Studies of SPEs as measured in the ISS in 2011-2012

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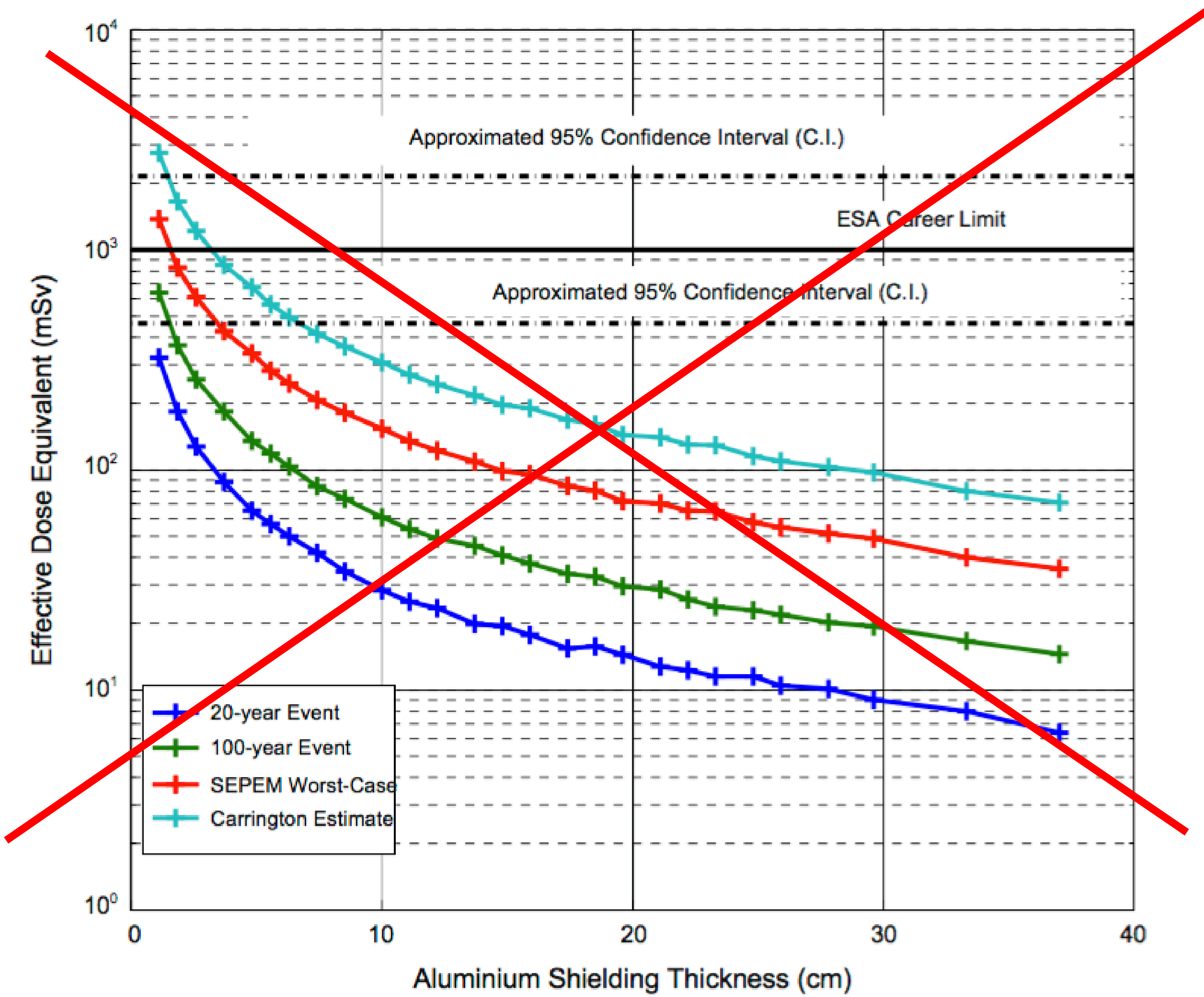
SPEs … a possible high risk

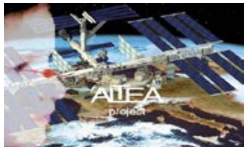
Active shielding?



Sporadic
Unpredictable
Low energy

Fig. 13. Effective Dose Equivalent (milli-sieverts) in an astronaut as a result of extreme SPEs compared to the recommended ESA career limit for the four SPEs shown in Figure 9.

Jiggens et al. J. Space Weather Space Clim. 4 (2014)



Mitigating SPE radiation

Mitigation of SPE related risks relies on a prompt warning.

- Real forecasting from Sun Physics is yet not in sight. It can just help in providing "warning" periods.
- Now-casting, based on the accurate study of the behavior of the Sun related radiation immediately before relevant events, can provide few minutes warning time.
- In any case fast SPEs will come un-warned
- A fast route to a shelter is a mandatory issue.

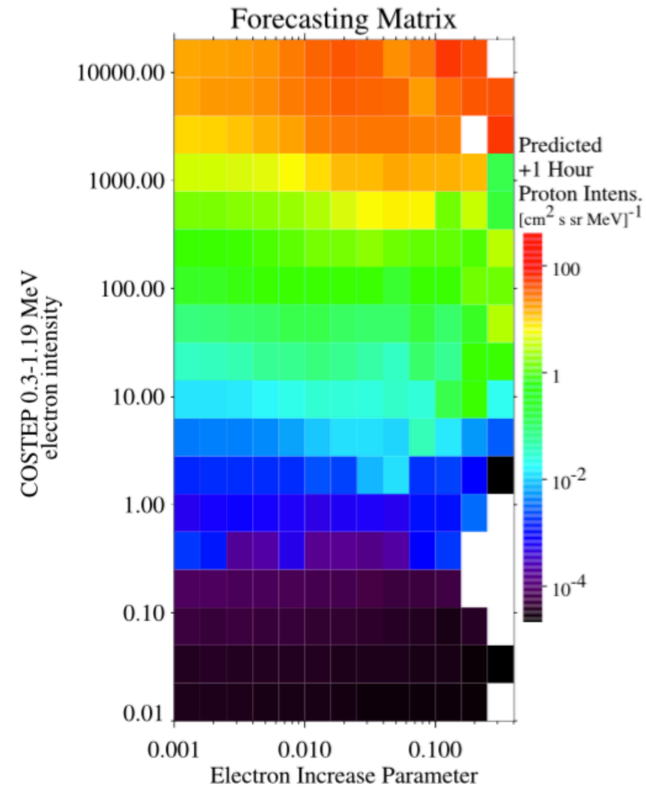


Figure 8. This color matrix provides a color code for the future proton intensity, 1 hour ahead of time, as predicted by relativistic electron measurements. The parameter space is given by the current maximum electron increase parameter, going back in time for at least 5 min, but up to 60 min, and the current relativistic electron intensity. The matrix is derived from the aggregate of all 1998–2002 relativistic electron observations and their corresponding 30–50 MeV proton intensities 1 hour later. The color shows the average for the proton intensity in each locus. Low statistics limit the extent of the matrix to the bottom and upper right. *Posner, Space Weather 2007*

SPE risk minimization

Forecasting SPE is a must, however:

- Forecasting can only lead to the definition of “alert” periods
- “Now-casting” is needed
- SPEs not only are sporadic, but also their features may significantly differ event by event
- Understanding the parameters of the SPE that produce events leading to higher health risks for the astronauts in deep space is a first priority issue, this includes the knowledge of which early features of the SPE / SPE precursor would better predict highly dangerous SPE
- Measurements of the effects of an SPE in a space habitat is therefore part of the needed information in this endeavor
- The space habitat available is the ISS

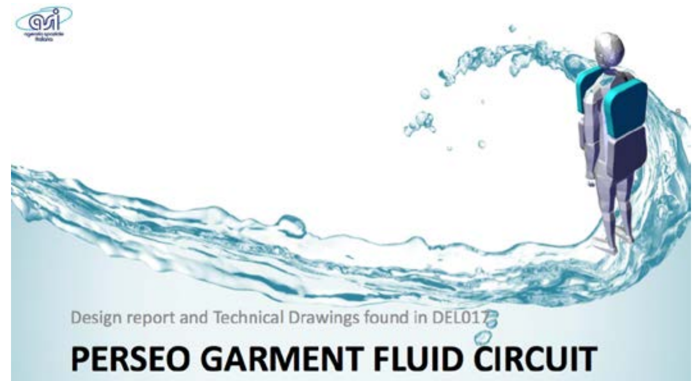
The minimization of the risk coming from an SPE is currently based on the shelter approach.

1) Observation of an SPE / SPE precursor either from a satellite or from a measurement from the exploration vessel
2) Integrated incoming data is evaluated
3) If the SPE or the precursor suggest a large SPE a call to shelter is issued
4) Shelter Procedure is implemented by the crew
5) Space Environment Operator (SEO) monitors the environment
6) Once SPE is over SEO makes the call to come out of contingency shelter status and put the cabin back in operational configuration

from K. Lee

Mitigating SPE radiation

A vest to increment personal shielding using available water (tomorrow: Giorgio Baiocco)



VITA mission with Paolo Nespoli

UniRMToV will use ALTEA to perform radiation shielding evaluations on board the ISS with a water filled vest container

SPE effects in the ISS measured by ALTEA

The ALTEA detector system

ALTEA (developed with ASI fundings) is a detector system with tracing and spectrometric capability.
From the point of view of this topic it offers:

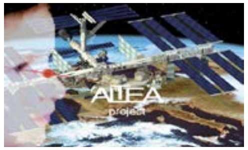
- Real time operation
- Ability to select any specific geo-magnetic region
- 6 identical telescopes (that can be used on the 3 directions, X Y Z), with single ion tracing capability
- 3.5 years of data, from 8/2006 to 9/2012 (not continuous)[1]
- Statistical nuclear discrimination for Z>3

[1] In this talk only the period 2010 – 2012 will be considered (ALTEA – shield, ESA sponsored program)

As all the active silicon telescopes ALTEA features
- not full Z, Ek coverage

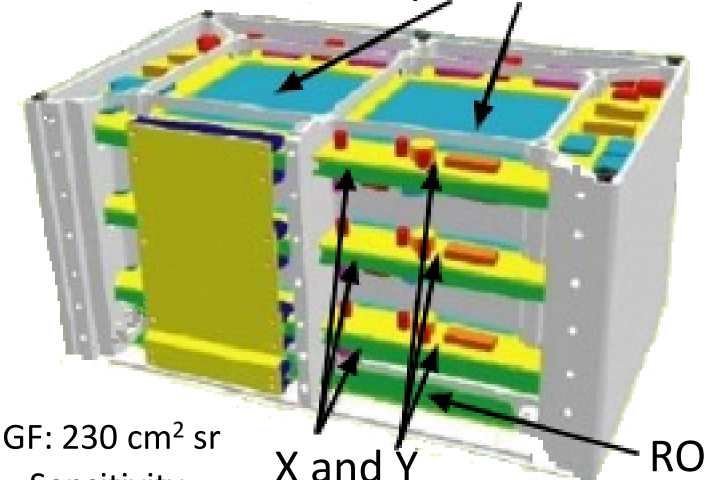
Furthermore typically, for the ISS
- Only approximate knowledge of shielding can be provided

Narici et al. J. Space Wea. and Space Clim. 5, A37 (2015)
Narici et al Radiat. Meas. 47:1030-1034 (2012)
Di Fino et al. Radiat Res. 176(3):397-406 (2011)



ALTEA detector characteristics

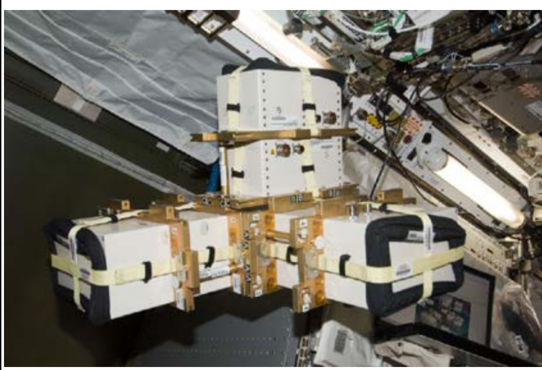
SDU

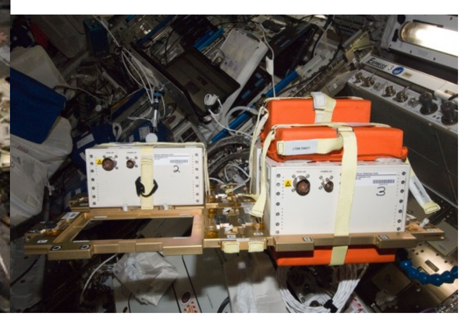


GF: 230 cm^2 sr
Sensitivity
3-800 keV/µm

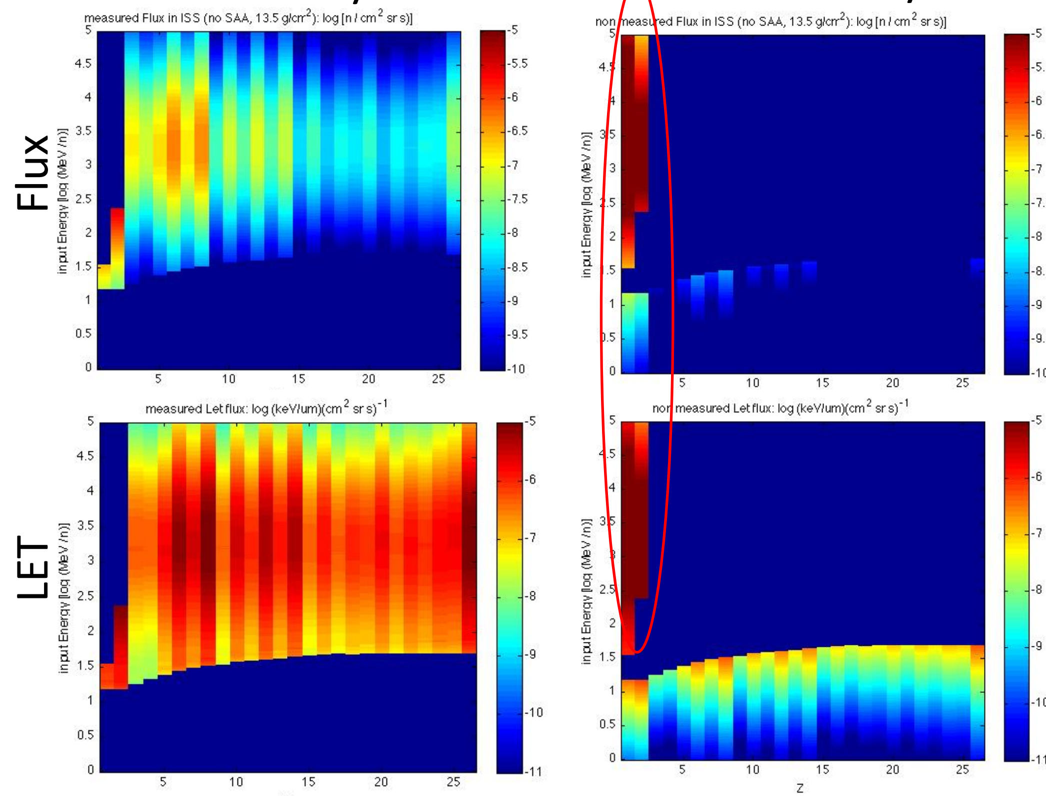
SDS

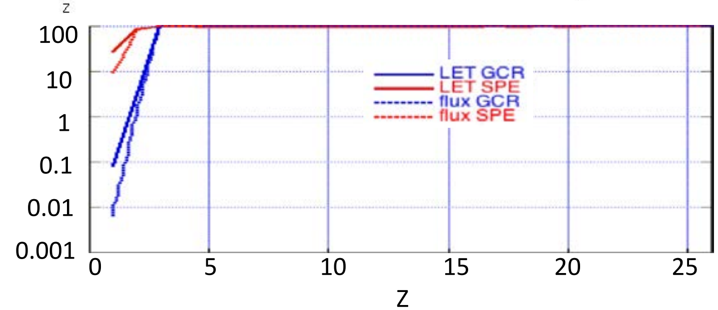
Large silicon detector system.
Deployed in the XYZ (6 SDU), or flat (3 SDU) configuration





ALTEA acceptance





A SPE in the ISS

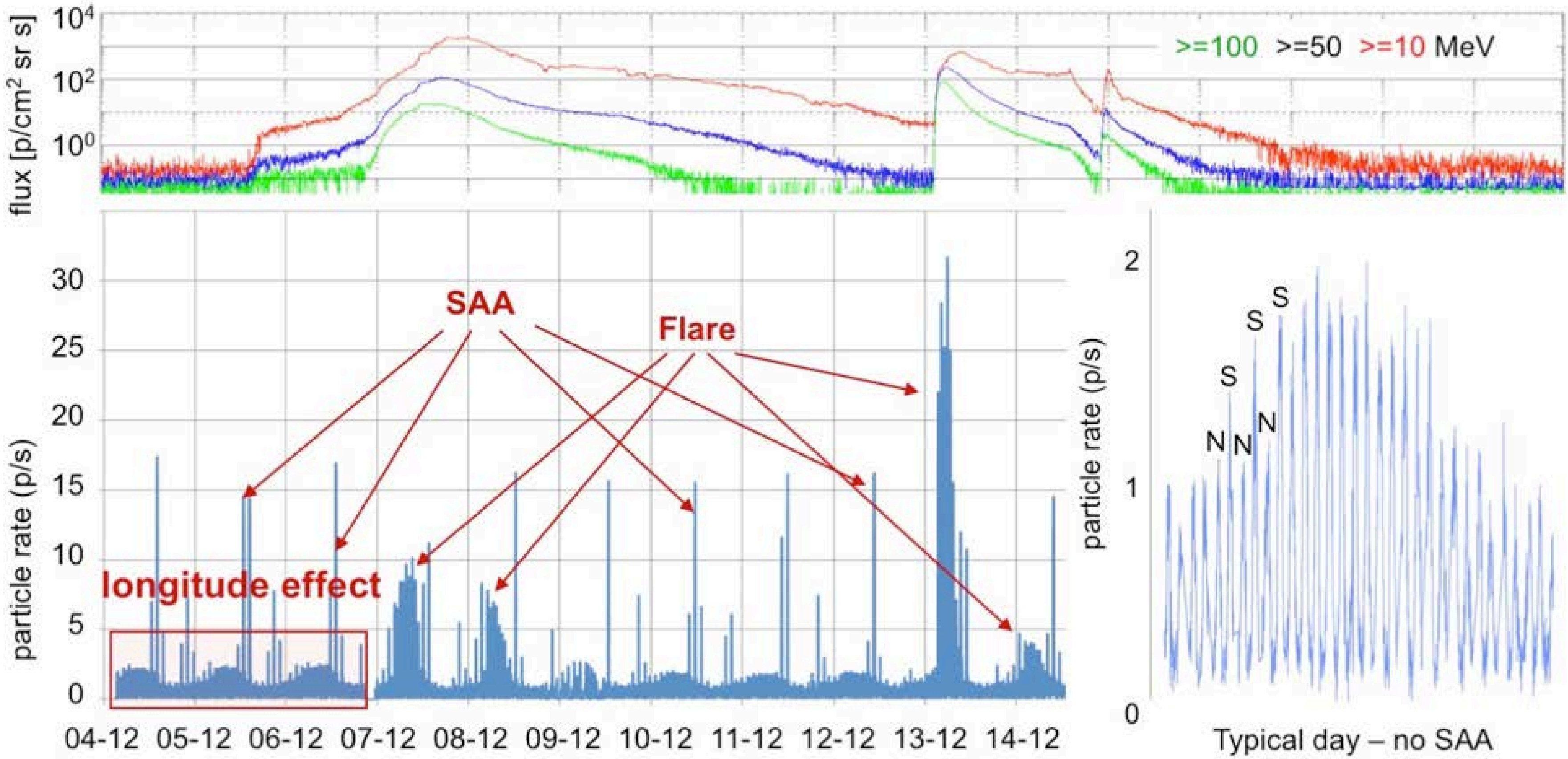
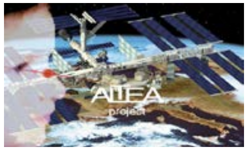


FIGURE 3 GOES proton data (above) and ALTEA data below, during the December 13th, 2006 SPE. The different component and modulation of the ALTEA measurements are marked. On the bottom right a typical day in a quite period to enlarge the south - north poles asymmetry

Narici et al. in Extreme Events in Geospace, Elsevier, in press



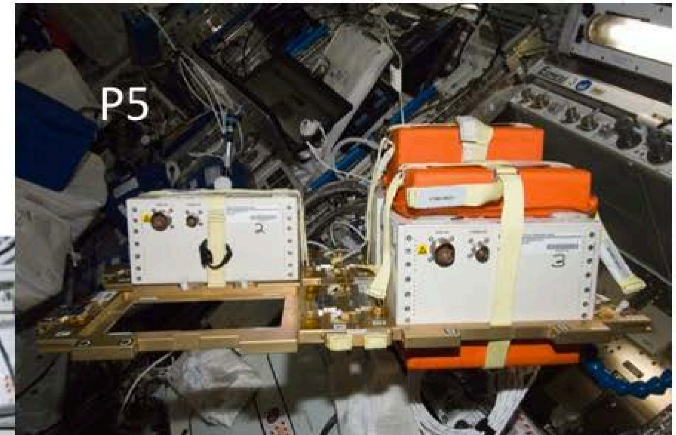
ALTEA measurement times

Table 1. Running days in the four ALTEA-shield/survey positions. The last line corresponds to the "shield" section of the experiment. The total duration might be less than the total number of days between start and end because of shut-off periods.

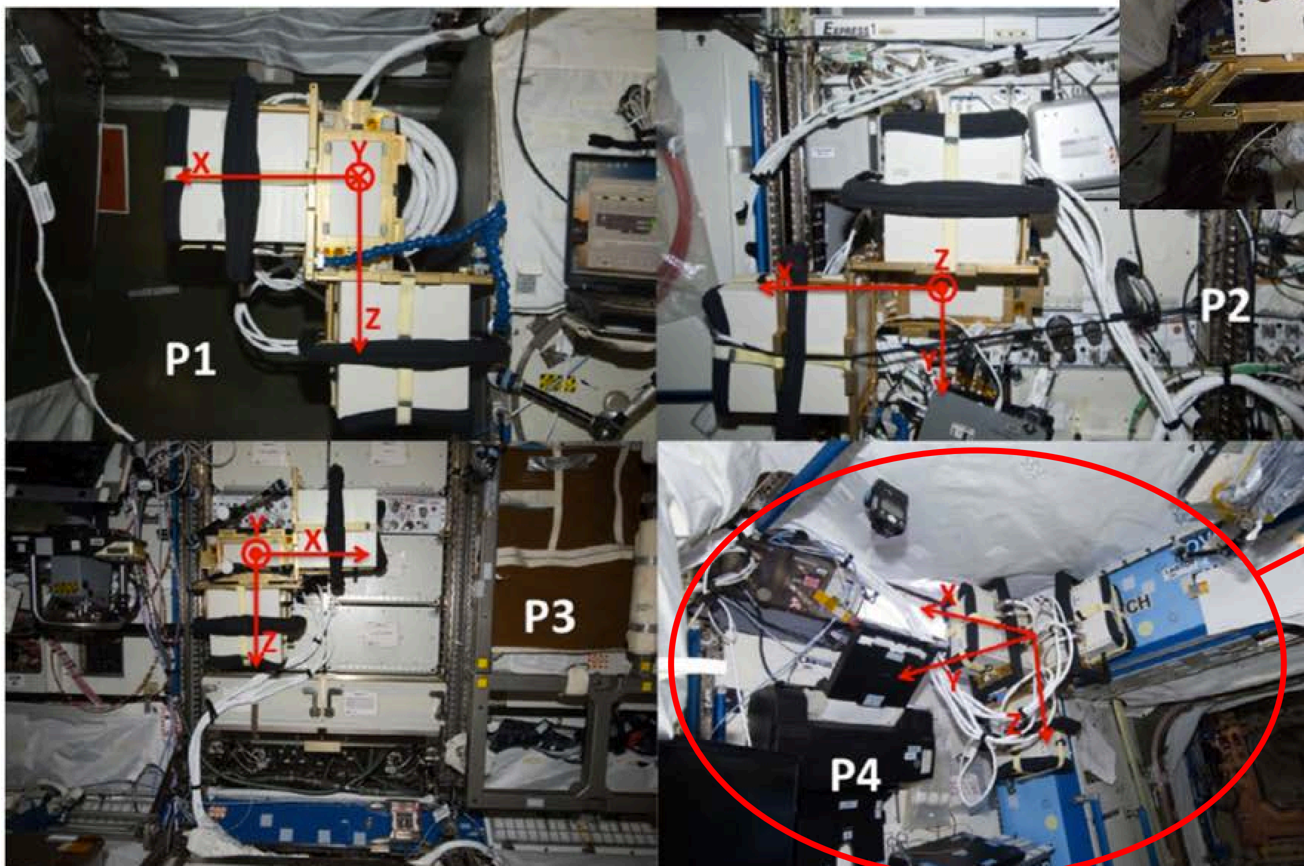
Year	Date	Total duration (days)	Position name	Position
2010	09/20–10/04	14	P1	Lab1S1
2010	10/15–11/30	40	P2	Lab1O2
2011	04/24–07/22	90	P3	Lab1P4
2011/ 2012	07/23/2011– 06/07/2012	263	P4	Lab1S6
2012	06/08–09/30	114	P5	Columbus ER 3

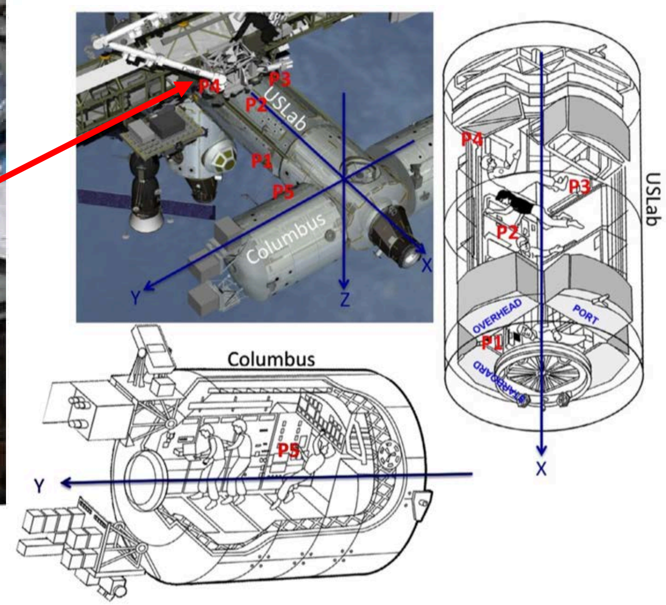
ALTEA detector locations

Positions of the ALTEA SDS
Pos 1-4 in the USLab
Pos 5 in Columbus



P5 in Columbus (ER3)





SPEs in the ISS

	Start	Max Flux [#/(cm² sr s)] P > 10 MeV	P >100 MeV	ALTEA x 10^{-2}	ISS mag low cut	CME	Flare Max.	Flare Importance	Flare Location	Region (SWO)
2011	Jun 07/0820 [1]	72	4.5	1.5	Y	SW/08 1750	Jun 07/0803	M2/2N	S21W64	1226
	Aug 04/0635	96	1.8	0.4	Y	NW/06 0515	Aug 04/0412	M9/2B	N15W49	1261
	Aug 09/0845	26	2.5	0.6	Y	NW/09 1710	Aug 09/0805	X6/2B	N17W83	1263
	Sep 23/2255	35	0.2	[2]	Y	NE/27 0430	Sep 22/1101	X1/2N	N11E74	1302
	Nov 26/1125	80	--		N	NW/28 0145	Nov 26/0710	N/A	N08W49	1353
2012	Mar 07/0510	6530	69	9.1	Y	NE/07 0036	Mar 07/0024	X5/3B	N17E15	1429
	Mar 13/1810	469	1.9	0.4	Y	NW/13 1736	Mar 13/1741	M7/	N18W62	1429
	May 17/0210	255	20	0.9	N	NW/17 0148	May 17/0147	M5/1F	N12W89	1476
	May 27/0535	14	--		N	/27 2112	N/A	N/A	N/A	1482
	Jun 16/1955	14	--		Y	SE/14 1430	Jun 14/1435	M1/1N	S17E14	1504
	Jul 07/0400 [3]	25	0.7	0.4	Y	SW/06 2312	Jul 06/2308	X1/	S18W50	1515
	Jul 12/1835	96	0.3	0.1	Y	SW/12 1649	Jul 12/1710	X1/2B	S16W09	1520
	Jul 17/1715	136	0.7		N	SW/17 1348	Jul 17/1715	M1/	S17W75	1520
	Sep 01/1335	59	--		Y	SE/31 2012	Aug 31/2043	C8/2F	S06E20	
	Sep 28/0300	28	0.2		Y	NW/28 0018	Sep 27/2357	C3/1F	N08W41	1577

Pos 4

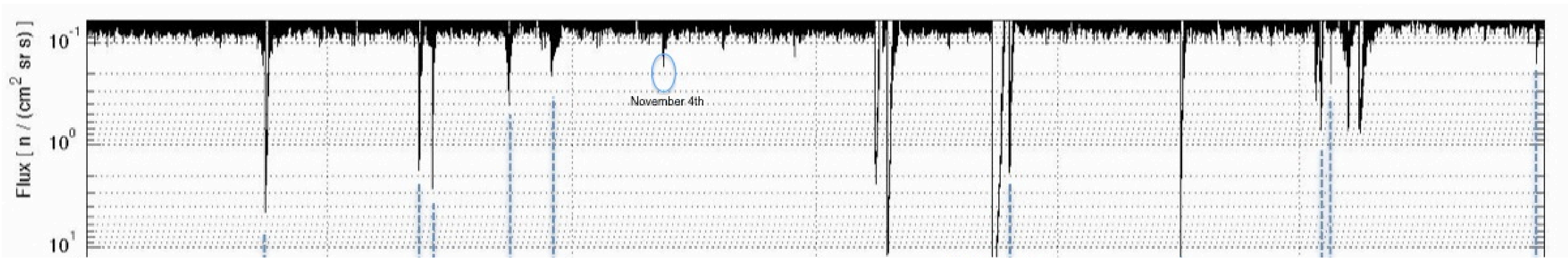
(1) GOES100 & ALTEA sees a start on the day before (June 6).

(2) Only Forbush

(3) Two events, on the 7th and on the 9th. ALTEA sees well the 9th one (indicated). The 7th has a maximum at high magnetic cut, and ALTEA barely sees it.

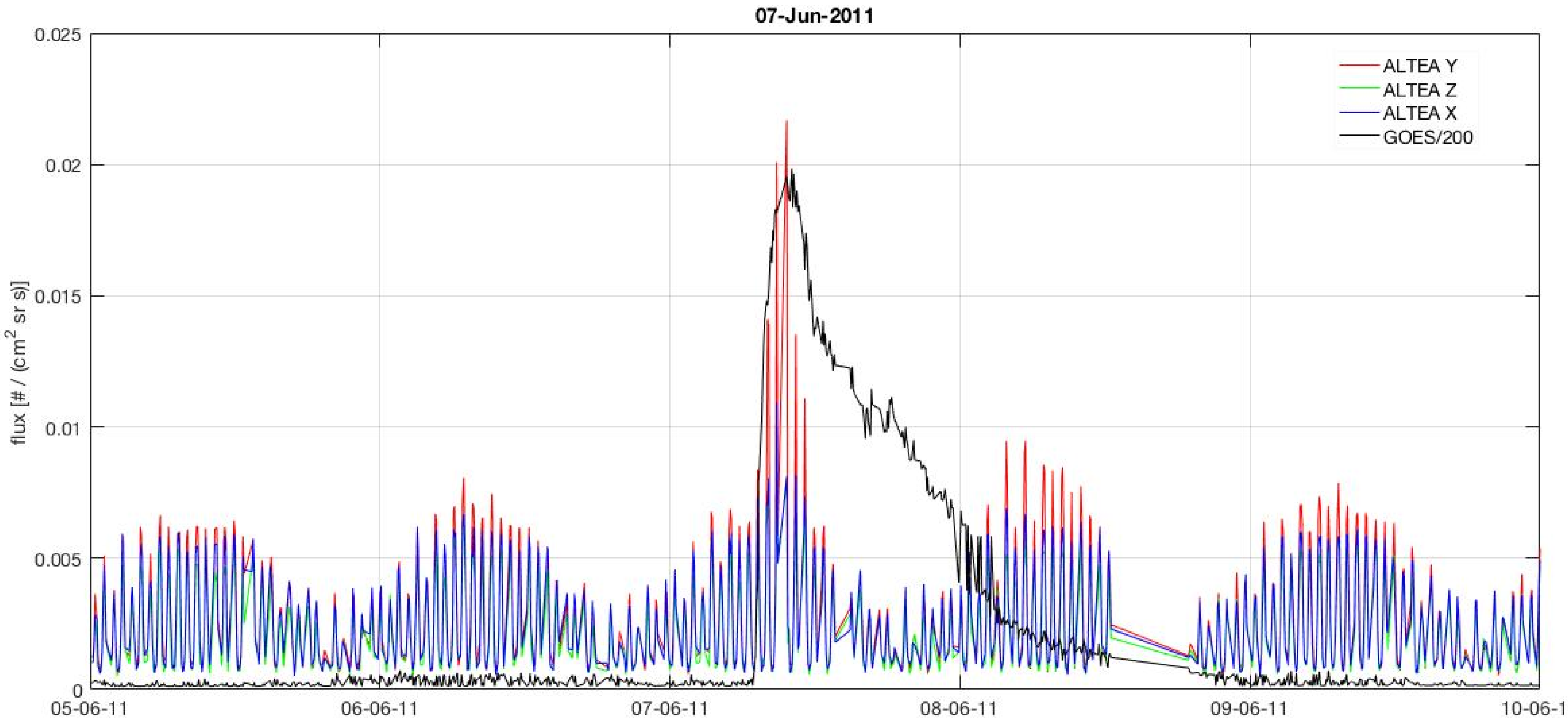
SPEs in 2010 – 2012: GOES and ALTEA results

GOES

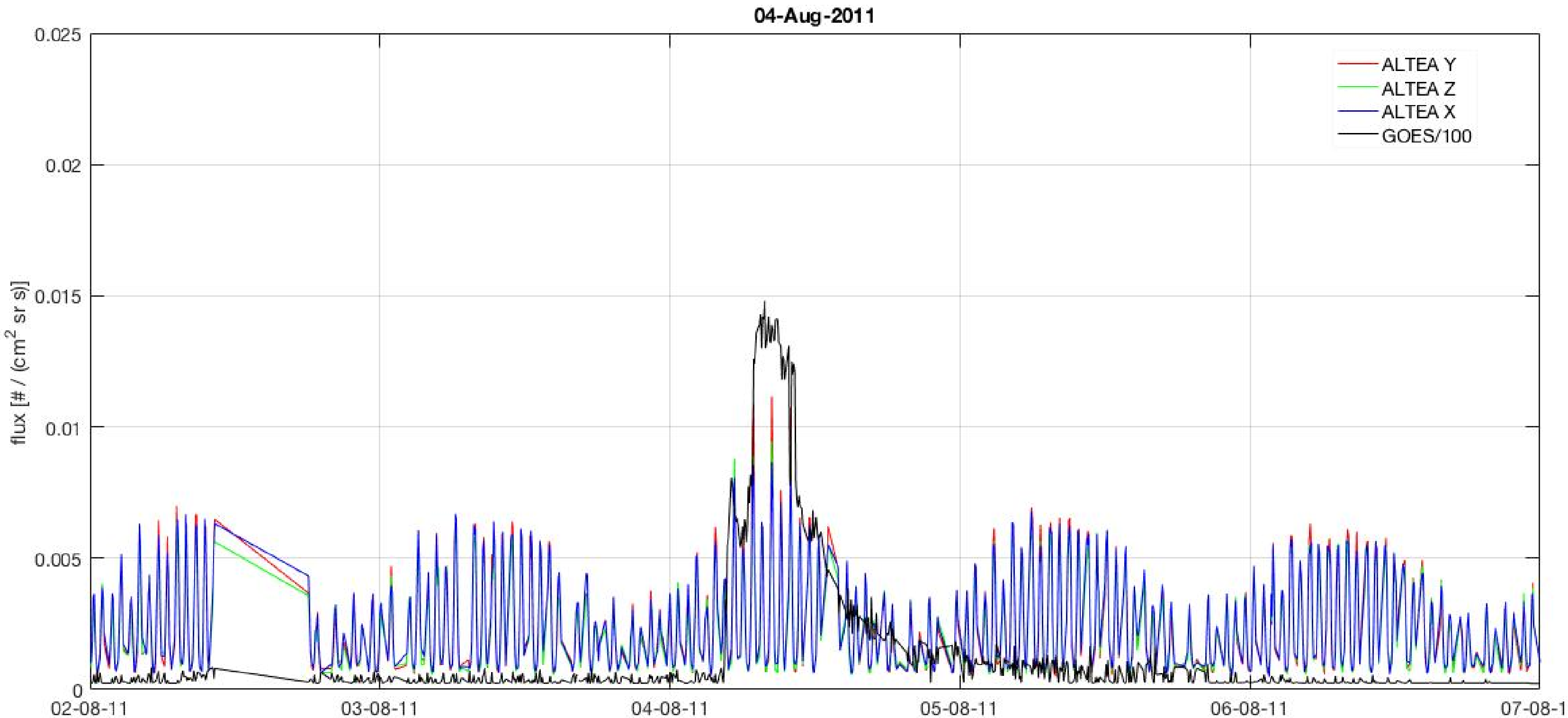


Pos 4

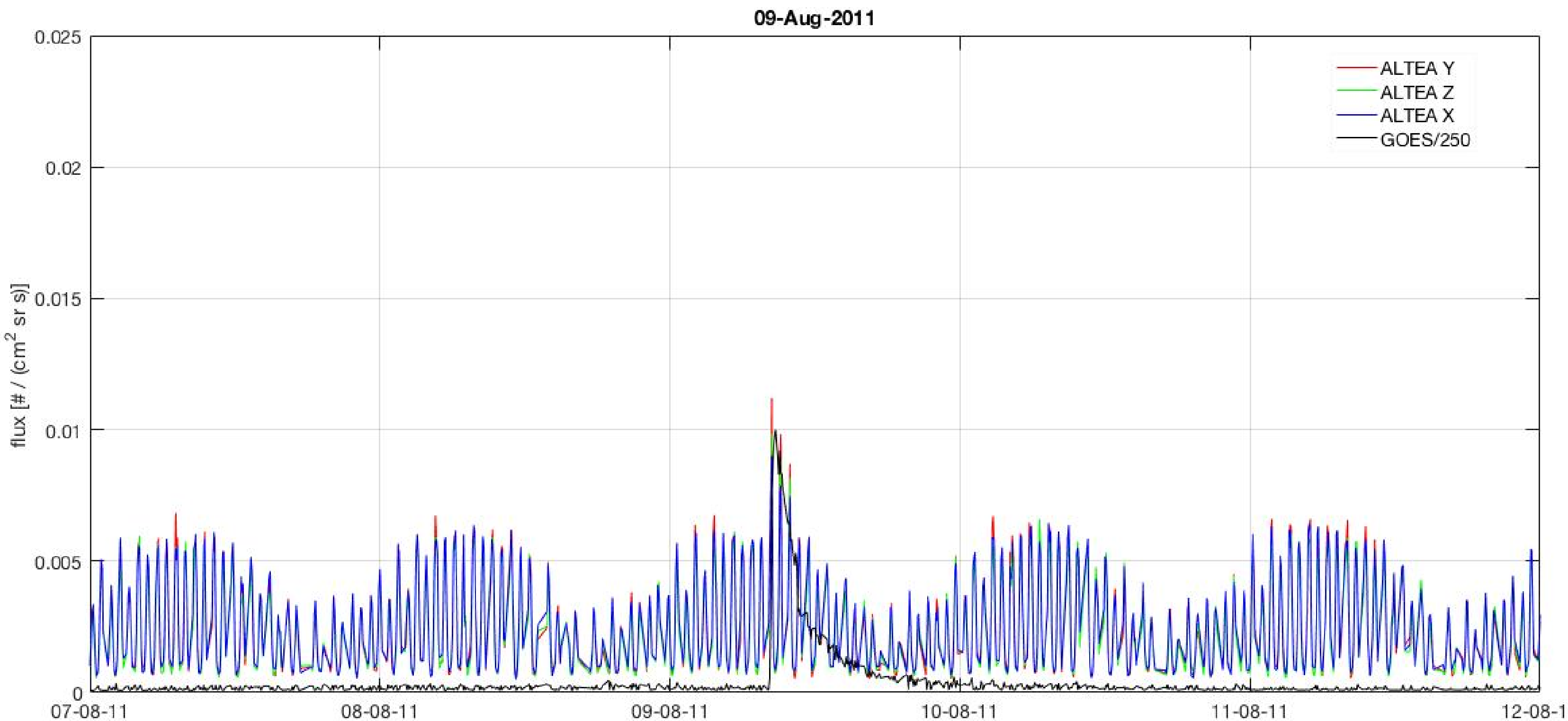
SPEs in the ISS



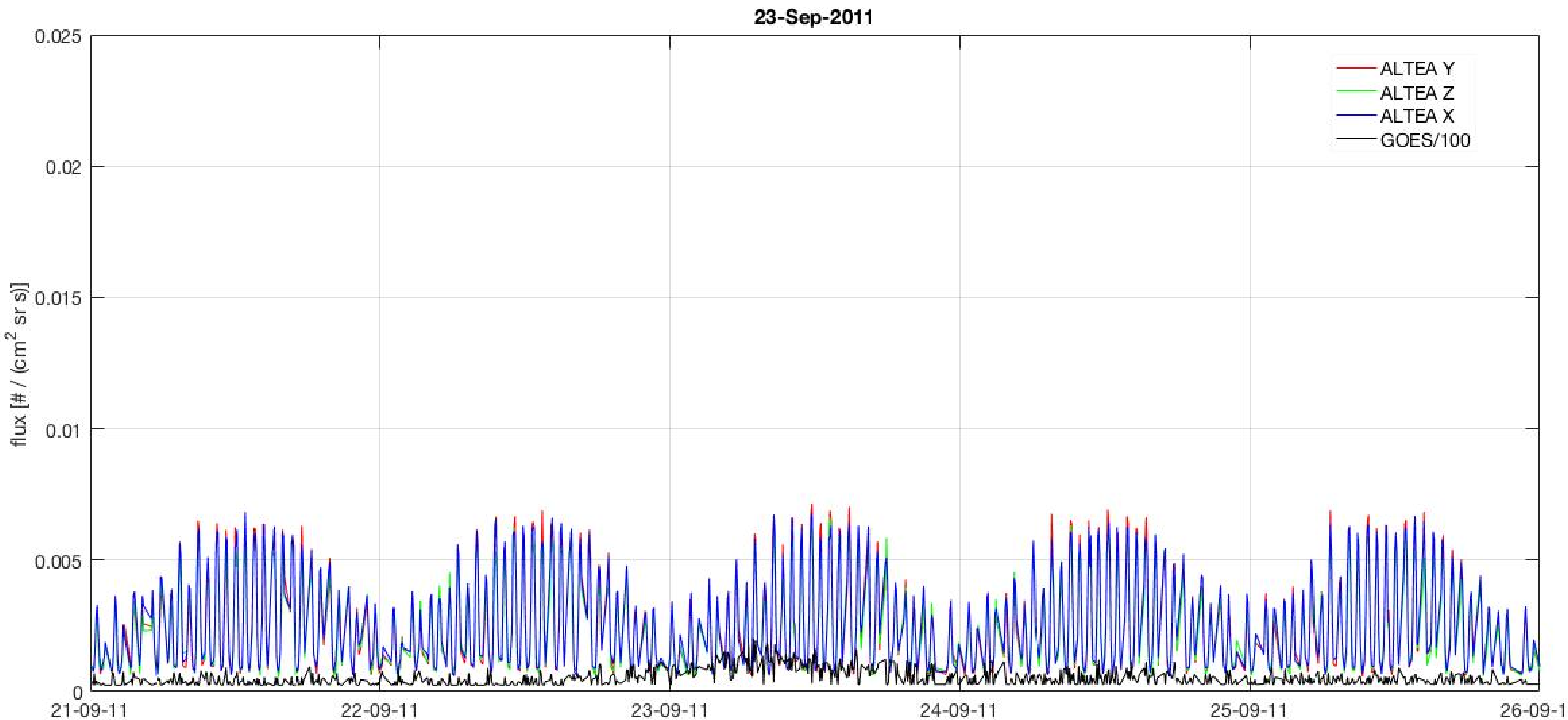
SPEs in the ISS



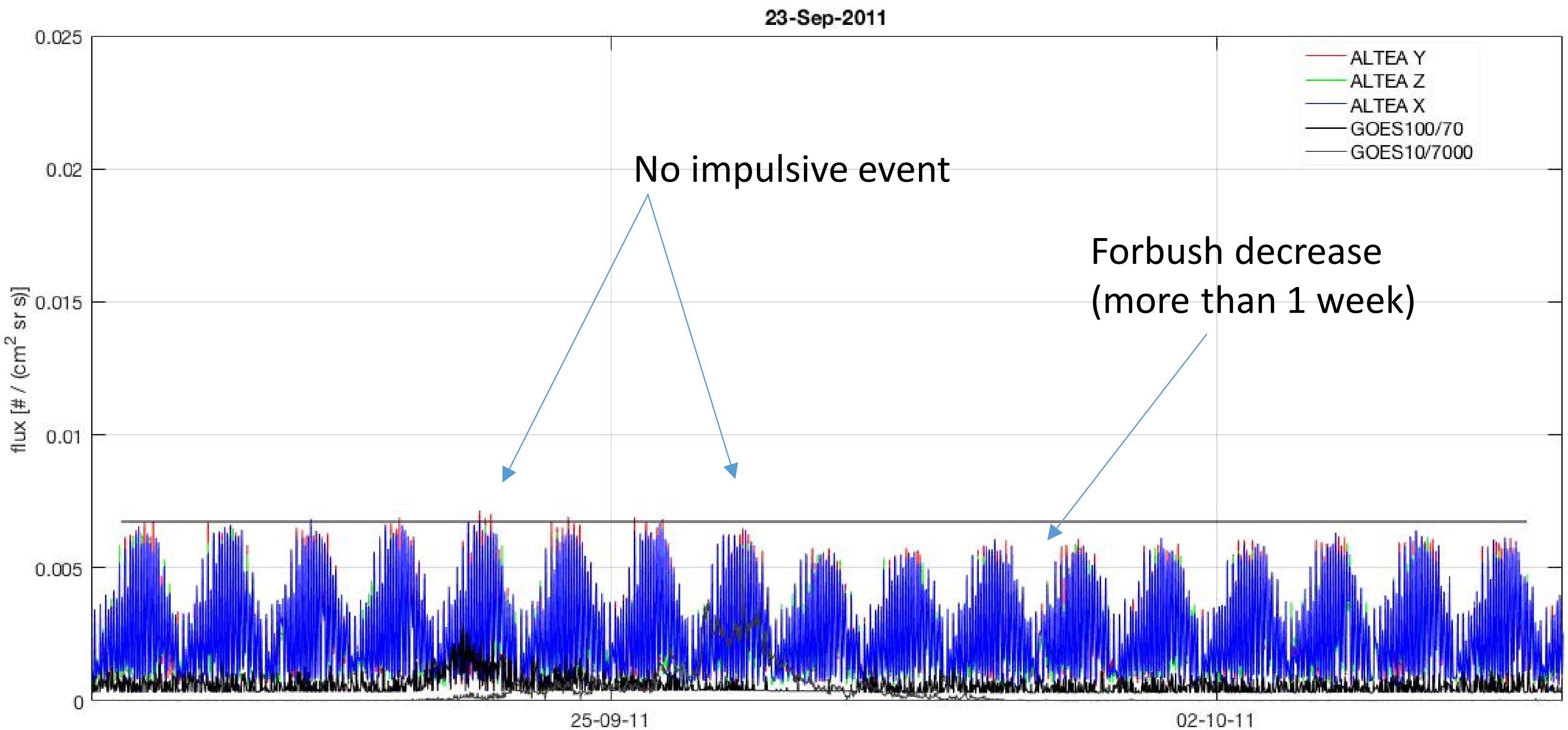
SPEs in the ISS



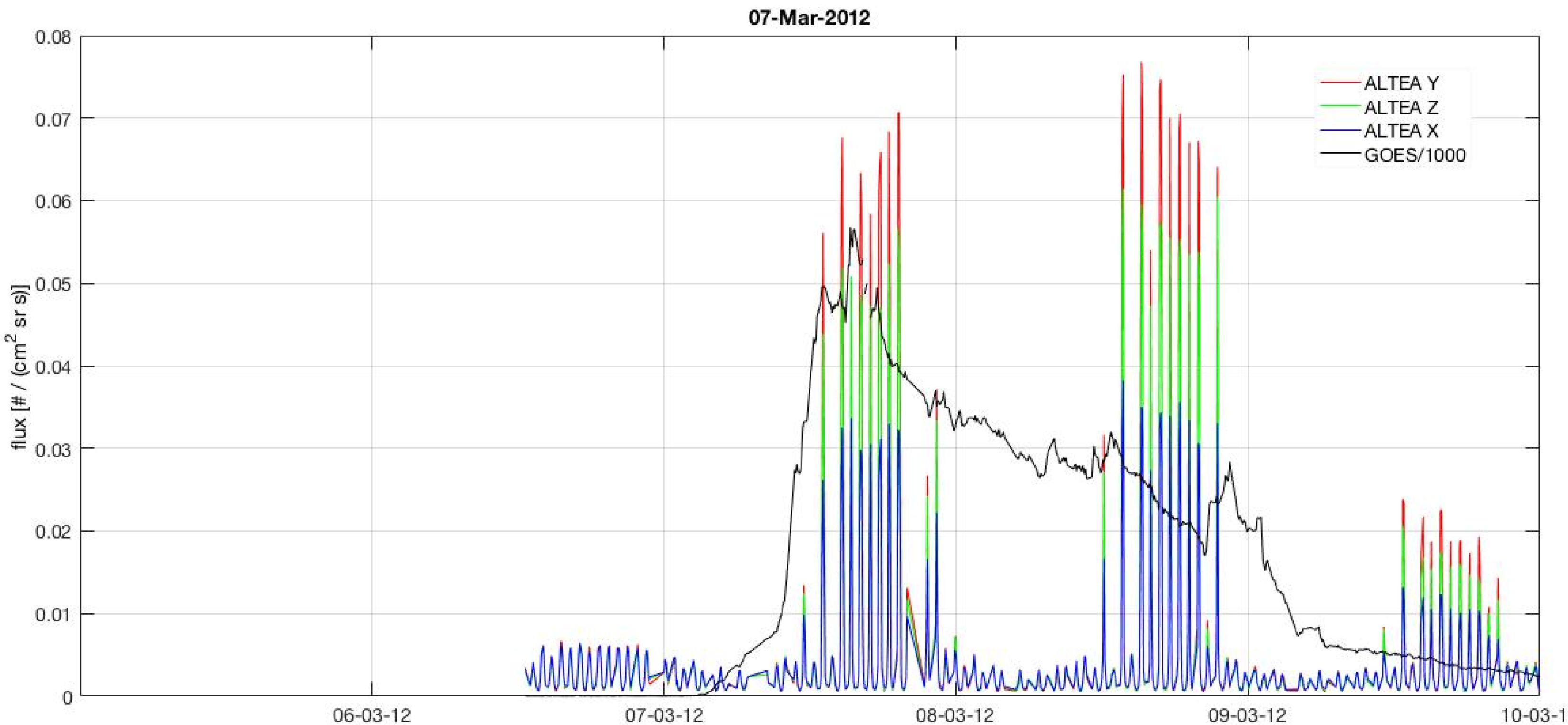
SPEs in the ISS



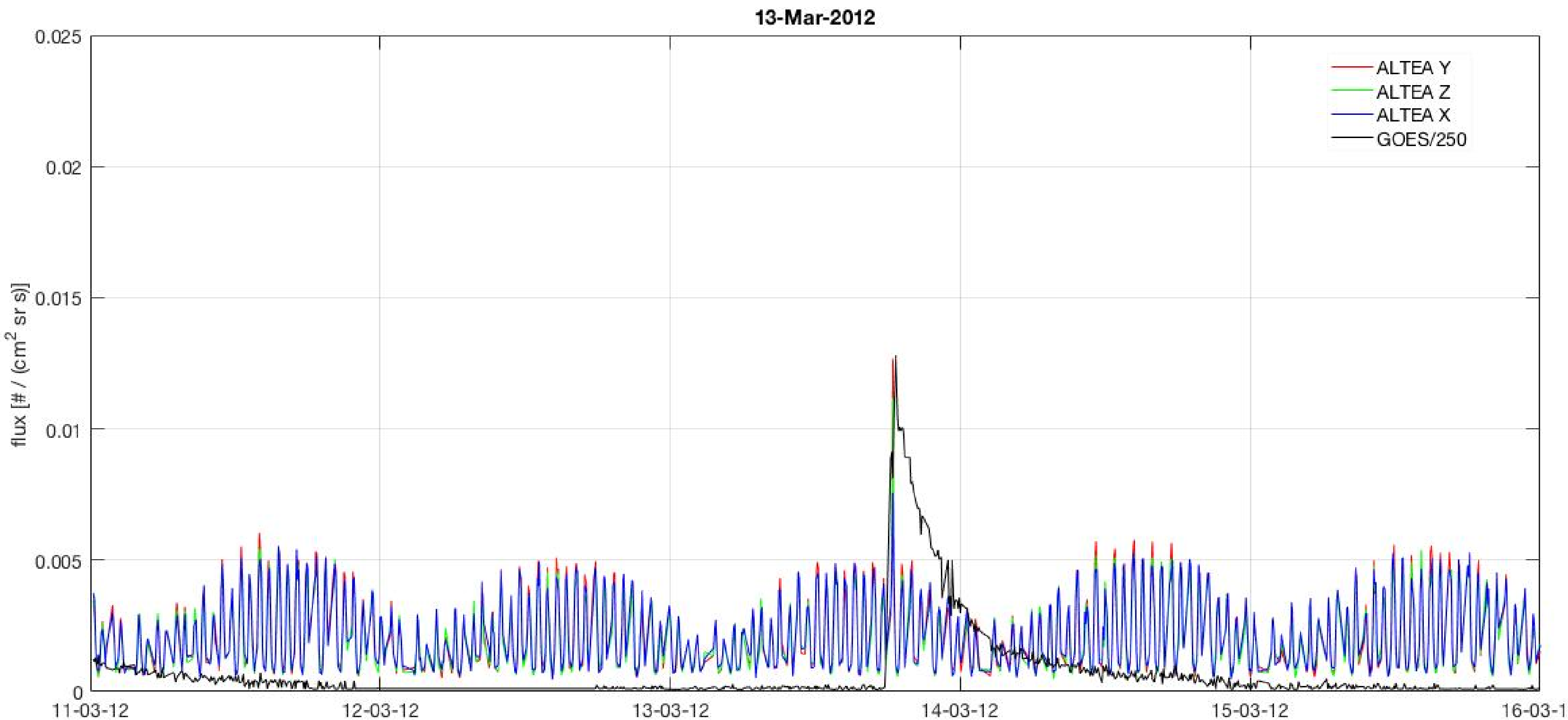
SPEs in the ISS



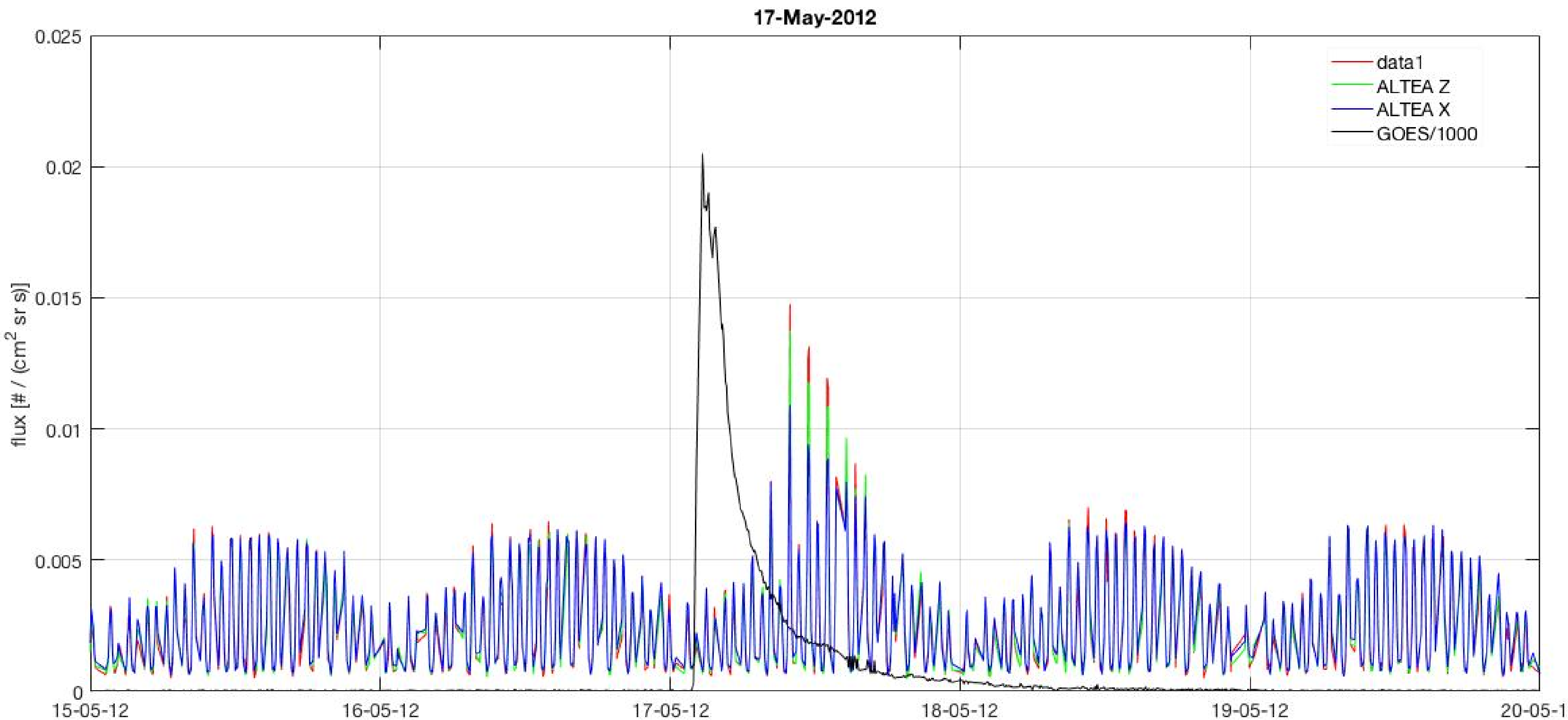
SPEs in the ISS



SPEs in the ISS



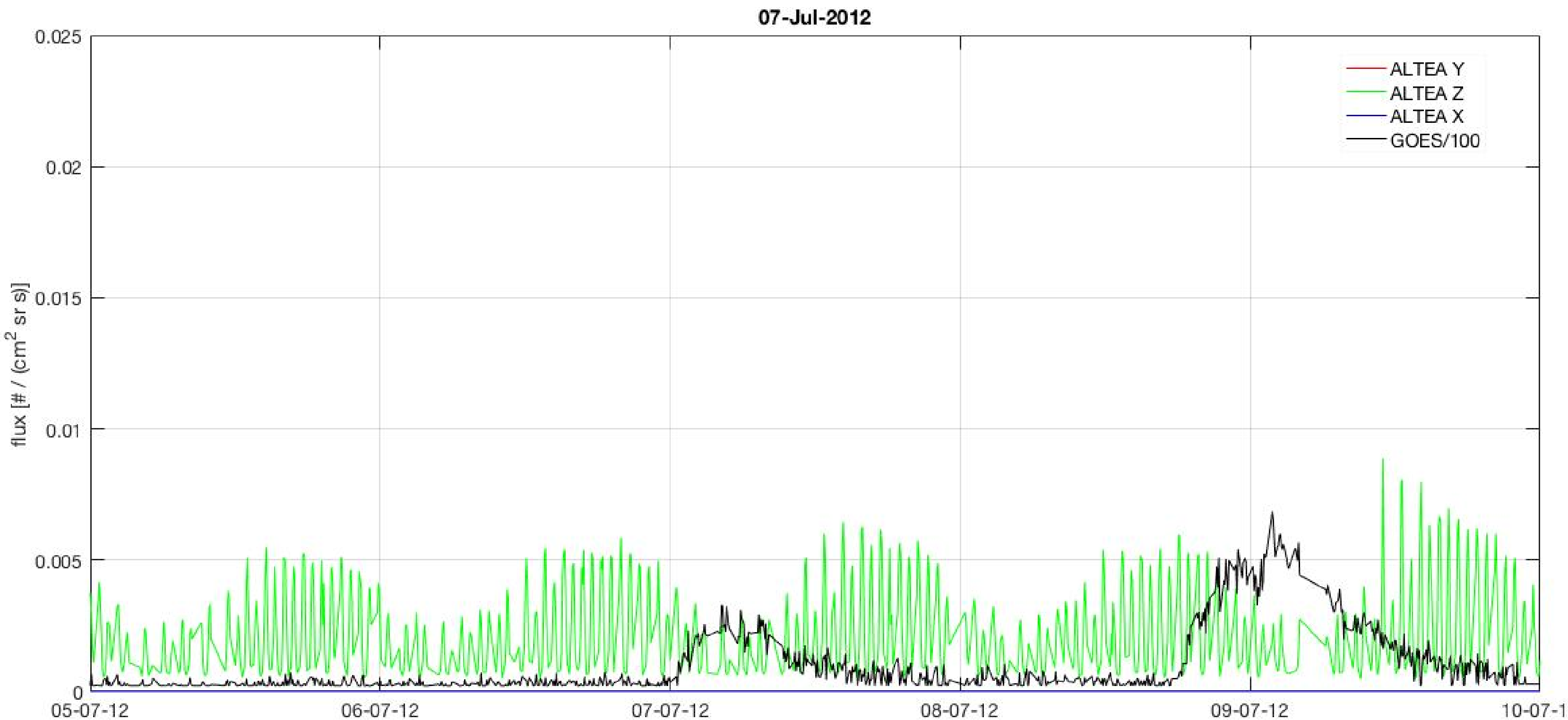
SPEs in the ISS



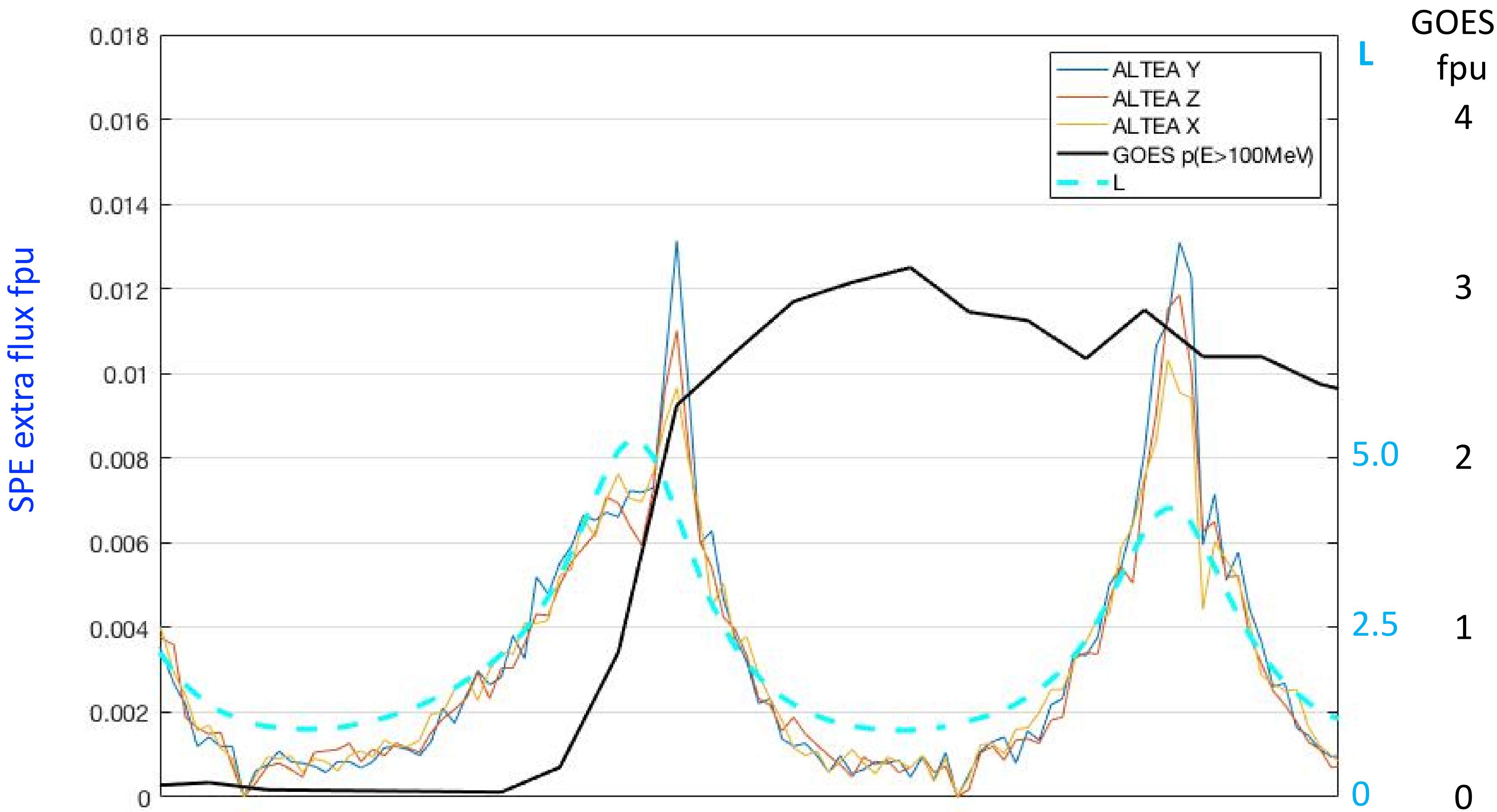
This is the only GLE in 2010 - 2012

Berrilli et al J Space Weath and Space Clim 2014

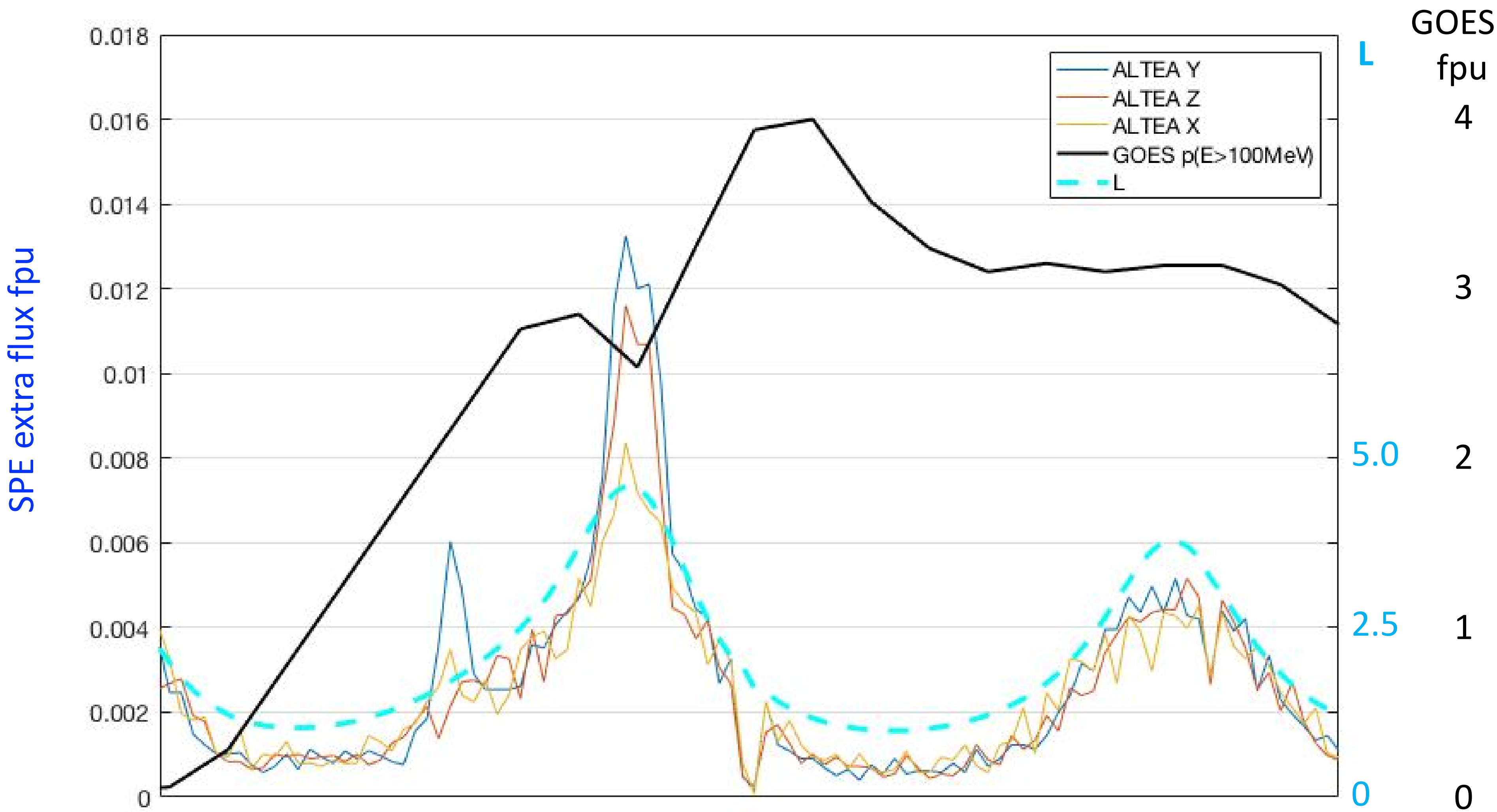
SPEs in the ISS



First part of Aug 9 2011 SPE

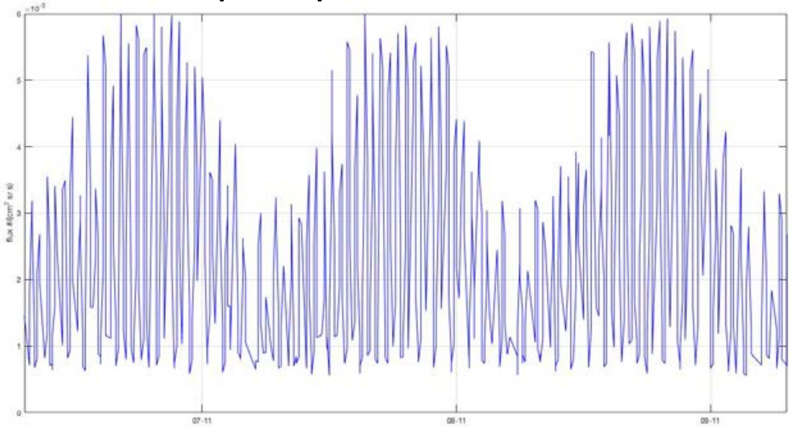


Mar 13 2012 SPE

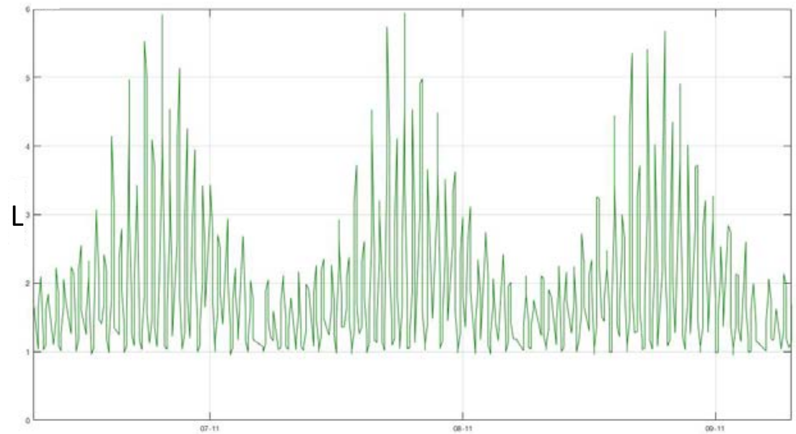


Simple model to describe GCR from McIllwain L

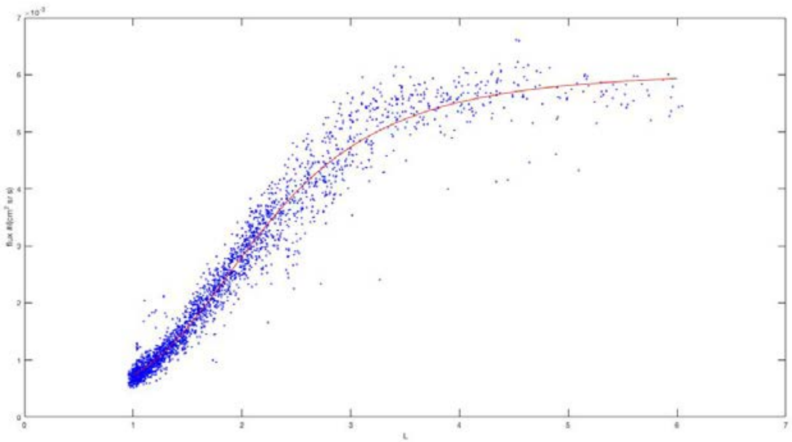
A quite period



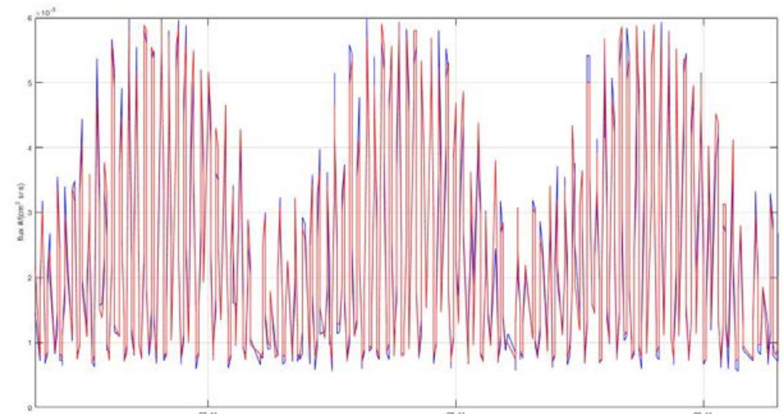
Corresponds to this L dynamics



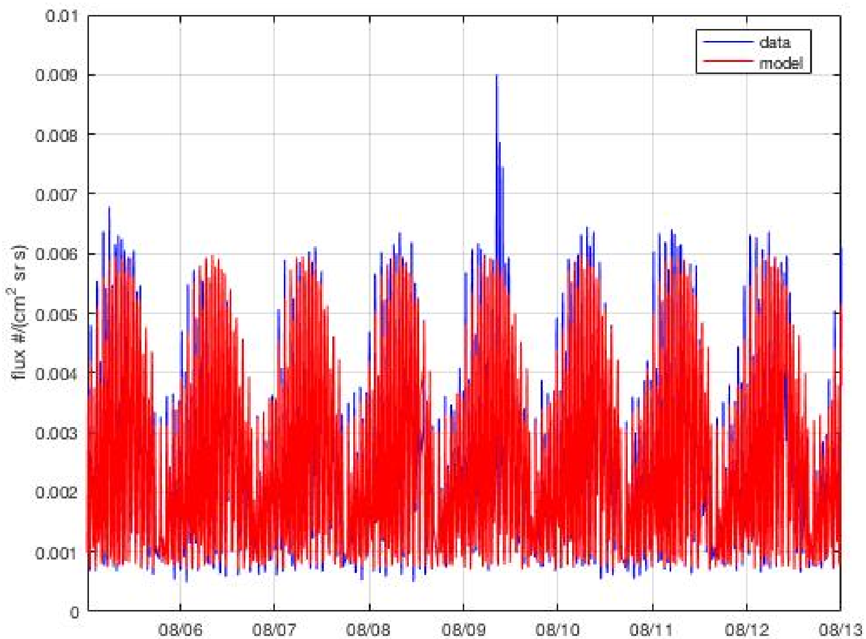
L and the ion flux are linked through a sigmoid

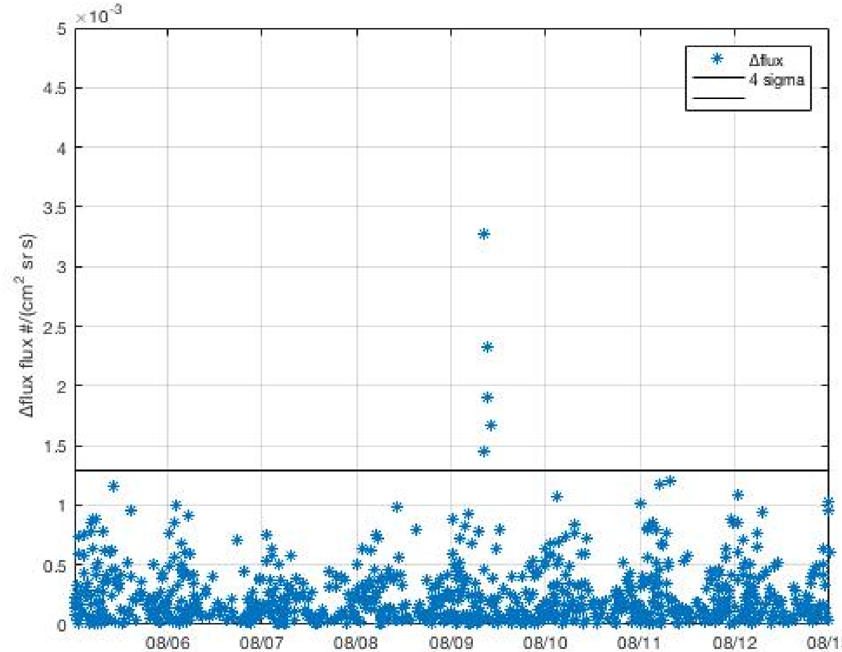


… this is the fit (red = model)



Simple model to describe GCR from McIllwain L

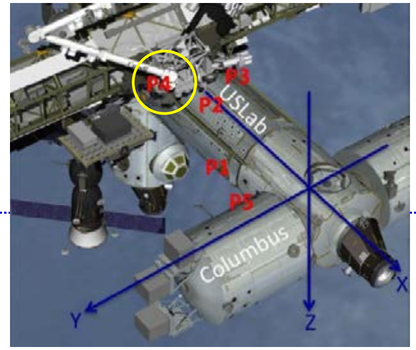


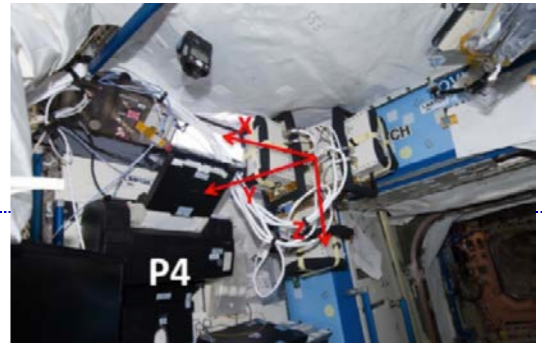


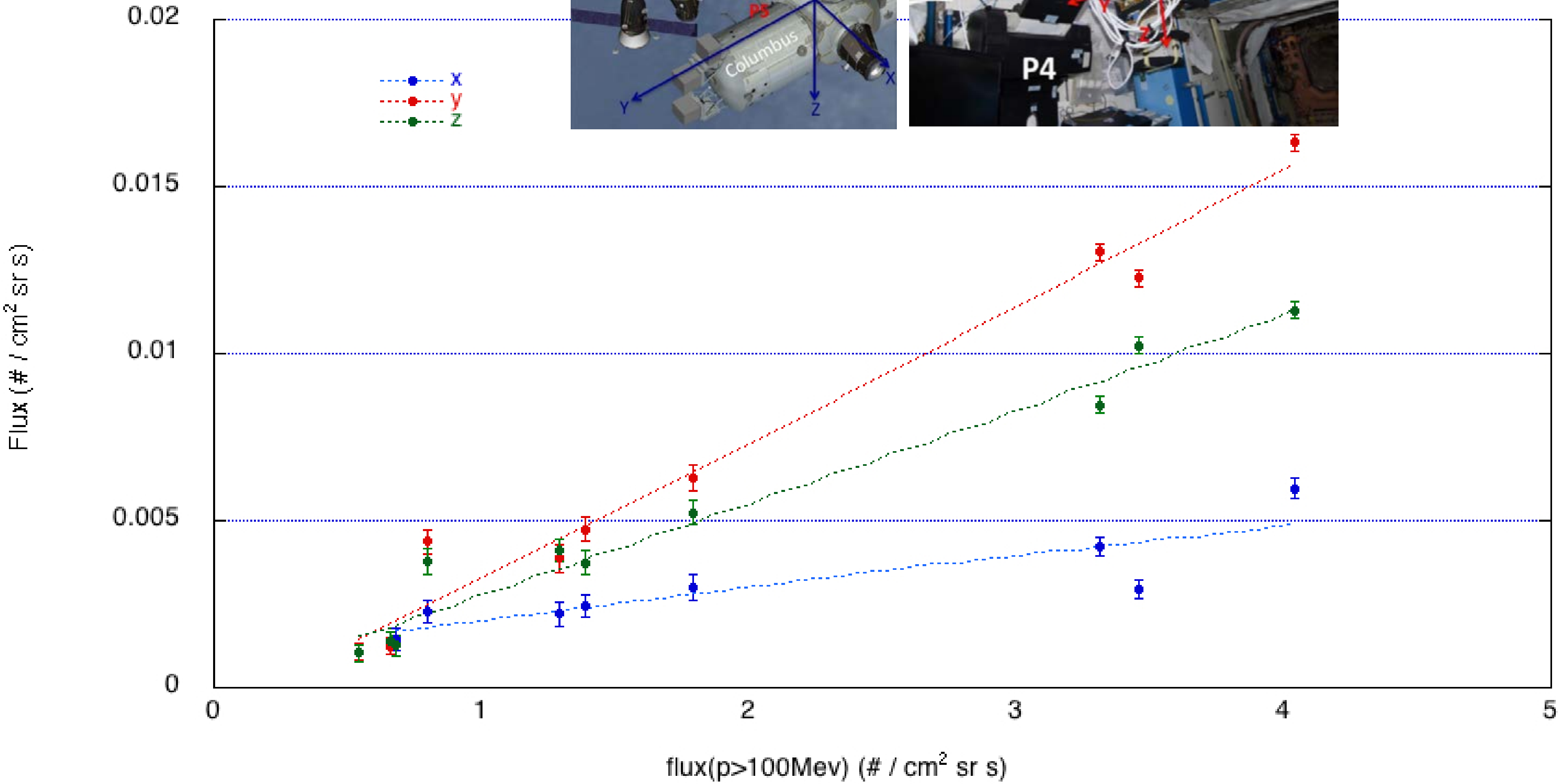
SPE: Aug 9, 2011

SPEs in the ISS

Only Pos 4 - Low p(>100) flux



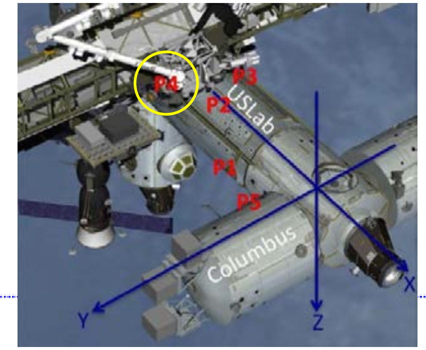


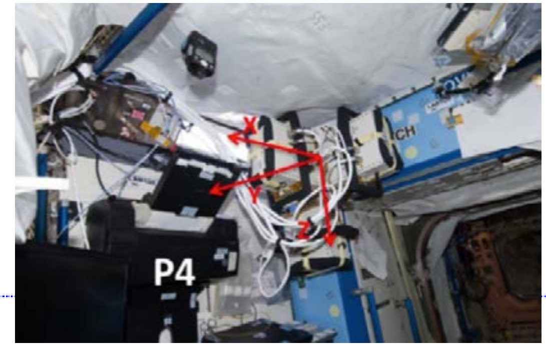


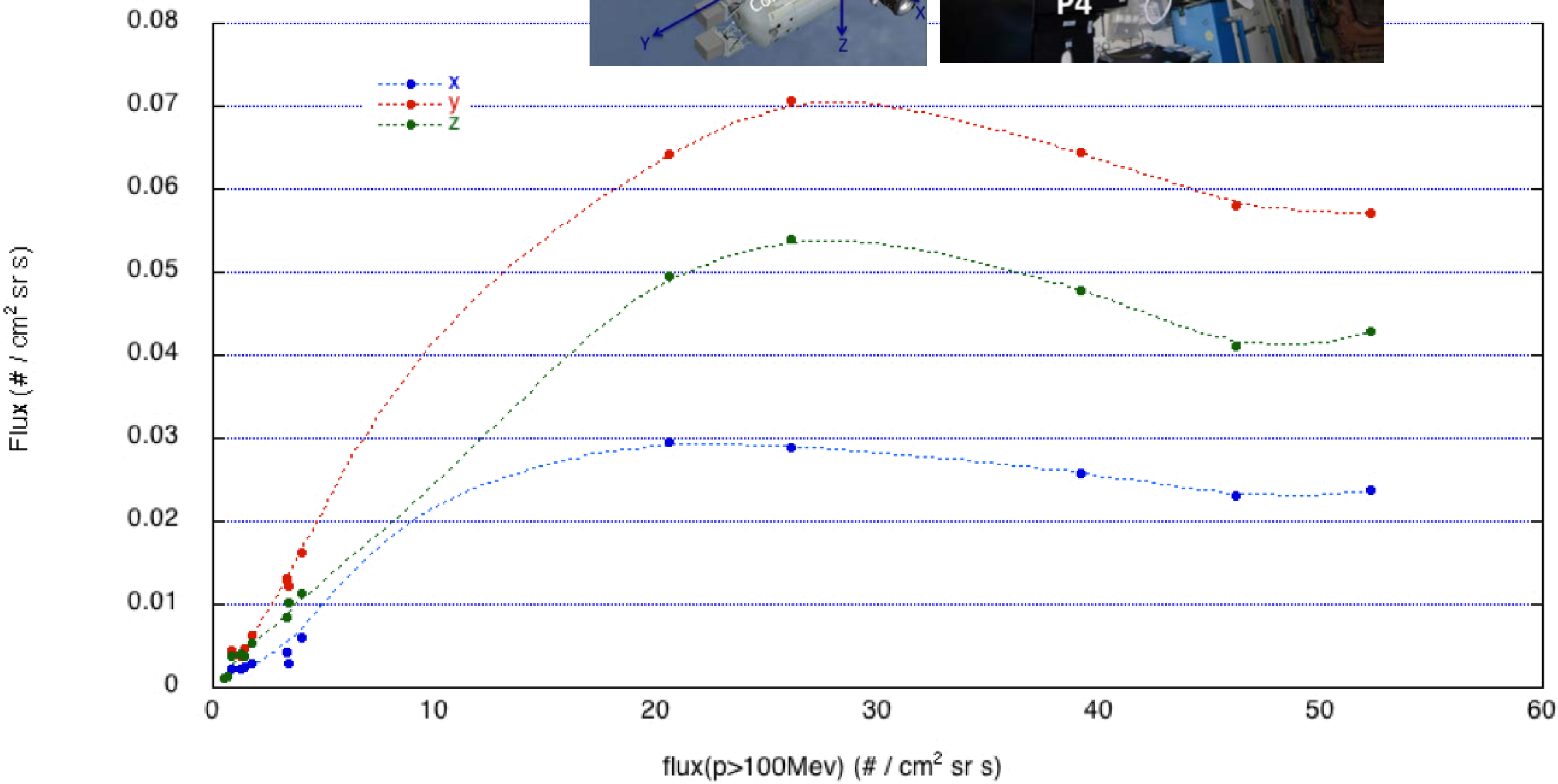
Each SPE value has been calculated as 'excess' from GCR radiation, modelling the GCR on the basis of the McIllwain magnetic coordinate

SPEs in the ISS

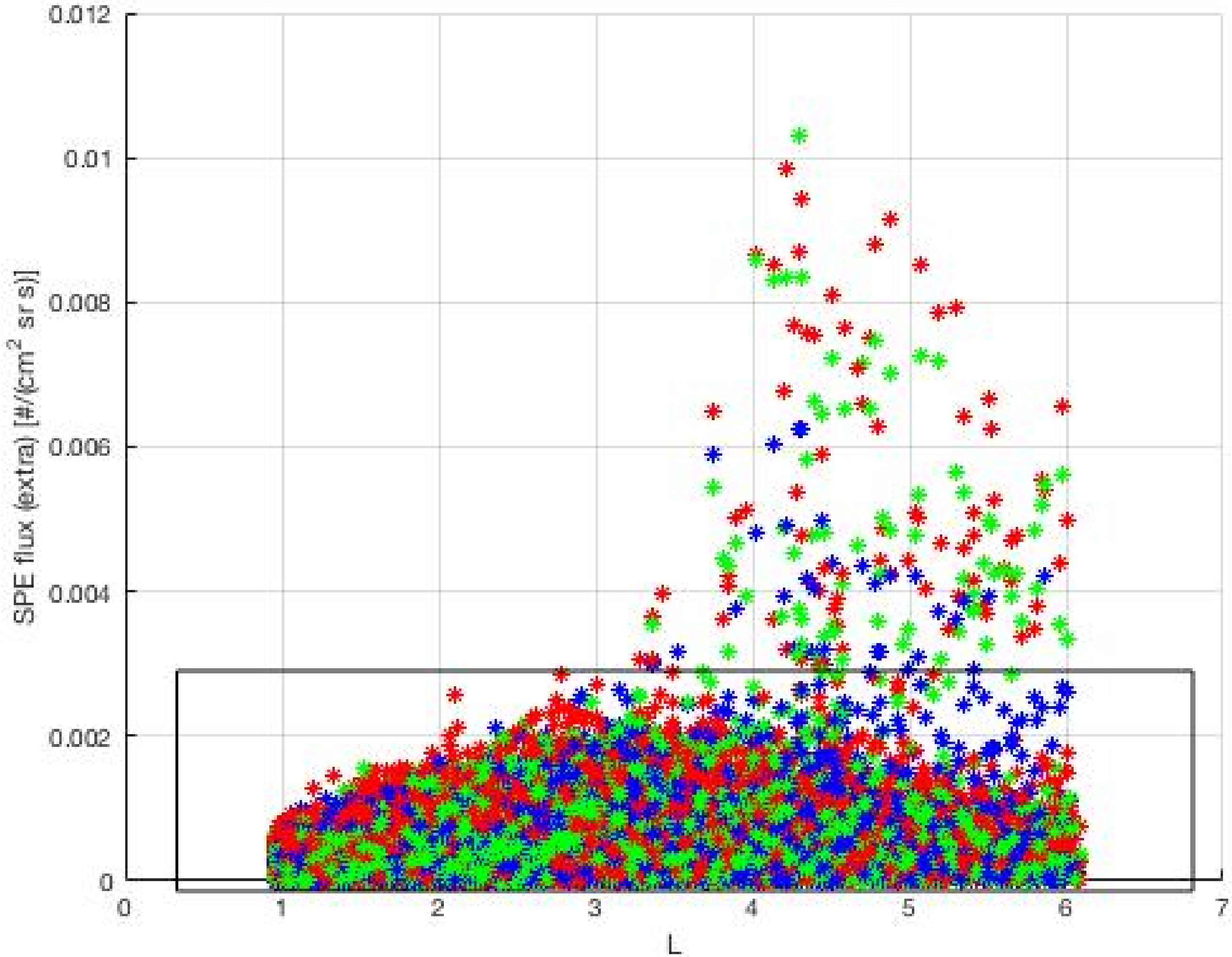
Only Pos 4 – All values





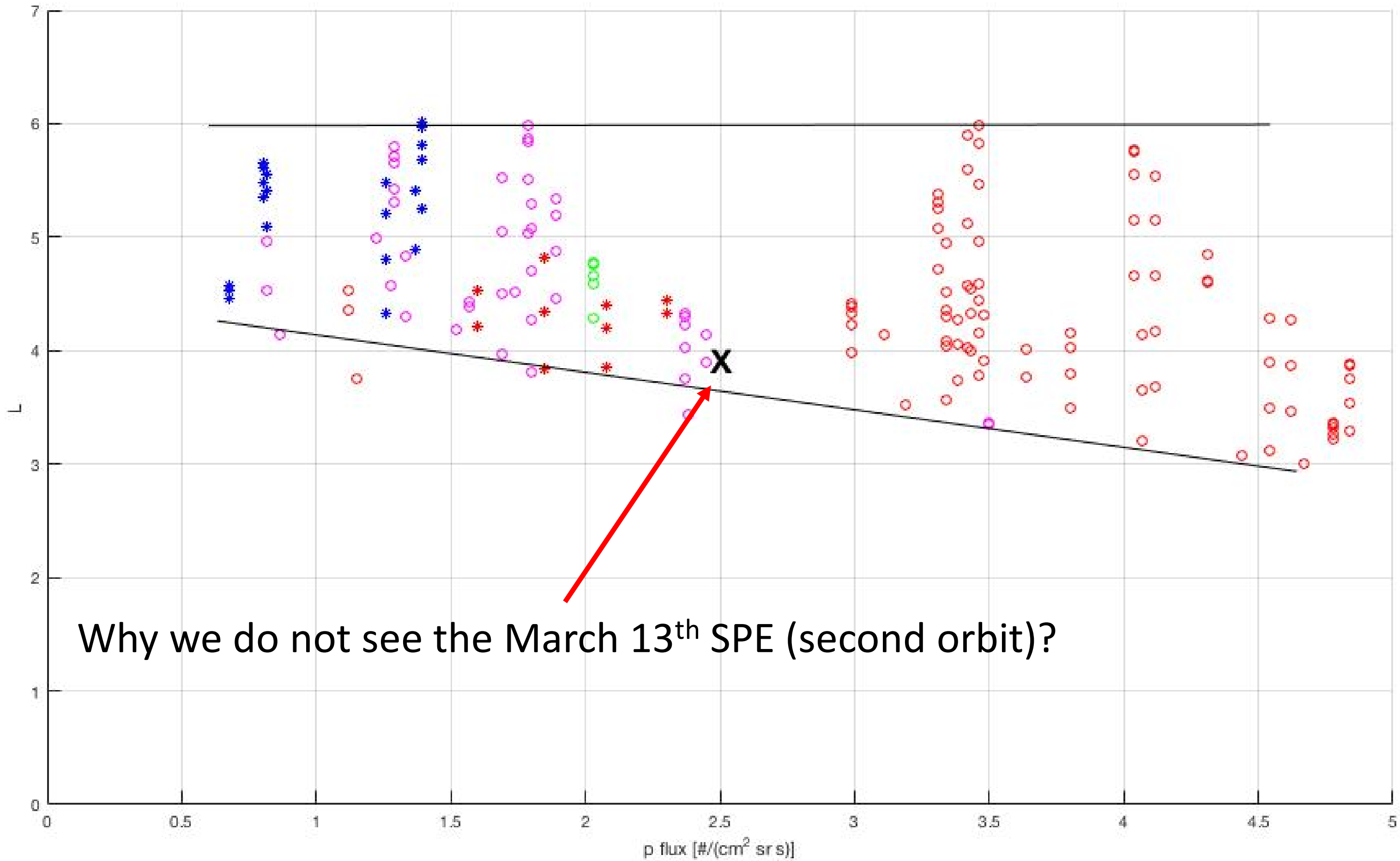


SPEs in the ISS: flux dependence vs L

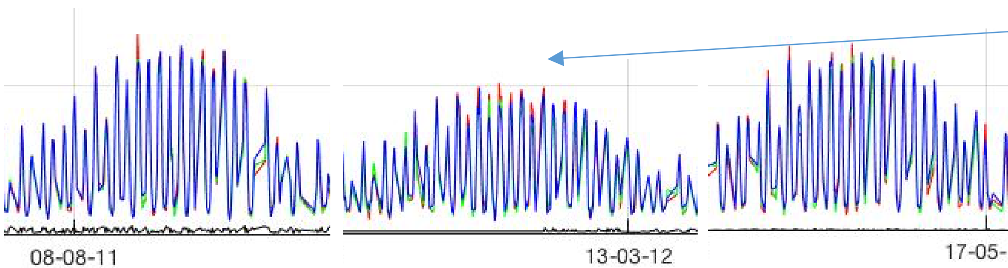


SPEs in the ISS: measurability vs L and p flux

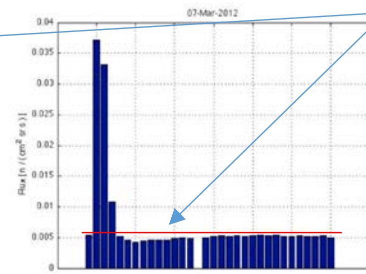
Different symbols different SPEs.



1) Forbush effect

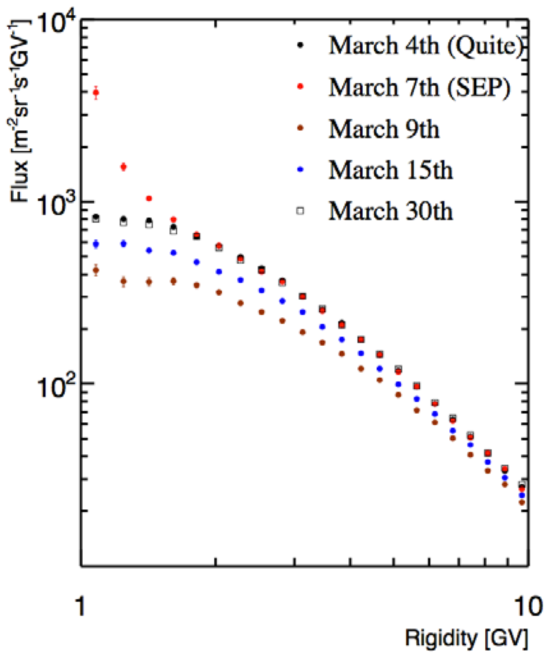


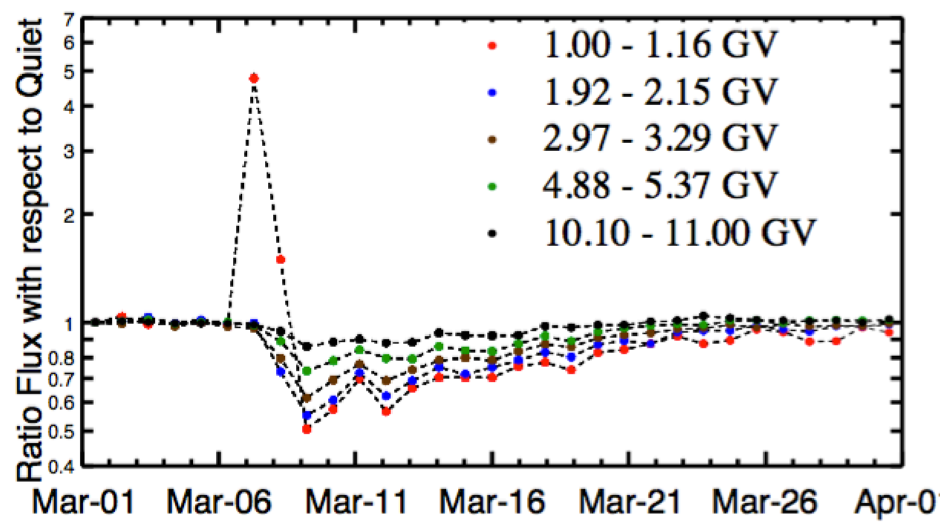
Just before Aug 9th 2011 SPE | Just before March 13th 2012 SPE | Just before May 17th 2012 SPE



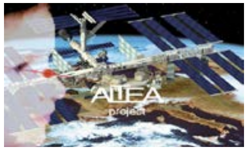
BUT:
Conditions were not normal during March 13th 2012 SPE: it was still strongly feeling the Forbush decrease due to the March 7th 2012 SPE

March, 2012 - Solar Event -



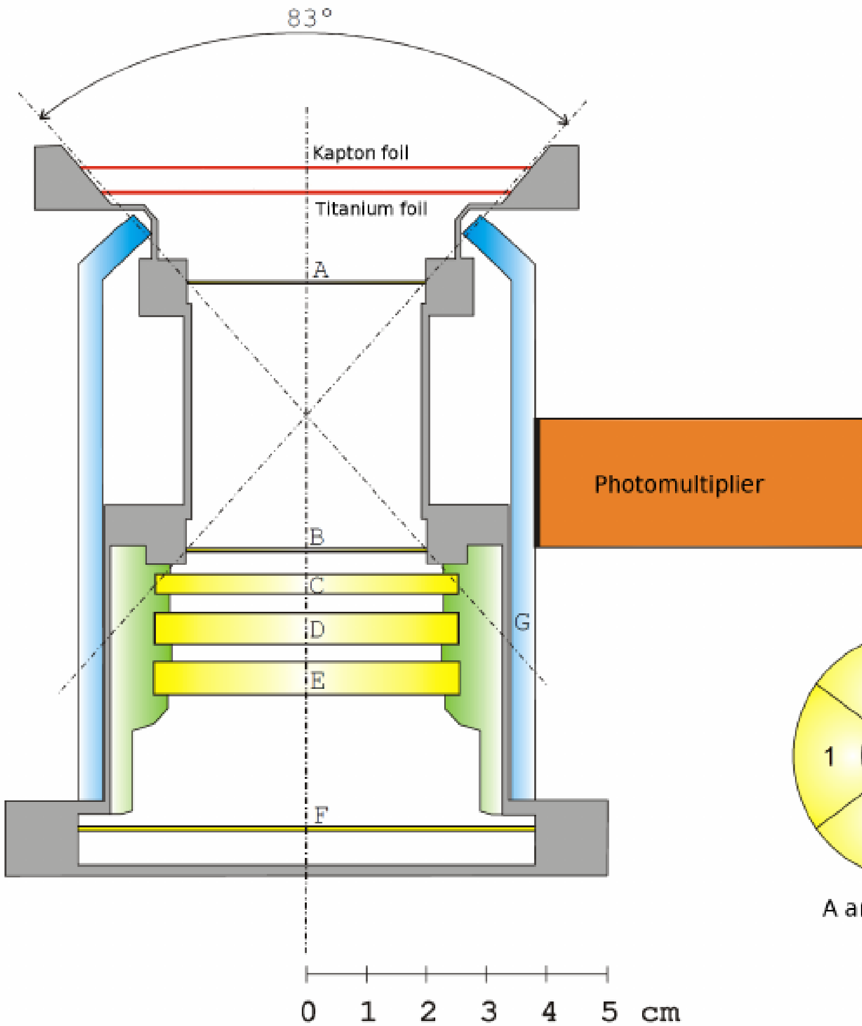


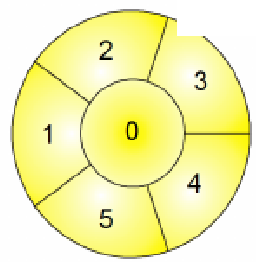
Della Torre et al. XXV European Cosmic Ray Symposium, Turin, Sept. 4-9 2016



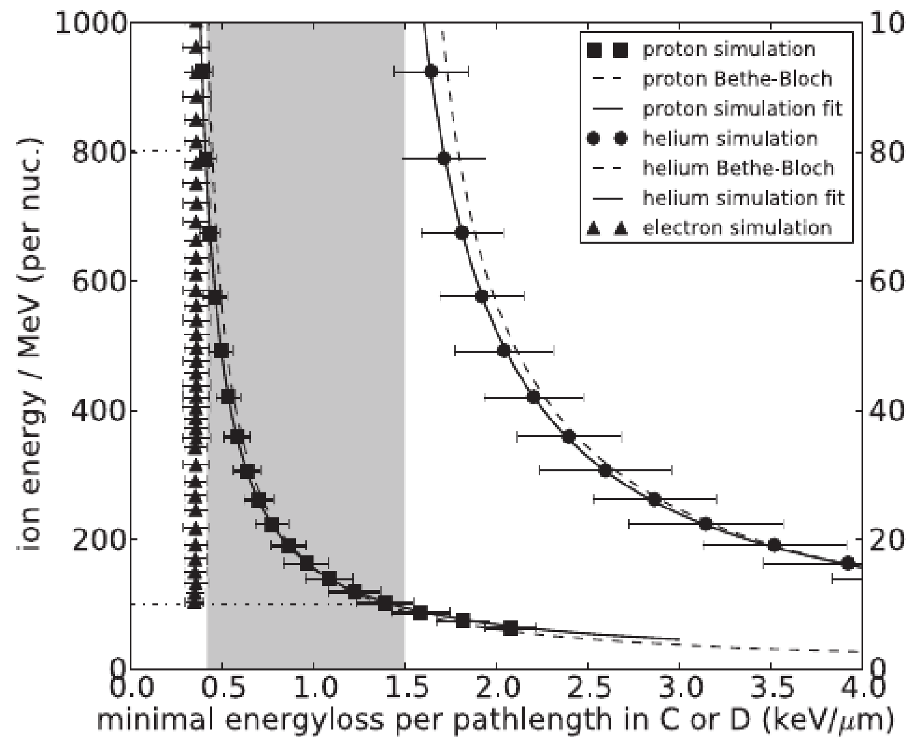
2) Different SPE spectra

The SOHO/EPHIN penetrating particle measurement



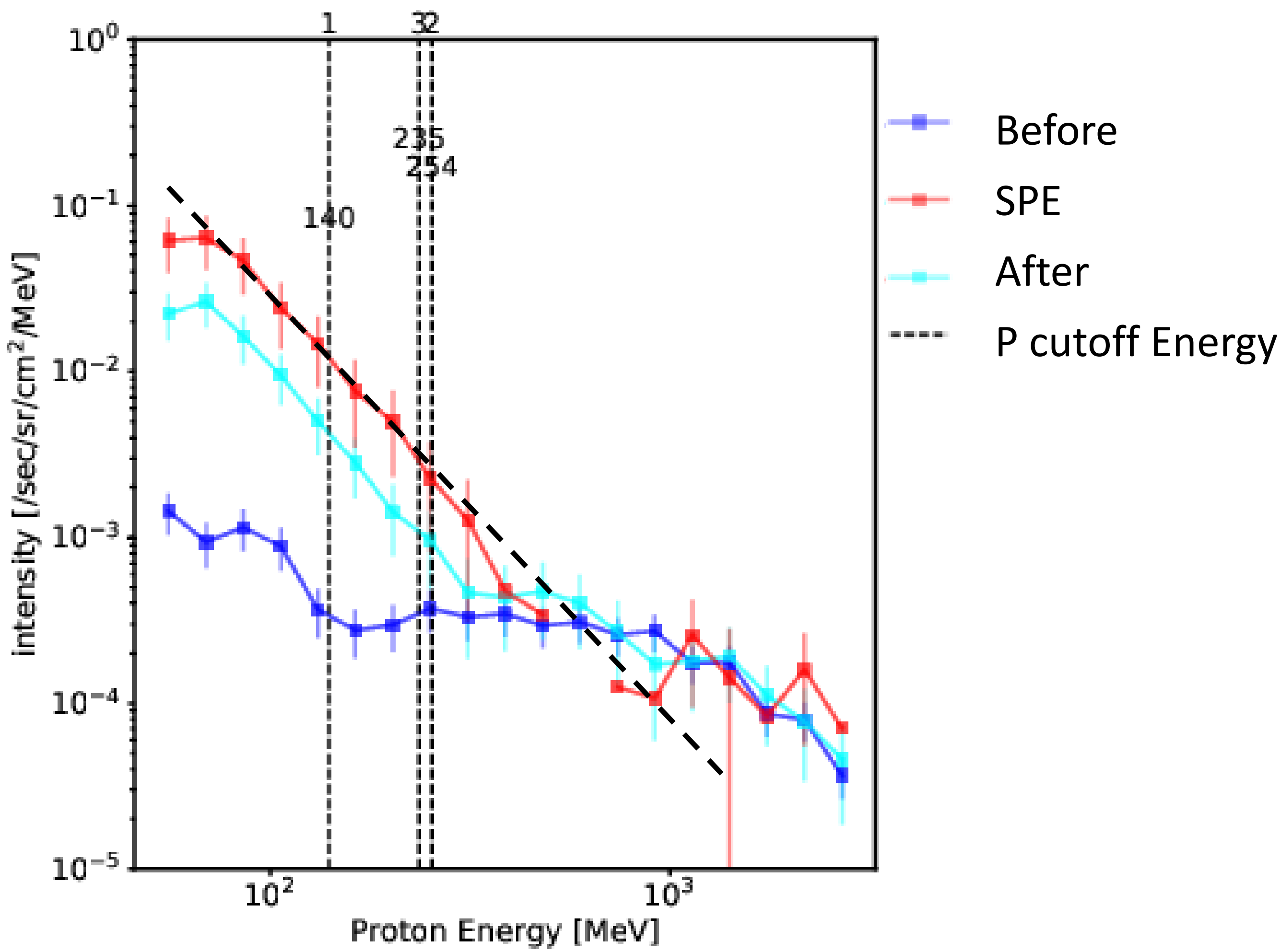


A and B detectors

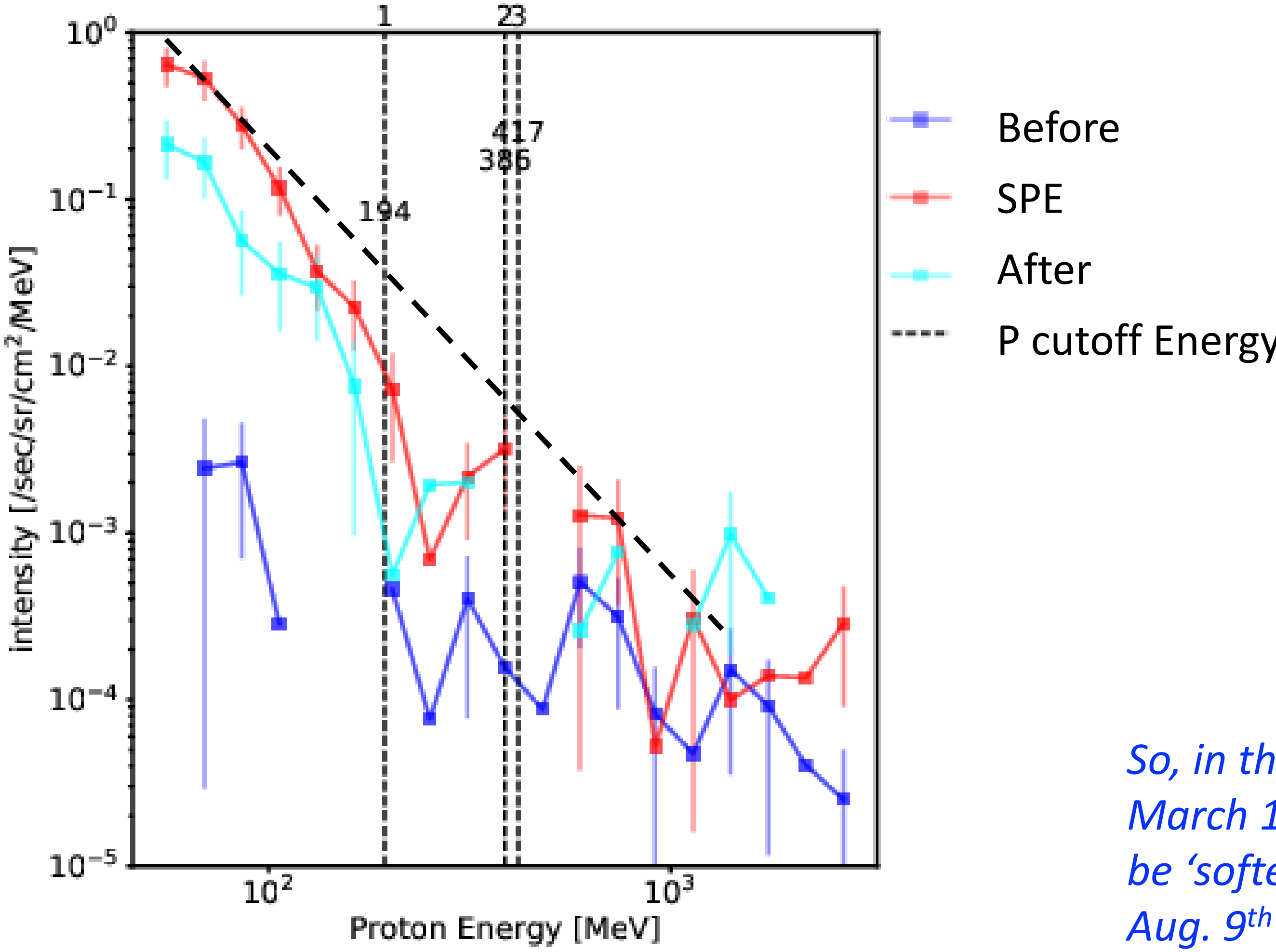


A method extracting the energy and spectra of penetrating particles through the detector (0.1 – 2 GeV) has been developed and validated by Kuehl et al 2015 A&A

2) Different SPE spectra



2) Different SPE spectra



The method, however, suffers from bad statistics at the high-energy part when the lower energy fluxes are more dominating (more low-energy stopping PHA events are sent back as a priority science product).

It would be helpful to have the PAMELA / AMS data for studying the original spectra of this event.

So, in the average the March 13th 2012 SPE might be 'softer' than the one in Aug. 9th 2011.

Concluding remarks

• The most immediate parameter linked to a SPE readability in a space habitat in LEO is

- p (E>100 Mev) [for example from GOES]

• Other parameters may play a role in the way SPEs are measured in LEO:

- Geomagnetic variations
- Forbush effects
- Spectral characteristics of an SPE
- Spectral variability of an SPE

• The understanding of these interactions will also help in using SPE ISS data for human exploration issues. [NOTE: ISS is the platform which will have relevant possibilities to study in depth SPEs in space habitat]

• Being able to study the behavior of the SPE in LEO inside a space habitat with good time resolution (≈≤ 10 min) is needed to study the above mentioned effects.

Thank you for your attention!