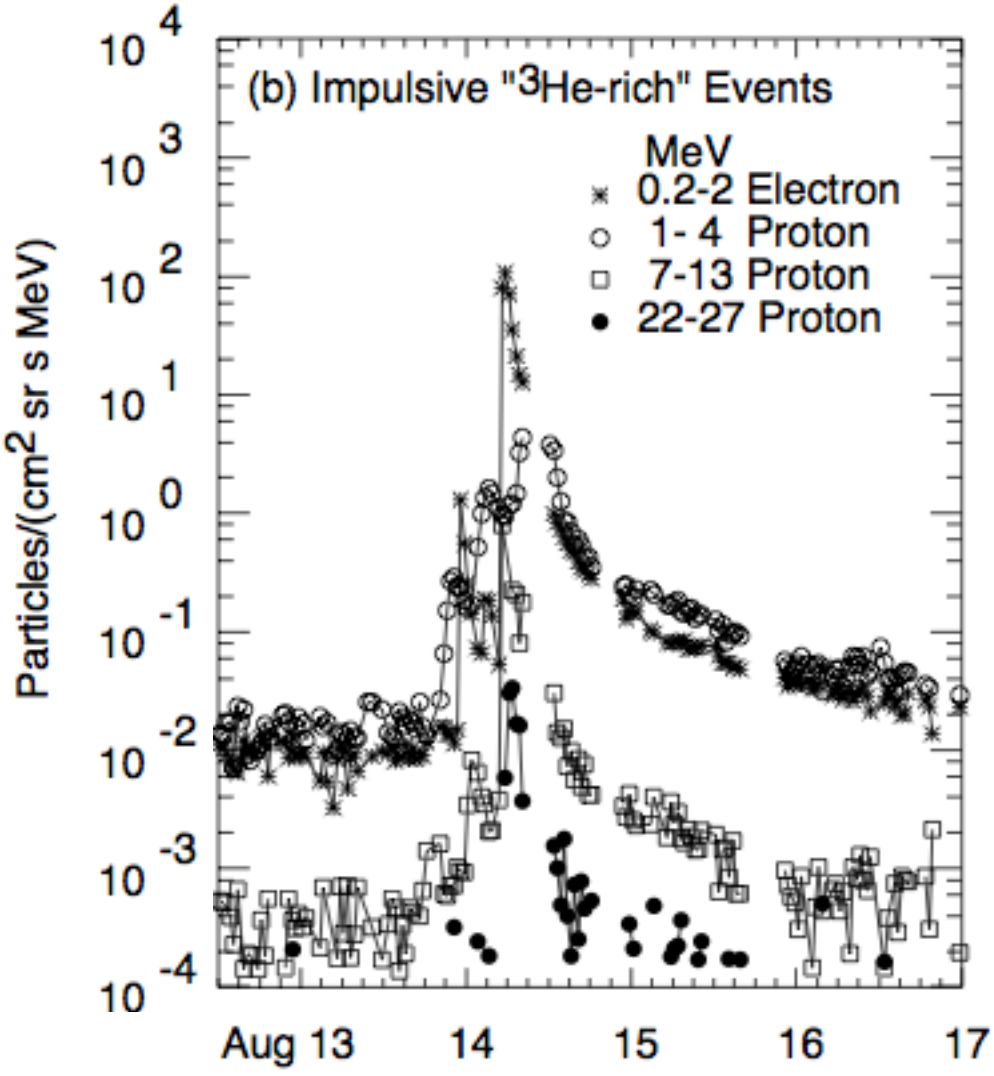
Outline.

- A fast introduction to SEP's
- … but not everything in the garden is rosy
- Trying to map the SEP in relation to connection to the shock
- Preliminary results
- Future work and possible collaboration

A fast introduction to SEP's.

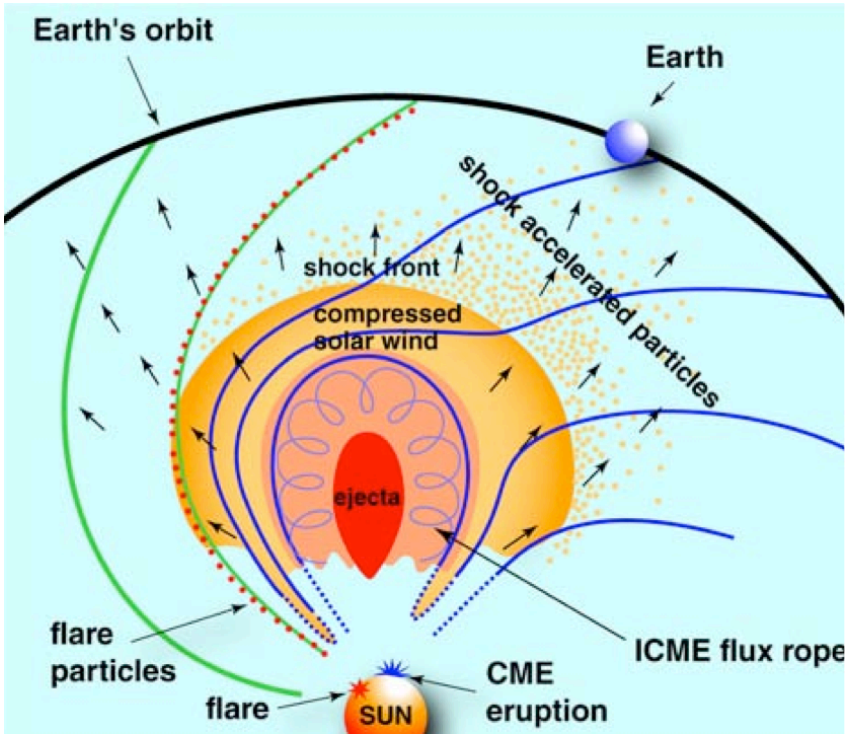
Reames et. al 1988

IMPULSIVE EVENTS



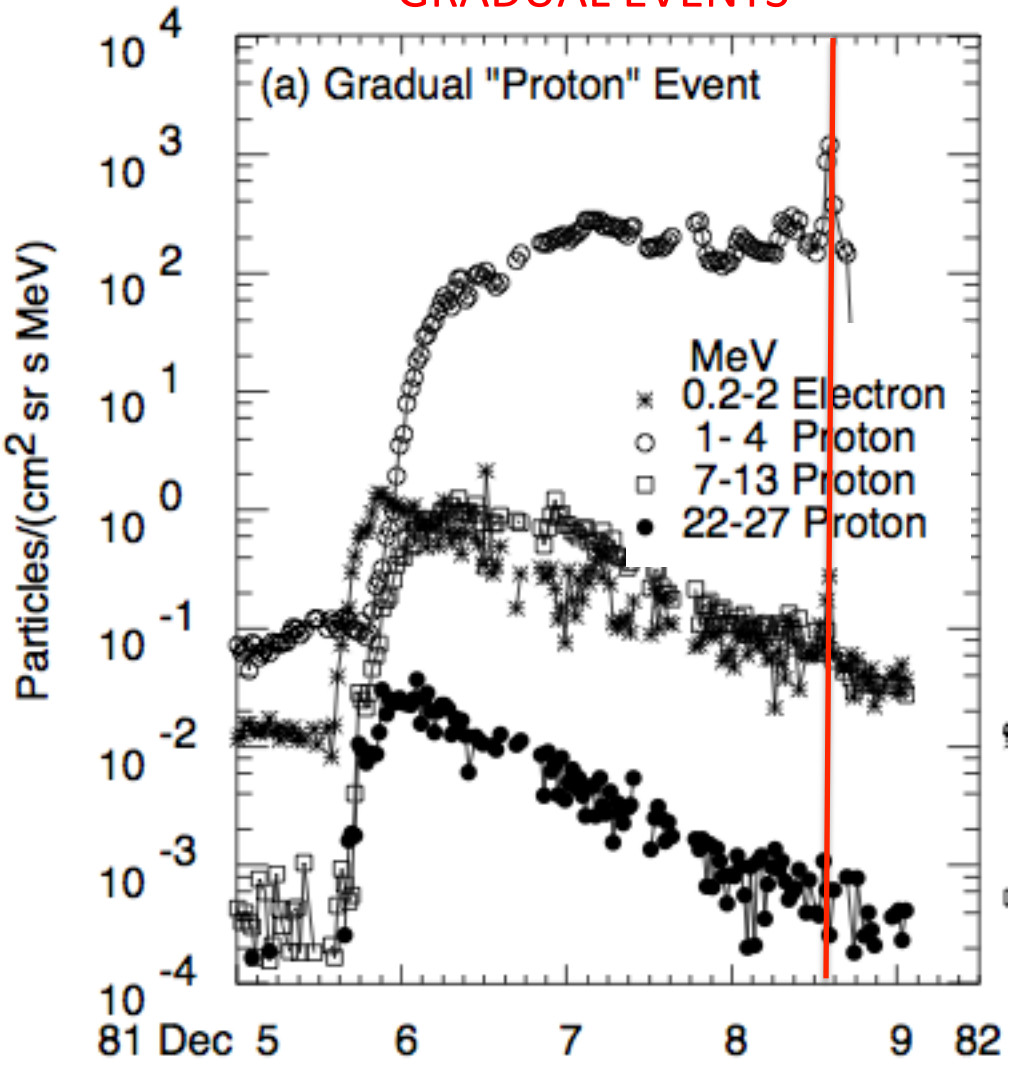
Aug 1982 well-know flare on the Sun.
Not CME.

Flare associated
Dominated by electrons
$^3He/^4He > 1$
$^3He/^4He \sim 5\ 10^{-4}$ in solar corona !!!
t ~ min !!!
peak electron intensity
the acceleration is not continuous



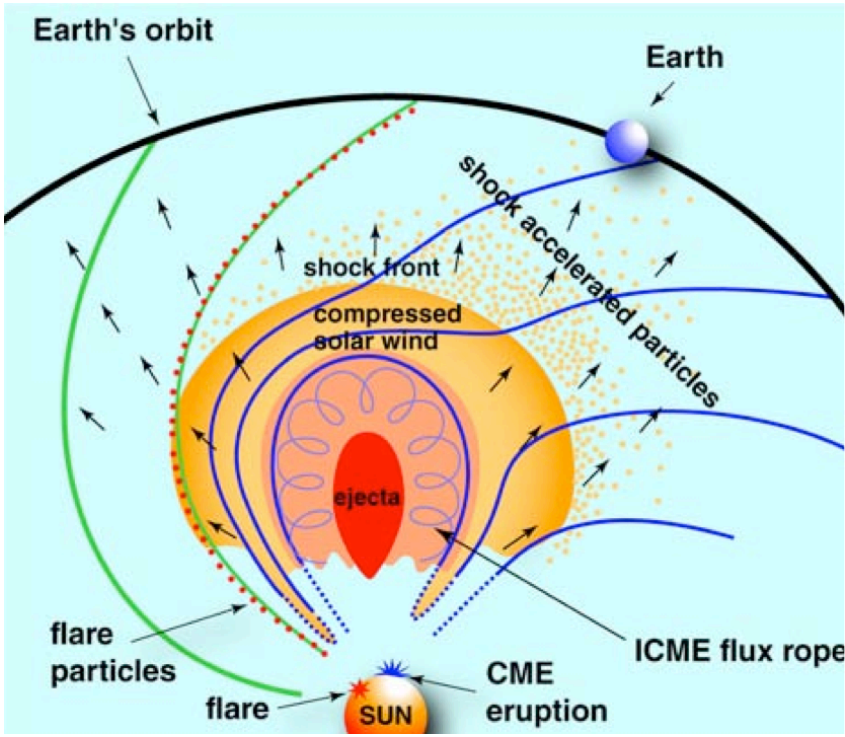
Kahler et. al 1986

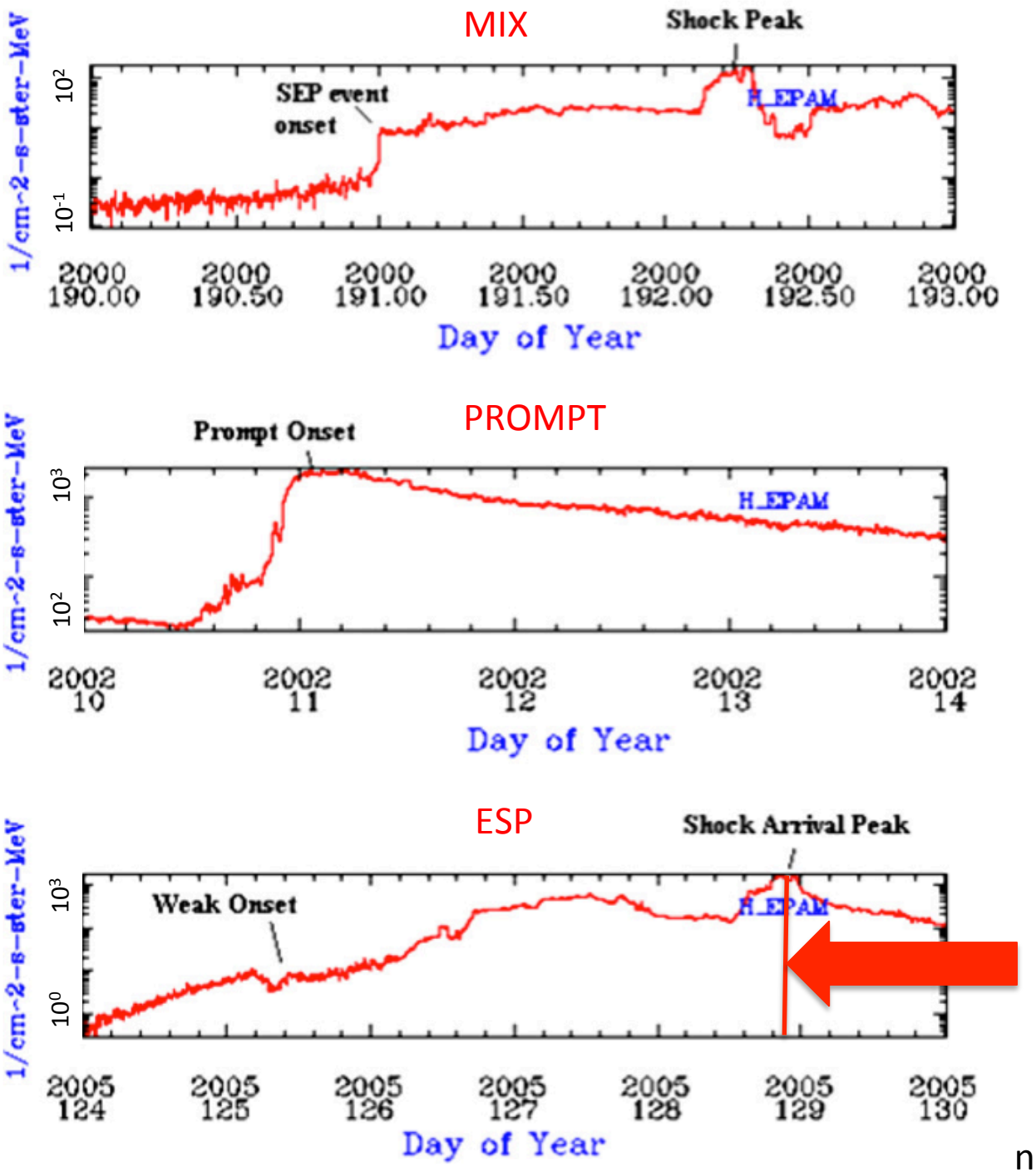
GRADUAL EVENTS



Dic 1981 well-know erupting filament as part of a CME.
Not flare, not in active region.

associated to CME shocks
Dominated by protons
Small peak near the shock passage
t ~ days !!!
continuous acceleration.




MIX
Shock Peak
SEP event onset
H_EPAM
1/cm^2-s-ster-MeV
10^2
10^-1
2000 190.00
2000 190.50
2000 191.00
2000 191.50
2000 192.00
2000 192.50
2000 193.00
Day of Year
PROMPT
Prompt Onset
H_EPAM
1/cm^2-s-ster-MeV
10^3
10^2
2002 10
2002 11
2002 12
2002 13
2002 14
Day of Year
ESP
Shock Arrival Peak
Weak Onset
H_EPAM
1/cm^2-s-ster-MeV
10^3
10^0
2005 124
2005 125
2005 126
2005 127
2005 128
2005 129
2005 130
Day of Year

n & Mann 2007

ESP event

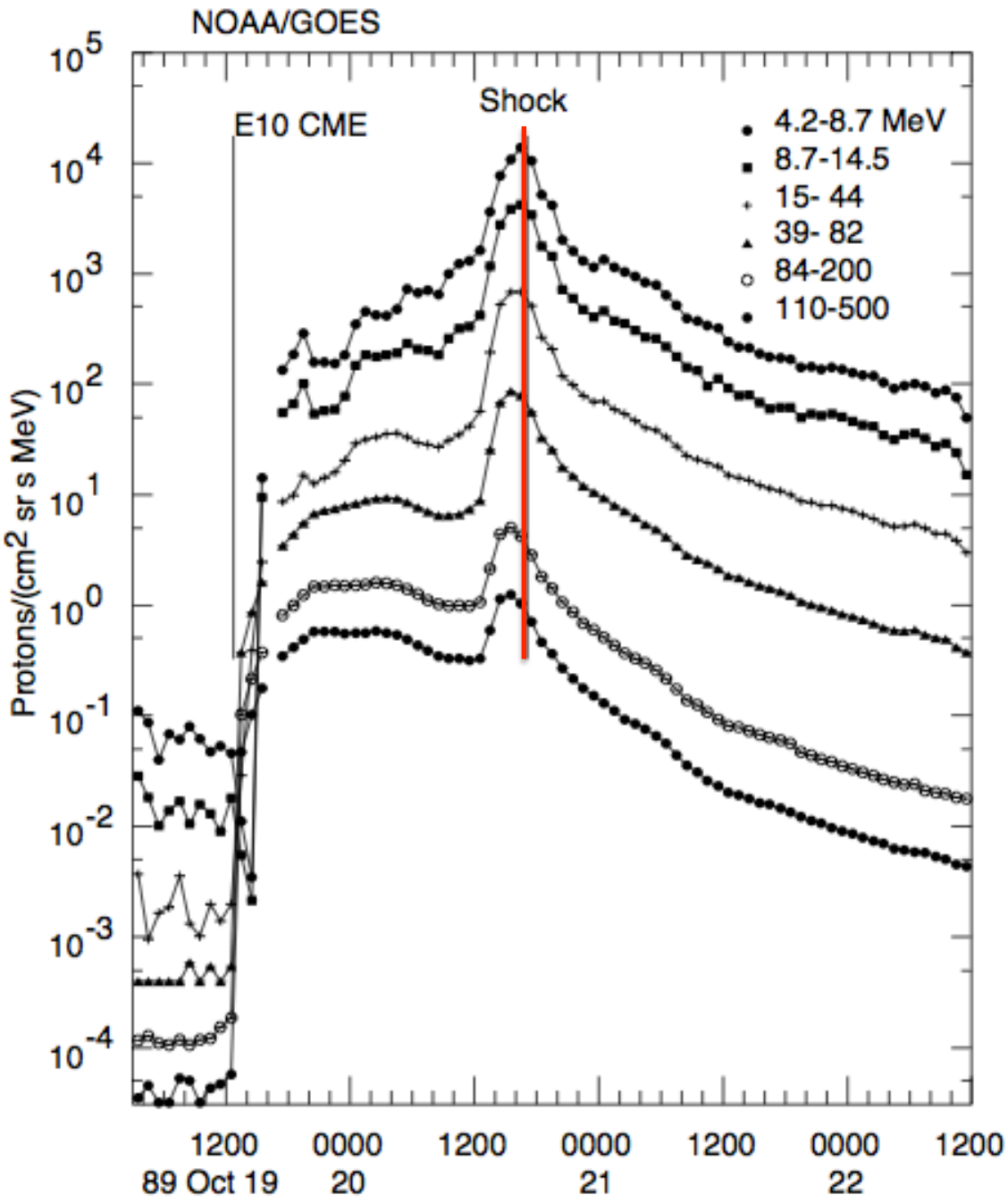


Figure 3.2. Intensity-time profiles at different energies for the large 1989 October 19 event show flat time profiles with intensity peaks near the time of shock passage even at very high energies at 1 AU.

Trying to map the SEP in relation to connection to Sun.

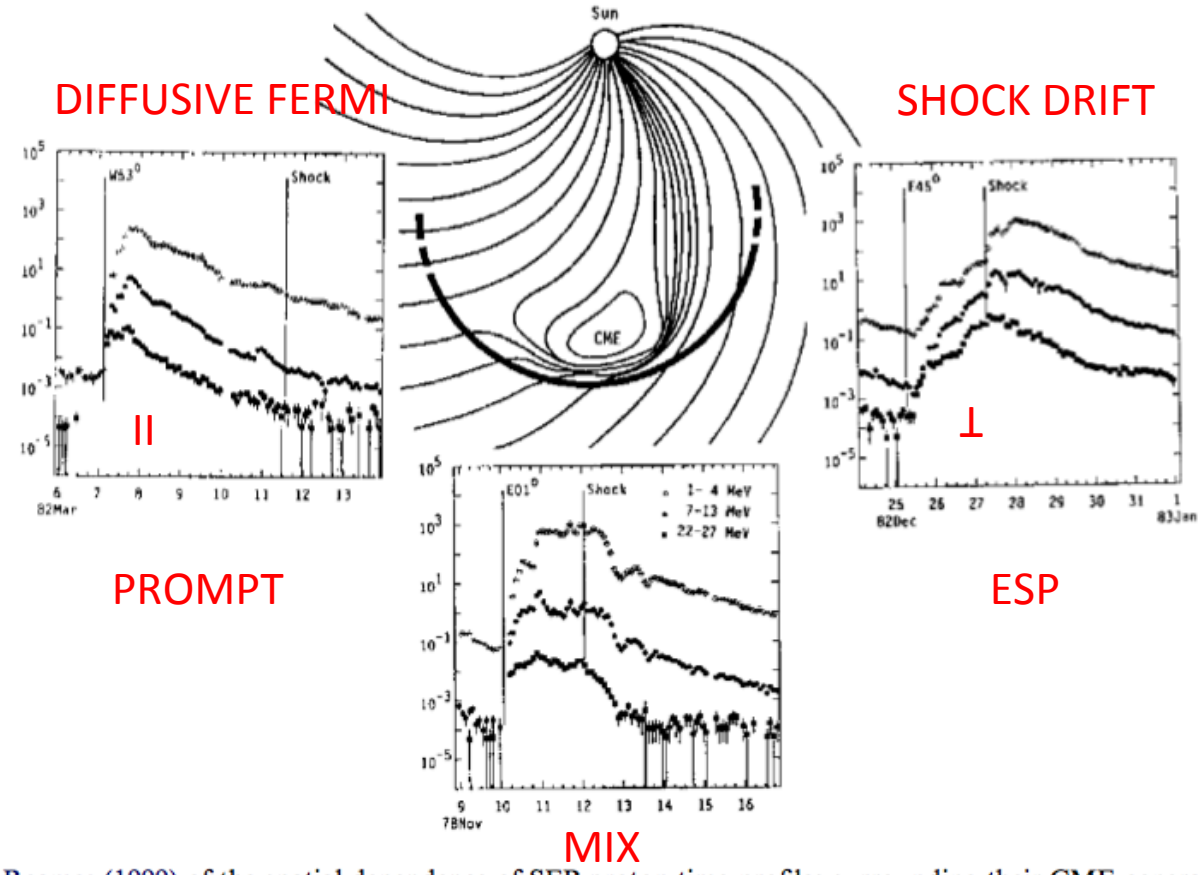


Fig. 1. Illustration from Reames (1999) of the spatial dependence of SEP proton time profiles surrounding their CME-generated shock source. The fact that the nose of the shock is the strongest part of source, and that the magnetic field connections to the observer (shown by the spiral field lines) channel the particles, combine to produce the different profiles. The timing of the peak flux with respect to the solar event (vertical lines on the left in the profiles) and the shock arrival at the observer (also indicated) is important to both SEP research and predictions.

… but not everything in the garden is rosy.

New results (WIND, SAMPEX, SOHO, ACE) shows that:

* Enrichments in ^{3}He are also common in IP shocks population
* The gain of energy : theory vs. observations
* No agremment with the Reames relative-position picture
* Contamination due to flare particles into the shock accelerated phenomena
* It is difficult to observe clean isolated events.
* Complex events?

Preliminary results.

Note: Last day analyzed is 6/30/2014 for STA and 12/31/2013 for STB. List is updated on 3/4/2015.

The event list is compiled by Dr. Lan Jian (lan.jian@nasa.gov) for reference purpose. Data of 8 s^{-1} (32 s^{-1} if available) cadence are used. The shock parameters are determined using the shock coplanarity theorem. Some of the events are arguable. For event details and ambiguous event, please consult Dr. Lan Jian. The criteria of event classification are published in the following paper.

L.K. Jian, C.T. Russell, J.G. Luhmann, A.B. Galvin, K.D.C. Simunac, Solar Wind Observations at STEREO: 2007 – 2011, Amer. Inst. Phys. Proceedings of Solar Wind 13, 1539, 191-194, doi: 10.1063/1.4811020, 2013.

Interplanetary Shocks at STEREO A

#	Year	Month	Day	Hour	Minute	Second	B_{down}/B^{1}_{up}	θ^{2}_{Bn}	β^{3}	Mach Num.[4]	32 s^{-1} data availability[5]	Source	Forward/Reverse Shock
1	2007	1	14	19	35	8	1.19	67.6	DG	1.1	Y	ICME	F
2	2007	2	12	8	10	6	1.27	47.3	DG	1.28	N	data gap, probably a SIR	F
3	2007	2	12	8	39	13	1.36	76.6	DG	1.28	N	data gap, probably a SIR	F
4	2007	4	21	18	59	15	1.57	76.6	3.91	1.4	N	SIR	F
5	2007	4	23	6	53	44	1.32	73.0	1.67	1.22	N	SIR	R
6	2007	5	7	8	11	54.4	1.72	80.3	4.35	1.53	N	SIR	F
7	2007	5	8	20	38	34	1.39	24.8	1.32	1.62	N	SIR	R

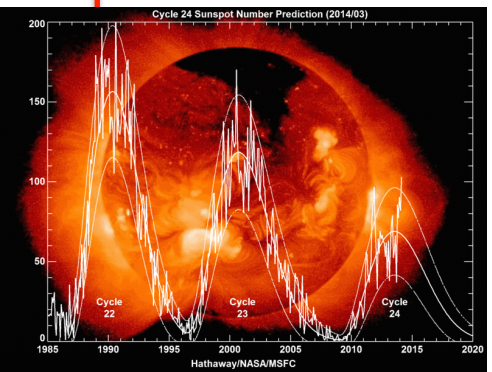
SEP Events from STEREO A (Dec. 2006 - Jan. 2015) and B (Dec. 2006 - Sept. 2014)
(Updated on 7/29/2015)

The list is compiled by Dr. Lan Jian (lan.jian@nasa.gov) using the criterion that the flux of 13-100 MeV protons from HET measurements > 10 pfu (1 pfu = 1 p $cm^{-2}sr^{-1}s^{-1}$), to mimic the list of Solar Proton Events provided by NOAA Space Weather Prediction Center using the GOES spacecraft data (http://www.swpc.noaa.gov/ftpdir/indices/SPE.txt). The start and end time is when the 10 pfu threshold is crossed and not necessarily the accurate start and end time of the events. This list is for reference only, to point out the high flux events. Checking with the data is highly recommended.

Hourly data from Hight Energy Telescope (von Rosenvinge et al., Space Sci. Rev., 2008) are used. The events in 2006 are in the solar wind, outside the Earth's bow shock. There are no events reaching the criterion in 2007-2010 at either STEREO spacecraft.

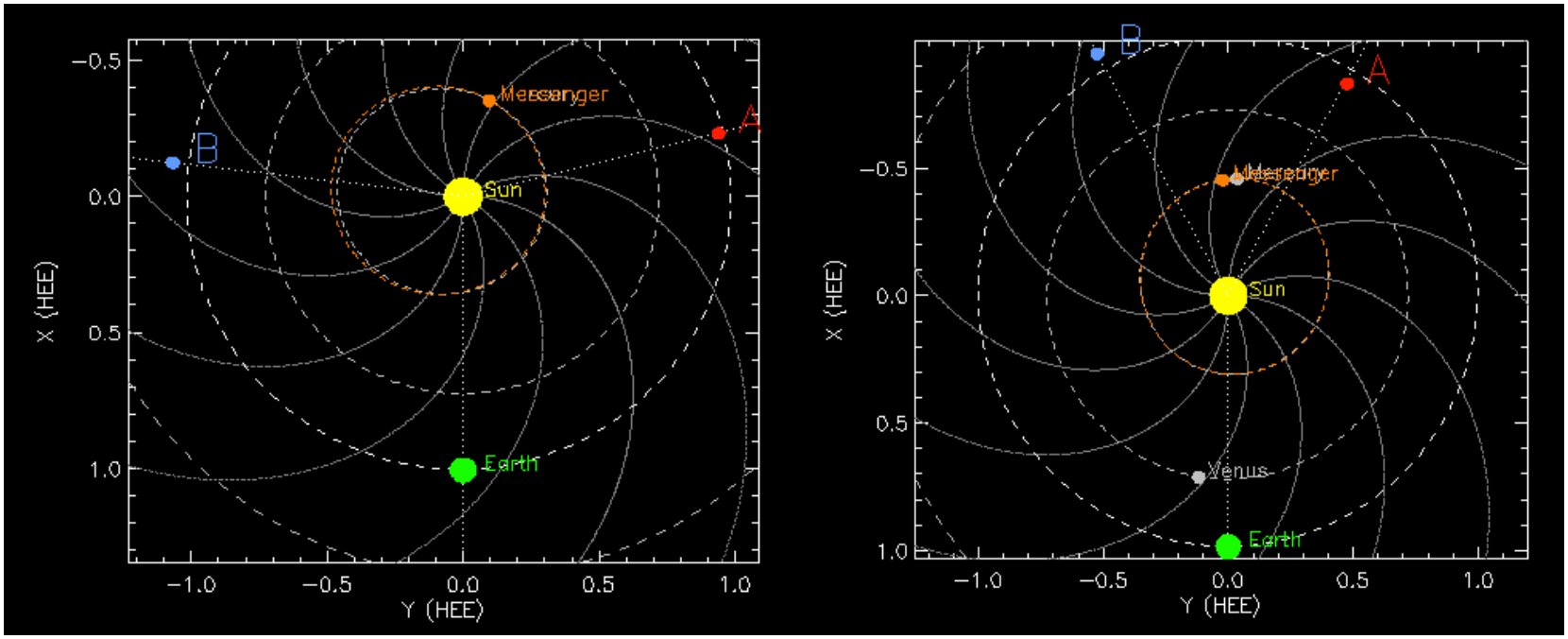
There is a list of >25 MeV proton events and relevant solar events in a separate study by Richardson et al. (Solar Phys. 2014).

# of STA	Start Time				End Time				Maximum Flux (pfu)	Fluence ($cm^{-2}sr^{-1}$)	Comments
	Year	Month	Day	Hour	Year	Month	Day	Hour			
1	2006	12	6	20.5	2006	12	11	22.5	1031.77	83391997	CME and flare
2	2006	12	13	3.5	2006	12	14	17.5	449.22	21894825	CME and flare
3	2011	3	9	8.5	2011	3	9	16.5	26.88	676257	gradual rise, CME and flare
4	2011	3	21	3.5	2011	3	22	21.5	685.06	25013660	CME
5	2011	6	4	16.5	2011	6	7	23.5	2021.23	103897555	CME and flare



Shock STEREO list: STA [2007/01/14 - 2014/06/17]
STB [2007/01/14 – 2013/12/30]
SEP STEREO list: STA [2006/12/06 – 2014/12/13]
STB [2006/12/06 – 2014/09/25]
SEP's: STA 32
STB 31
Shocks: STA 269
STB 206

# of observations by both spacecraft events: ~ 6 :(

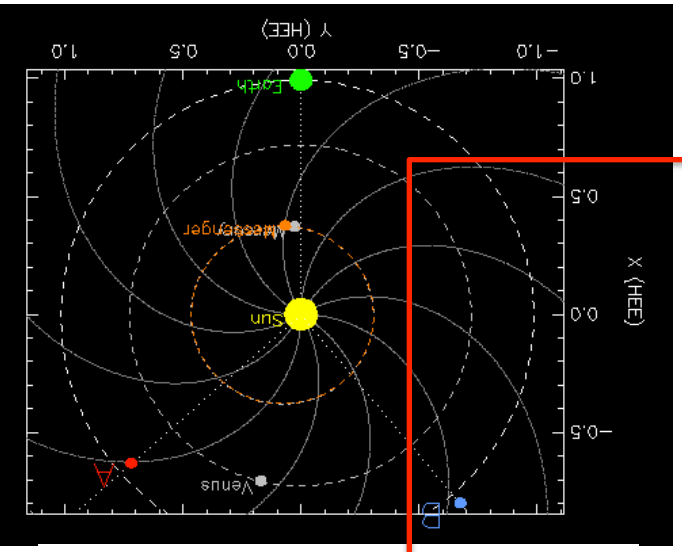


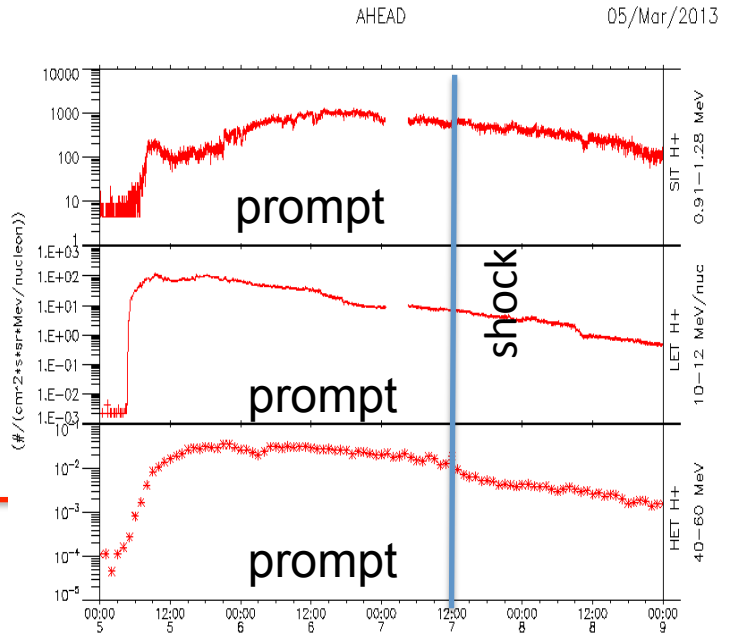
2012 2013

Case 2
2013/03/05-06

STA

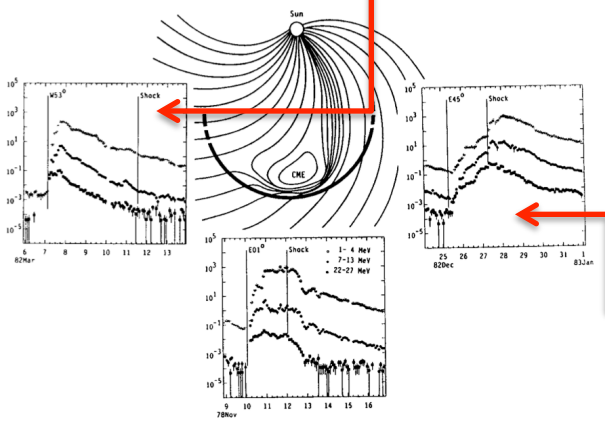
θ=67.3
M=1.59
β=1.23

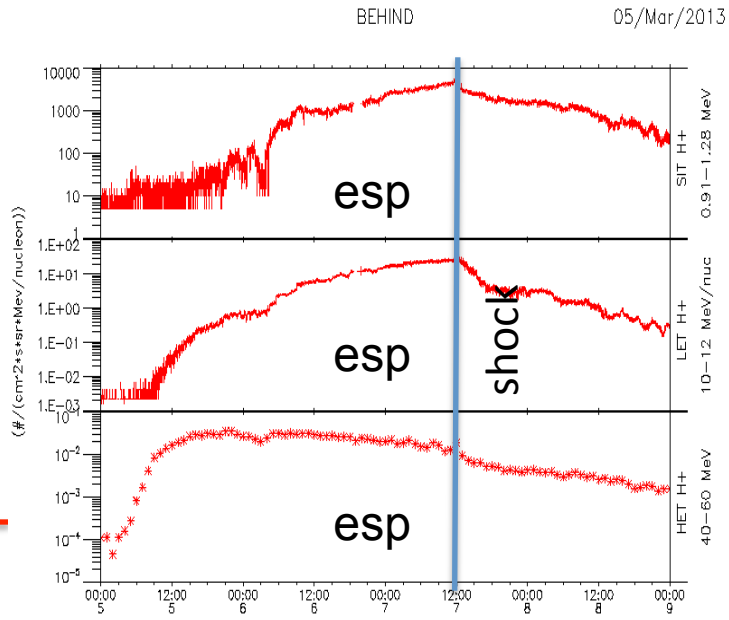


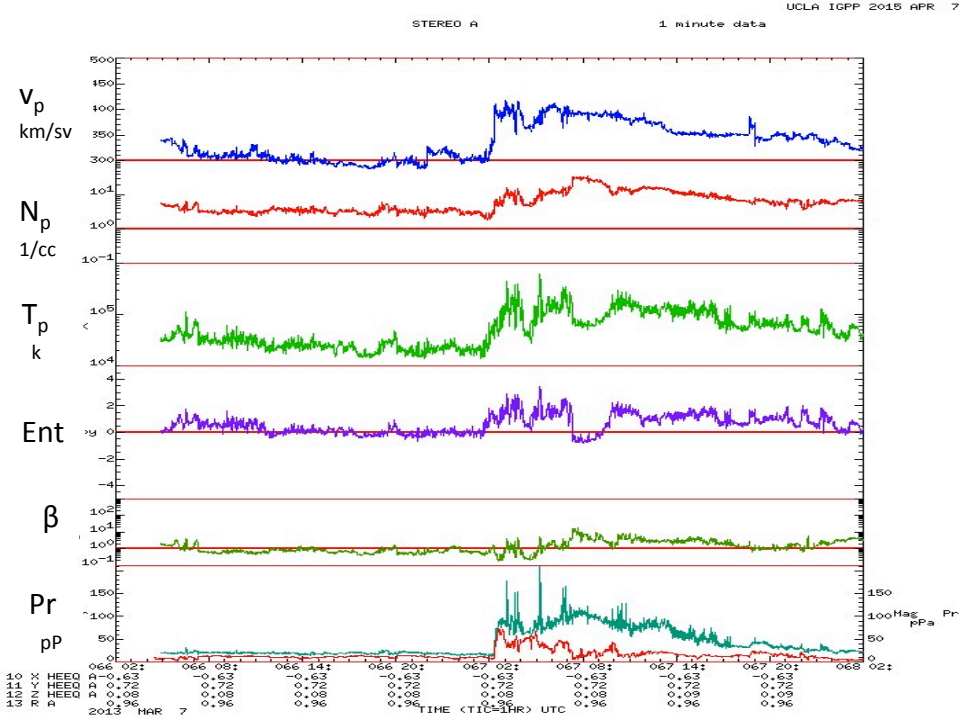


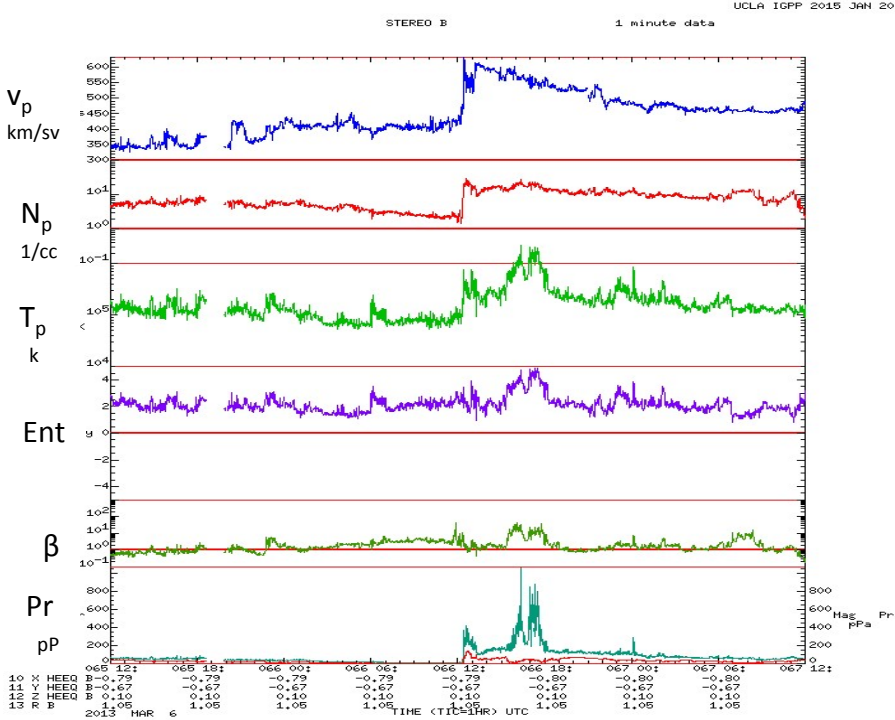
STB

θ=60.2
M=1.69
β=1.60



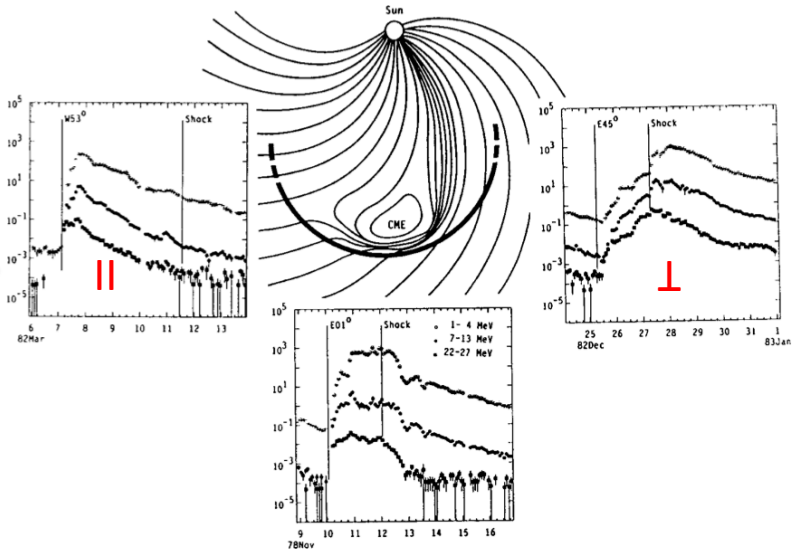


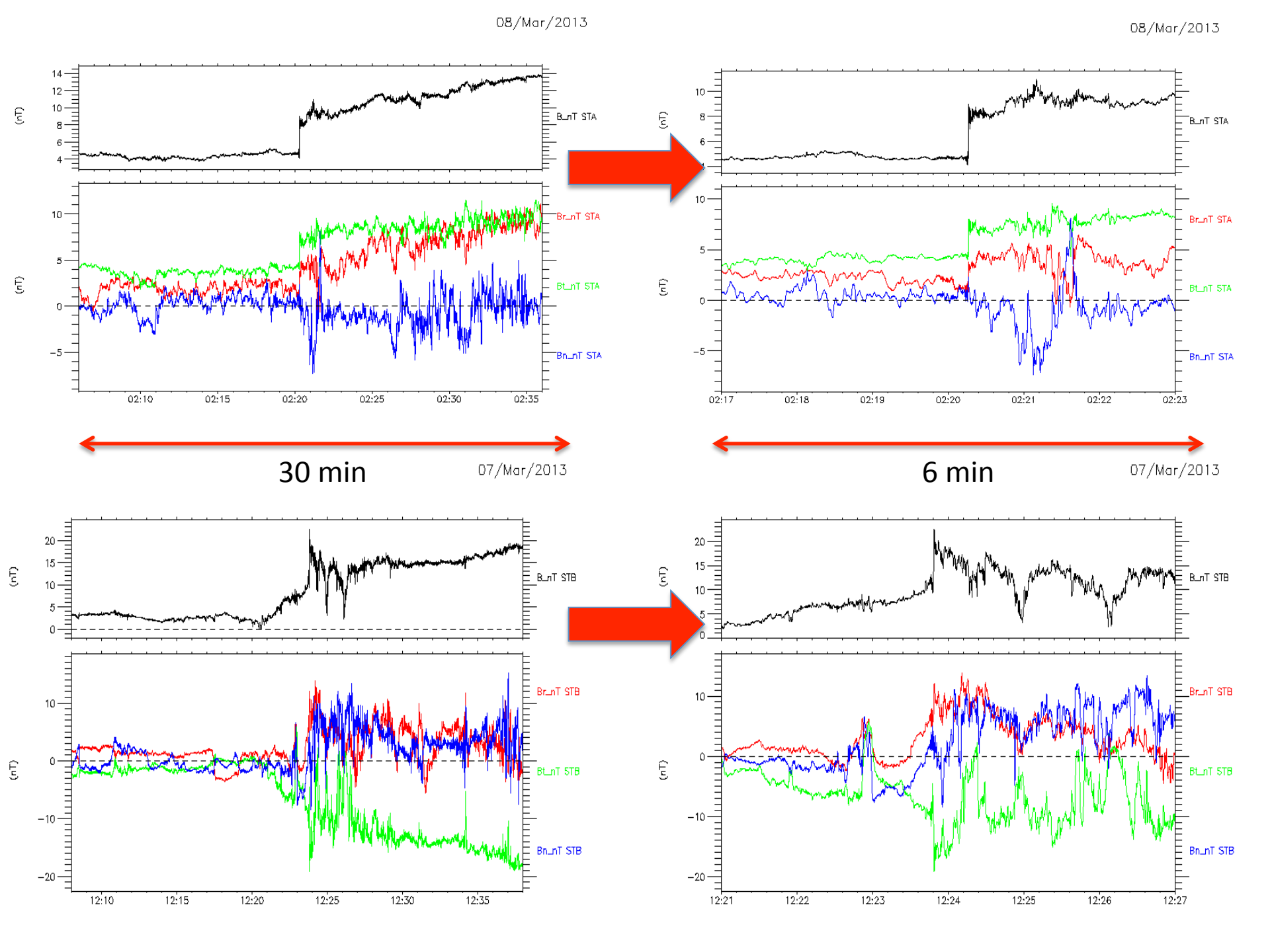




θ=67.3
M=1.59
β=1.23

θ=60.2
M=1.69
β=1.60




08/Mar/2013
08/Mar/2013
B_nT STA
Br_nT STA
Bt_nT STA
Bn_nT STA
(nT)
02:10
02:15
02:20
02:25
02:30
02:35
02:17
02:18
02:19
02:20
02:21
02:22
02:23
30 min
6 min
07/Mar/2013
07/Mar/2013
B_nT STB
Br_nT STB
Bt_nT STB
Bn_nT STB
12:10
12:15
12:20
12:25
12:30
12:35
12:21
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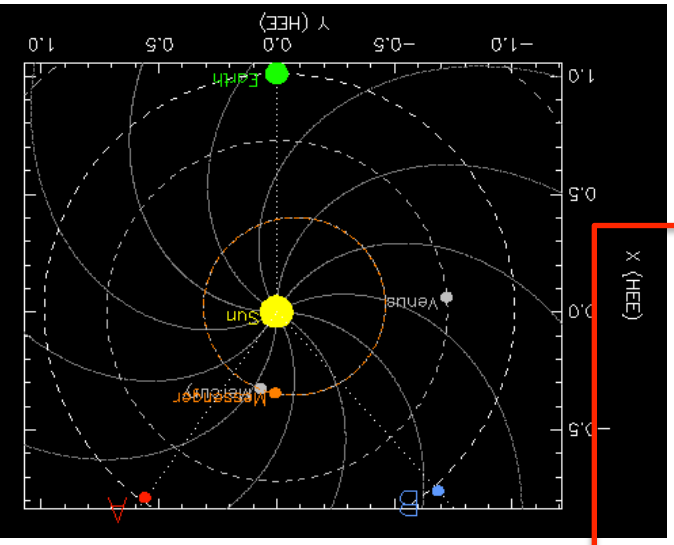
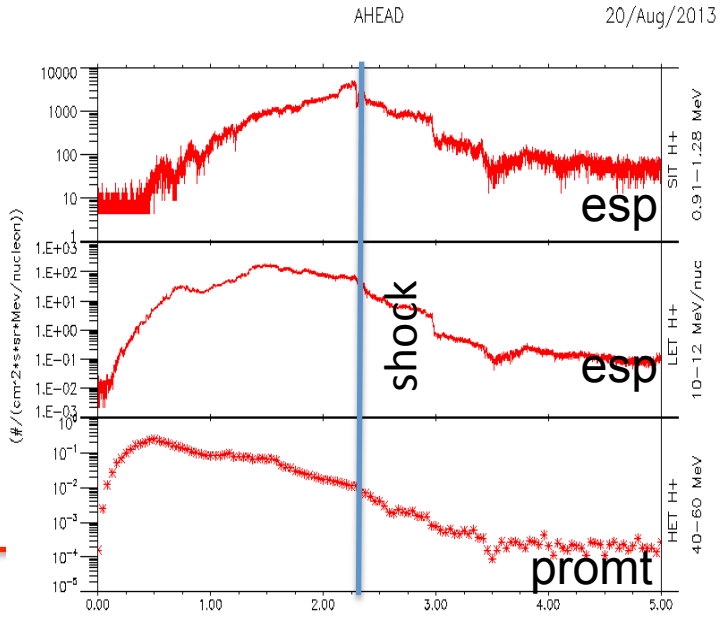
12:26
12:27

Case 3
2013/08/20-21

STA

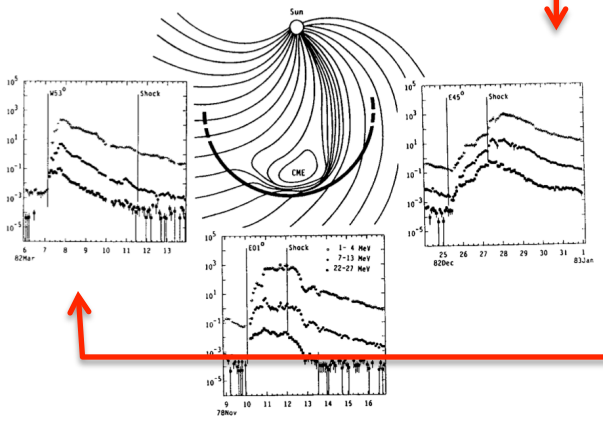
θ=81.4
M=2.24
β=3.12

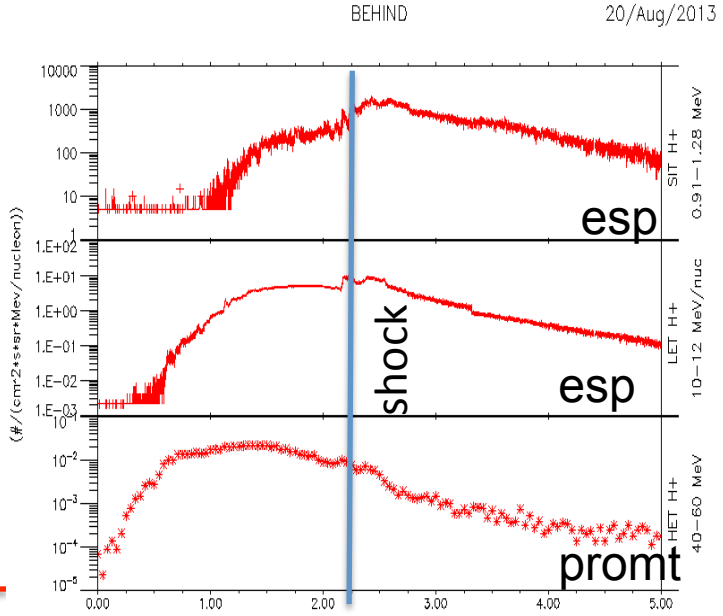


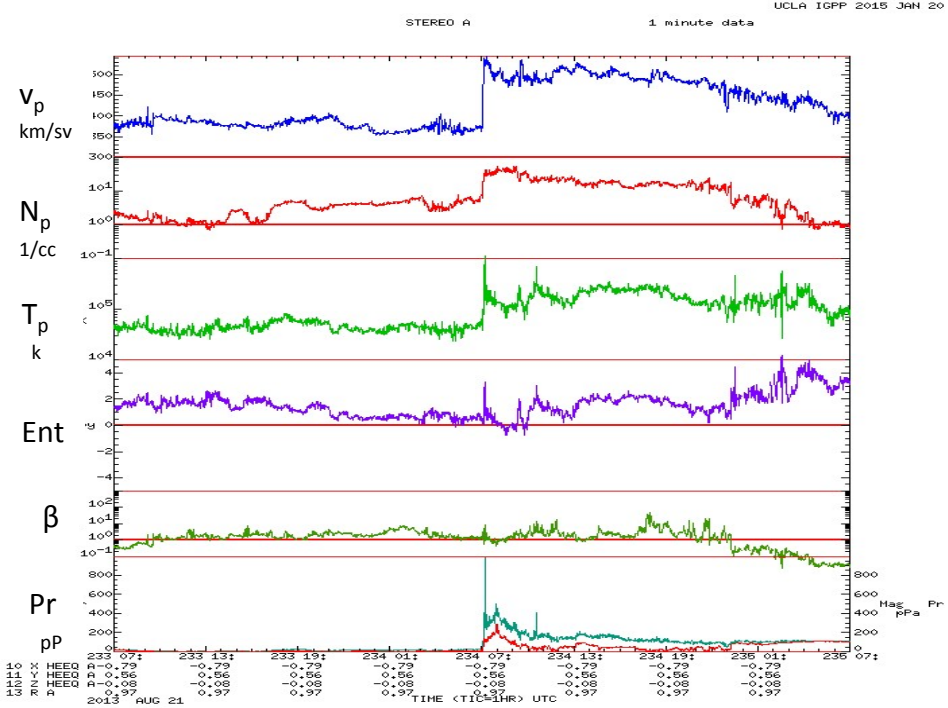


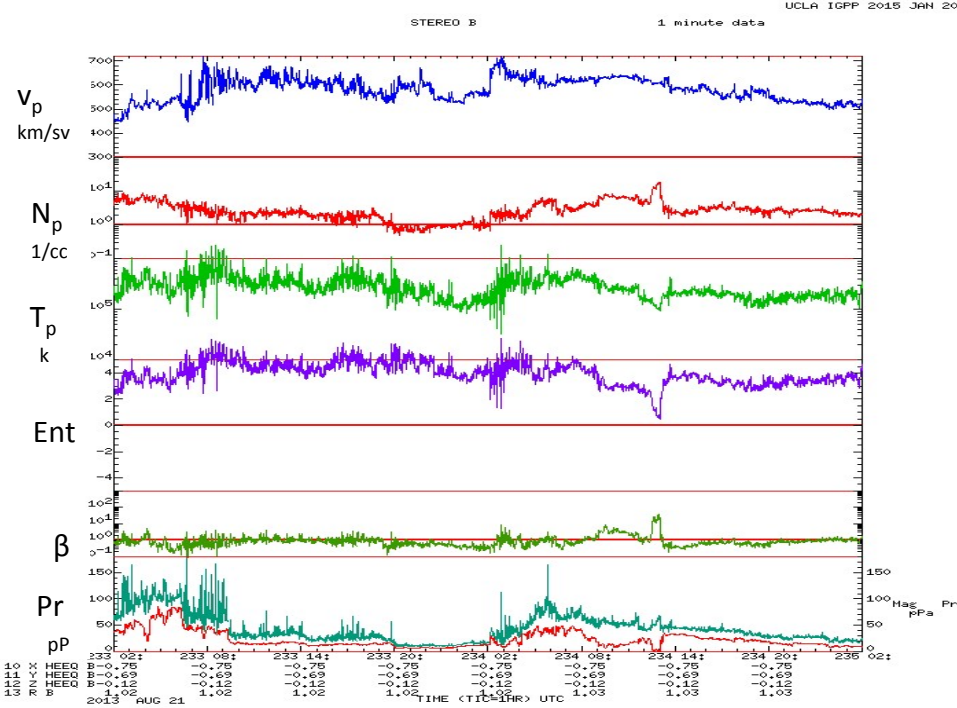
STB

θ=50.0
M=1.12
β=0.16



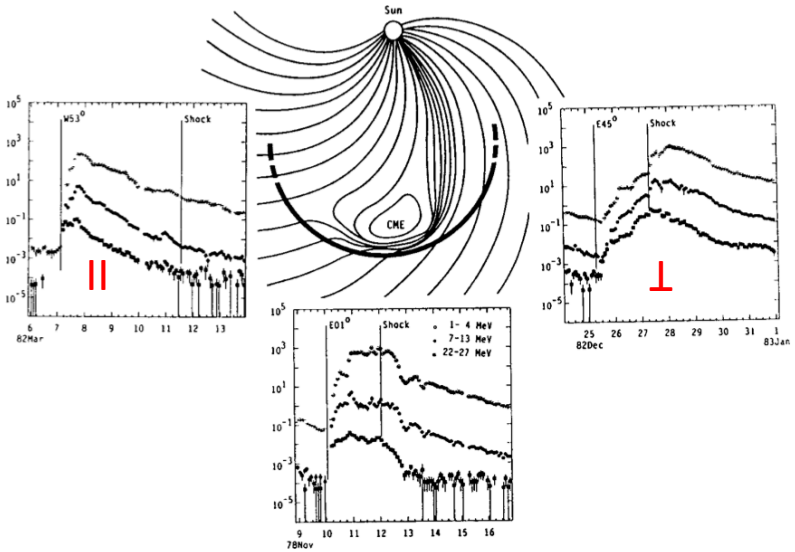


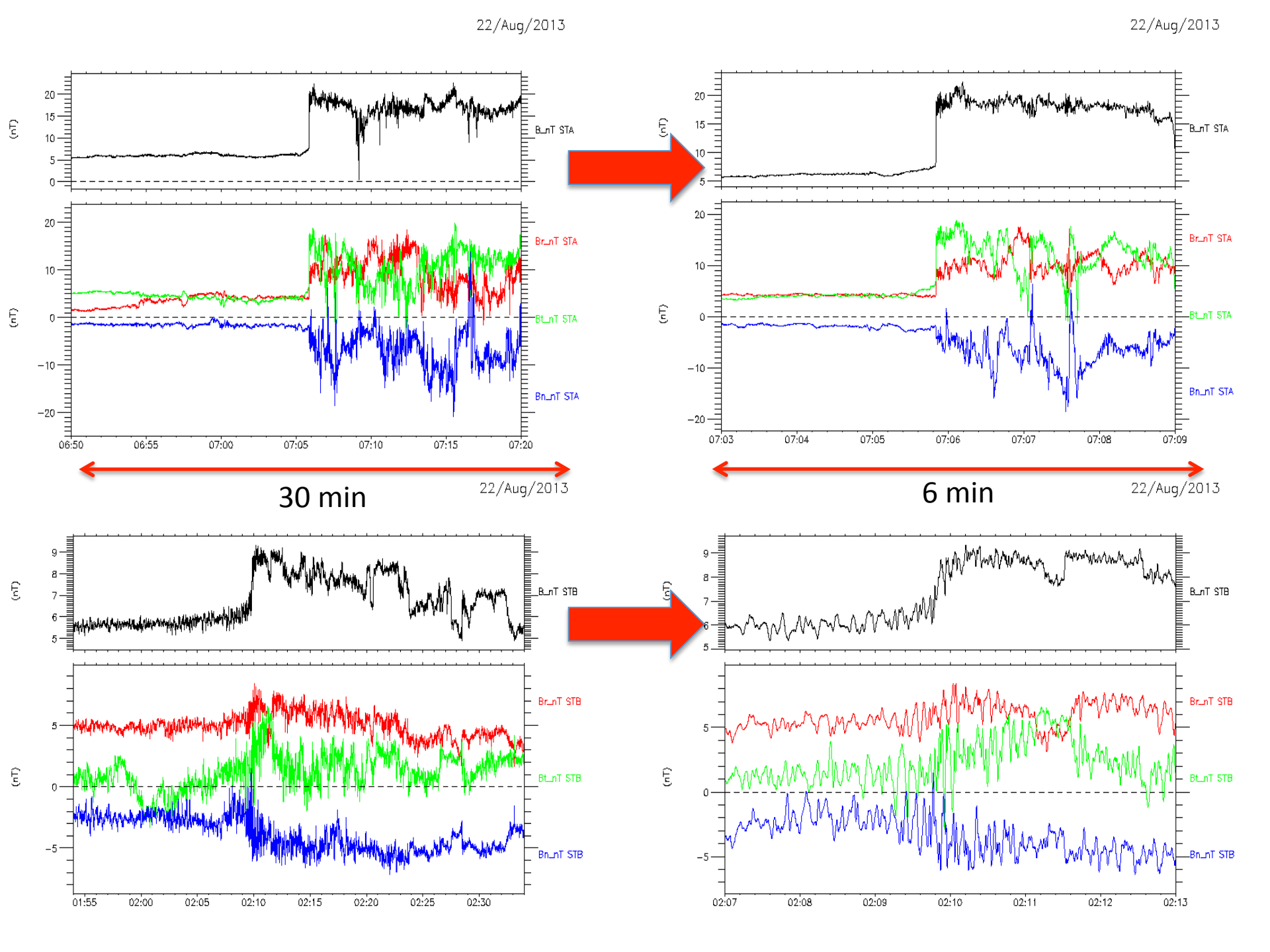




θ=81.4
M=2.24
β=3.12

θ=50.0
M=1.12
β=0.16




22/Aug/2013
22/Aug/2013
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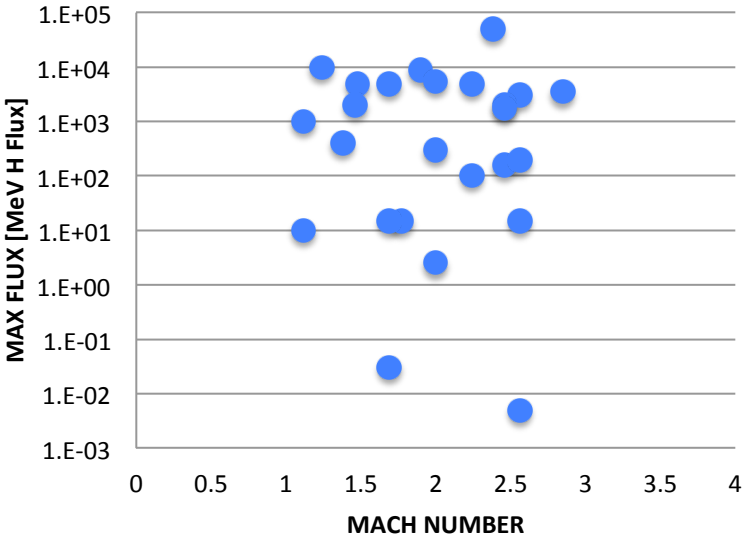
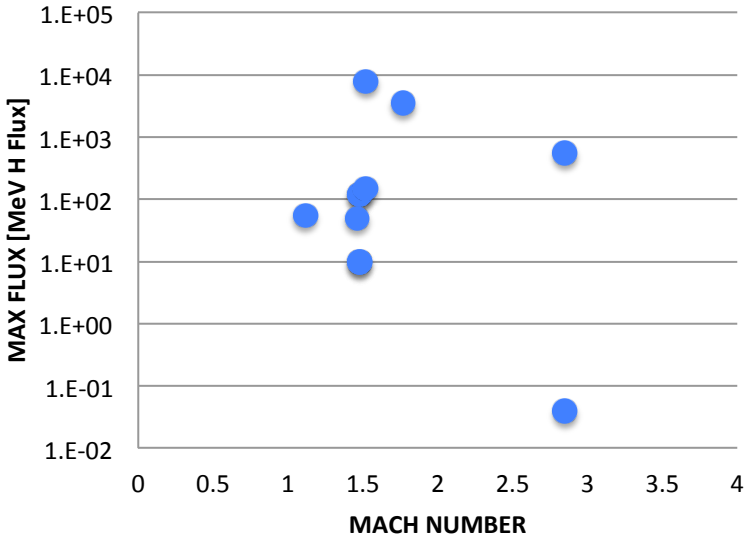
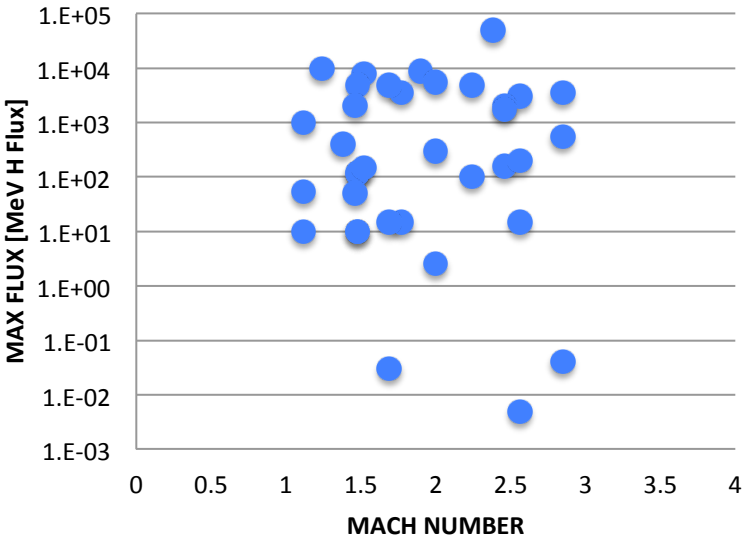
ESP



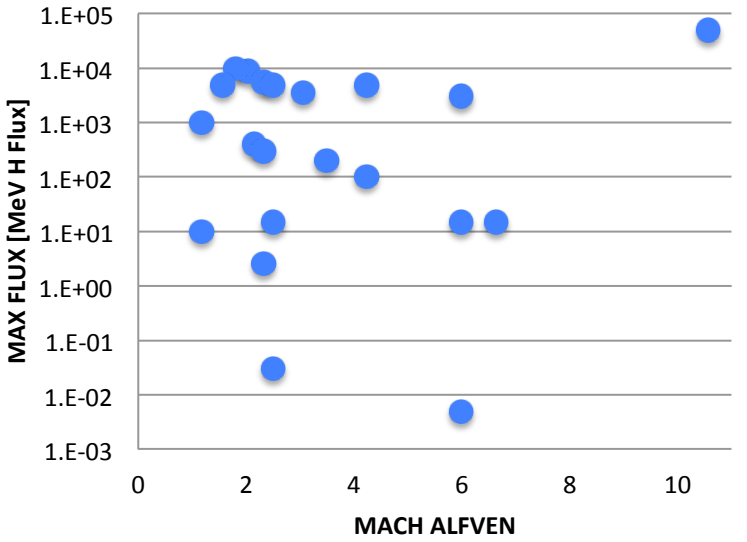
MIX



MIX & ESP

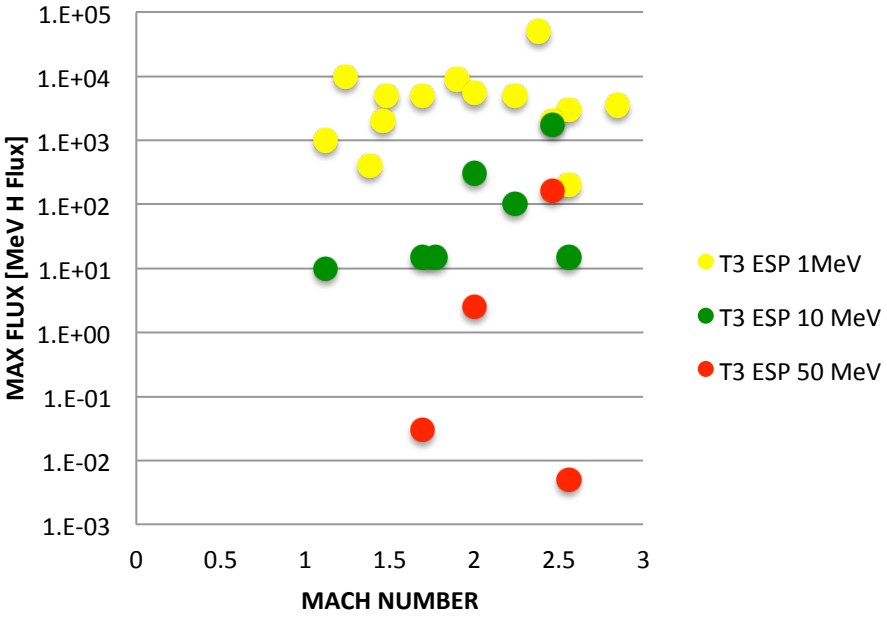


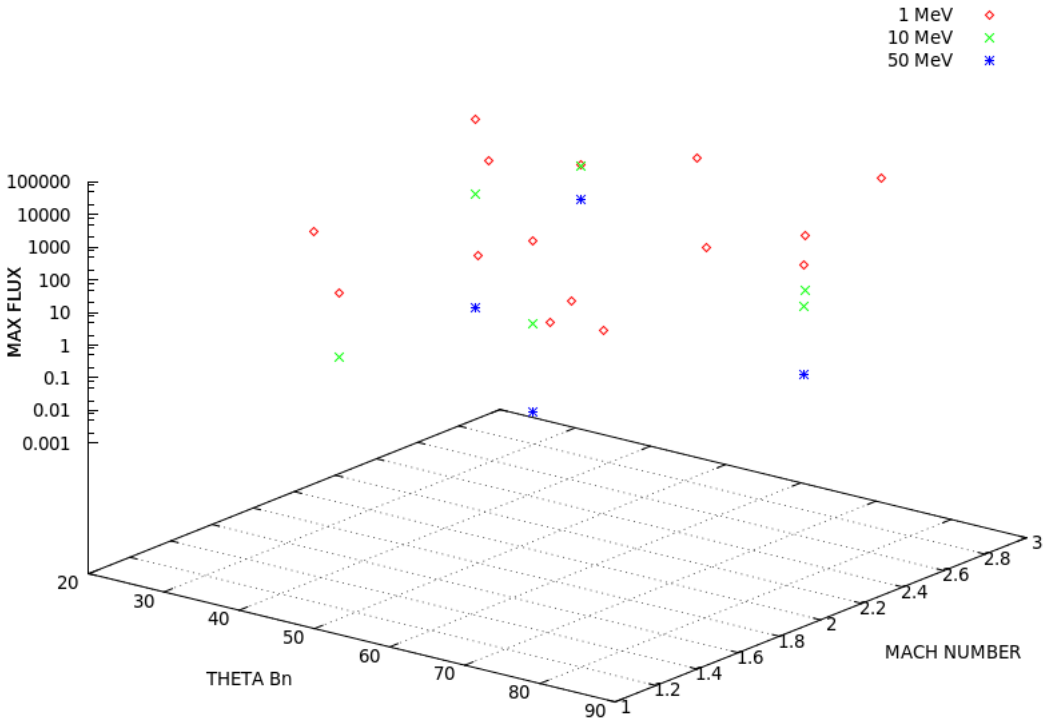
ESP



[1-50] MeV by both STEREO

ESP EVENTS MULTISPACECRAFT





Future work and possible collaboration.

* More spacecraft in order to improve the mapping

* Correlation between SEPs and waves

* Shock rippling ~ shock geometry

* Kinetics effects via hybrid simmulations

* List of this kind of events

* and a large …

THANKS !!!