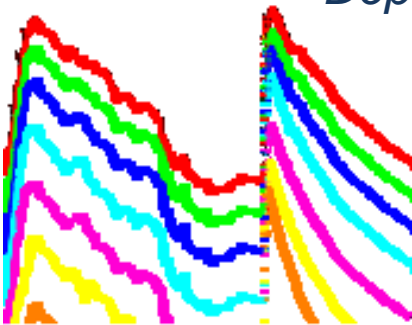# Cross-calibration of solar proton detectors

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Institute of Accelerating Systems and Applications, Greece
Department of Physics, University of Athens, Greece

P. Jiggens, P. Nieminen, H. Evans
ESA/ESTEC

Outline

- **Motivation**

- **Chain cross-calibration of "standard" datasets**

- **Reference dataset: IMP8/GME**

- **ESA SREM datasets by INTEGRAL (Rosetta, Planck, Herschel)**

- **NOAA GOES/EPS datasets**

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Motivation & temptation

- **Motivation**: create a broad cross-calibrated dataset. In radiation environment modelling the timespan is a major issue:
  - ➢ Need a sample as broad as possible
  - ➢ Requires combining different data
  - ➢ Use of a common – if possible – "gold reference" dataset
- **Temptation**
  - ➢ Calibrate U.S. NOAA GOES/EPS dataset; determine EPS energy bands; understand EPS measurements;
  - ➢ Verify quality of ESA/SREM fluxes, as derived by a non-trivial unfolding approach of the measurements

Overall processing schemes

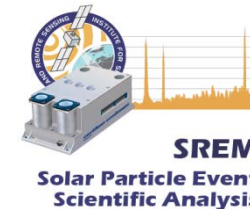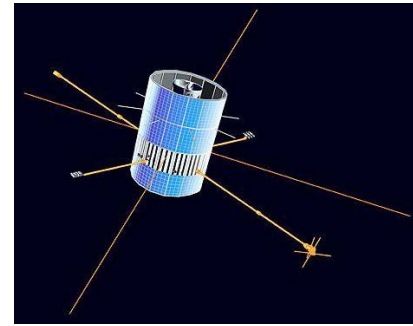# Interplanetary Monitoring Platform-J NASA Explorer 50   (IMP-8)

Launch Date:　　　26-10-1973
**Official termination:** 26-2-2001
Last data received:　7-10-2006
Orbit: Near-circular, 35 Earth Radii, 12-day orbit

IMP 8 (IMPJ or Explorer 50): the last satellite of the IMP series, was a drum-shaped spacecraft,　instrumented for interplanetary and magnetotail studies of cosmic rays, energetic solar particles, plasma, and electric and magnetic fields.


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IMP8/Goddard Medium Energy Experiment

IMP-7/8 LED
LOW ENERGY
DETECTOR

50°

FOIL ———— C

———— A

———— B
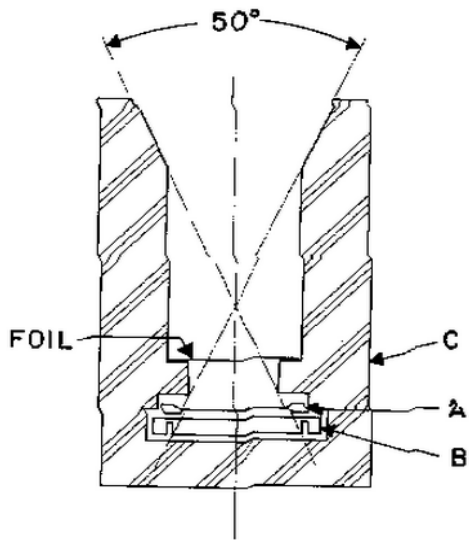
A = 150μ Si, 300 MM.²
B = 3 MM. Si, 500 MM.²
C = PLASTIC SCINTILLATOR
FOIL = I MG./CM² Ti

IMP8/GME/LED		
Our notation	Channel name	Energy range
#0	DIntn_1	0.88–1.15
#1	DIntn_2	1.15-1.43
#2	DIntn_3	1.43–1.79
#3	DIntn_4	1.79–2.27
#4	DIntn_5	2.27–3.03
#5	DIntn_6	3.03–4.20
#6	DIntn_7	4.20.4.94
#7	DIntn_8	4.94–5.96
#8	DIntn_9	5.96–7.25
#9	DIntn_10	7.25–8.65
#10	DIntn_11	8.65–11.10
#11	DIntn_12	11.10–13.60
#12	DIntn_13	13.60–16.10
#13	DIntn_14	16.10–18.70
#14	DIntn_15	18.70–22.50

IMP-7/8 MED
MEDIUM ENERGY
DETECTOR

46°

D

G ————

E

F
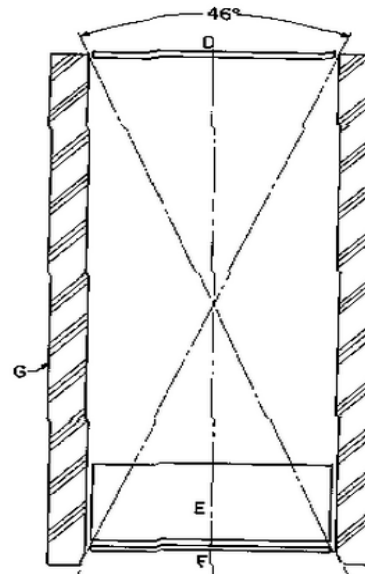
D, F – I MM x 20 CM²
    CsI SCINTILLATOR
E – 2 CM x 20 CM²
    CsI SCINTILLATOR
G – PLASTIC SCINTILLATOR

IMP8/GME		
Our notation	Channel name	Energy range
#15	DIntn_16	19.80–24.20
#16	DIntn_17	24.20–28.70
#17	DIntn_18	28.70–35.20
#18	DIntn_19	35.20–42.90
#19	DIntn_20	42.90–51.00
#20	DIntn_21	51.00–63.20
#21	DIntn_22	63.20–81.00
#22	DIntn_23	87.00–92.50
#23	DIntn_25	107.0–121.0
#24	DIntn_26	121.0–154.0
#25	DIntn_27	154.0–178.0
#26	DIntn_28	178.0–230.0

The highest quality long- term solar proton flux measurements available

NASA Principal Investigator:
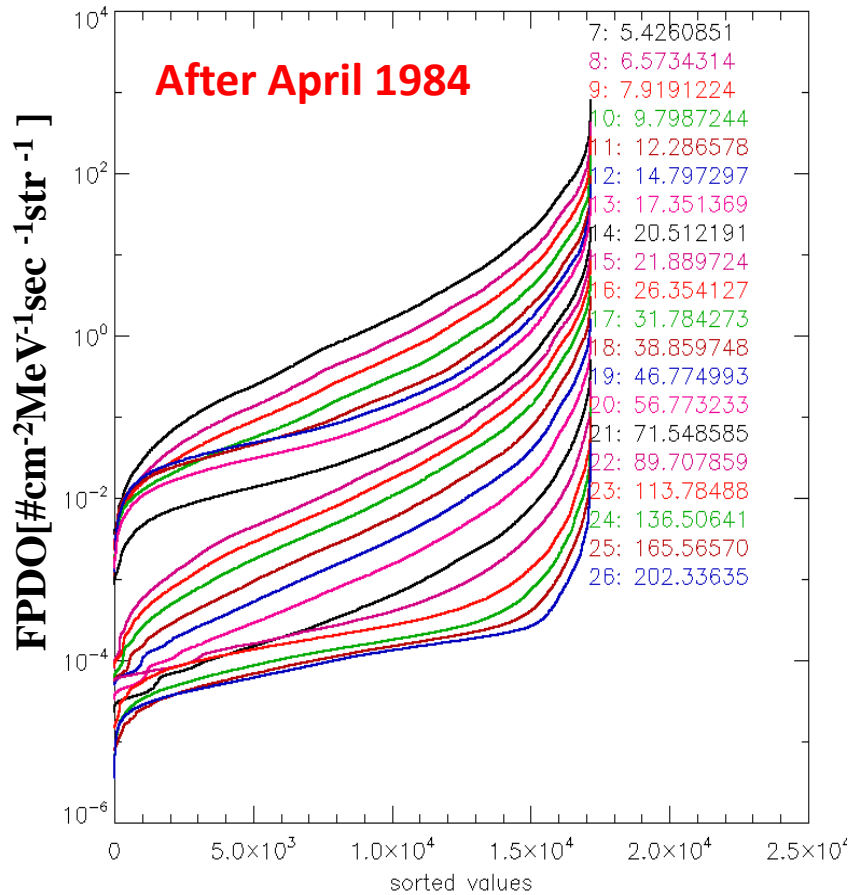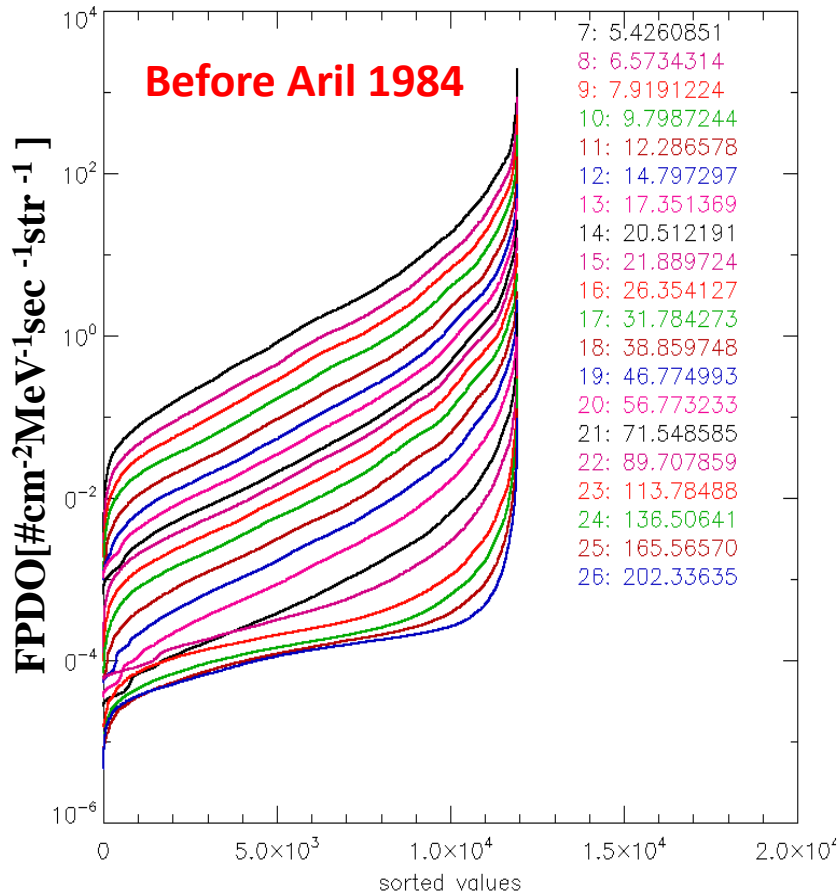*Dr. Robert E. McGuire*   6

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LED failure

Mean spectra of concurrent measurements
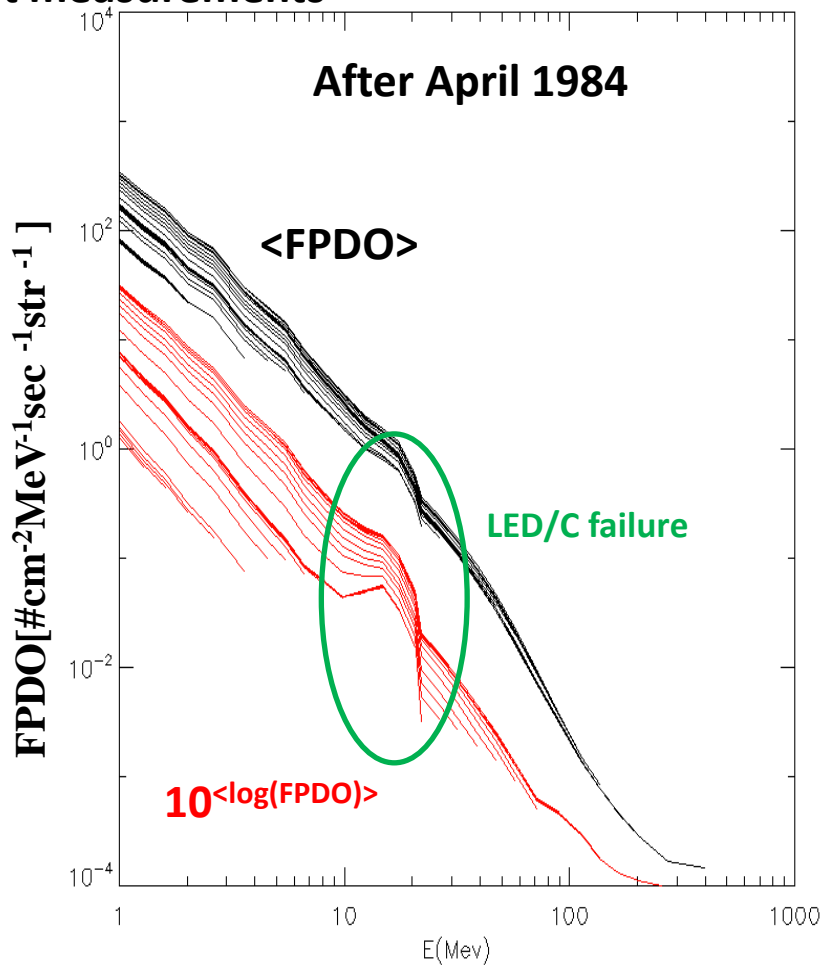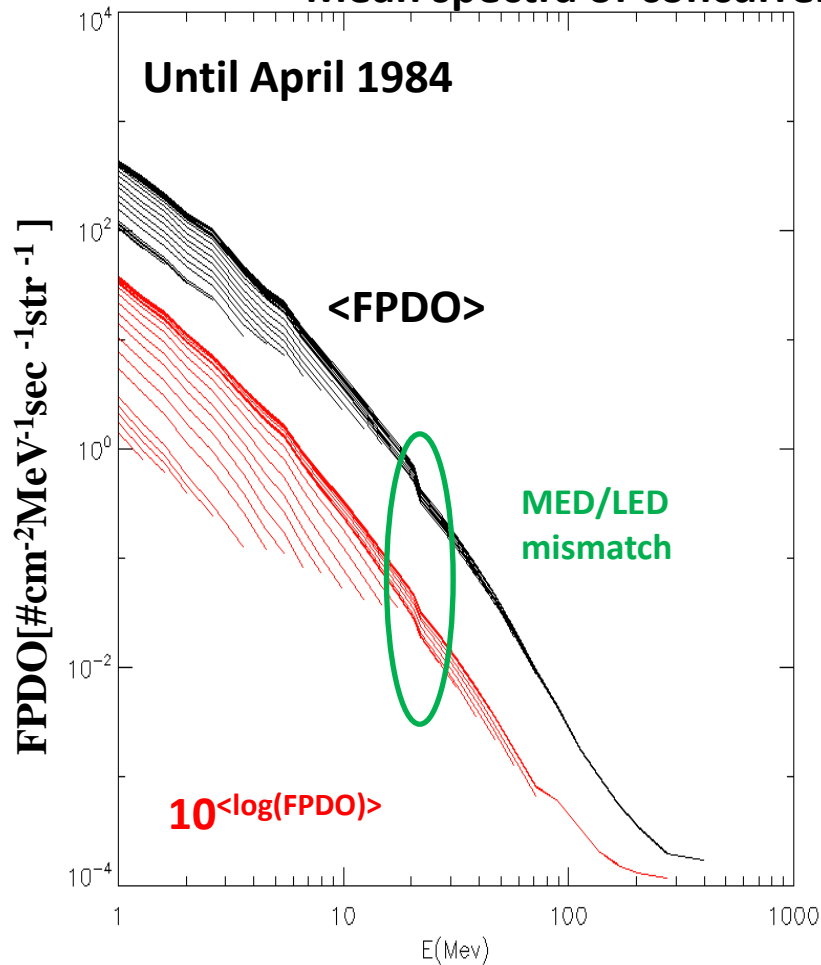
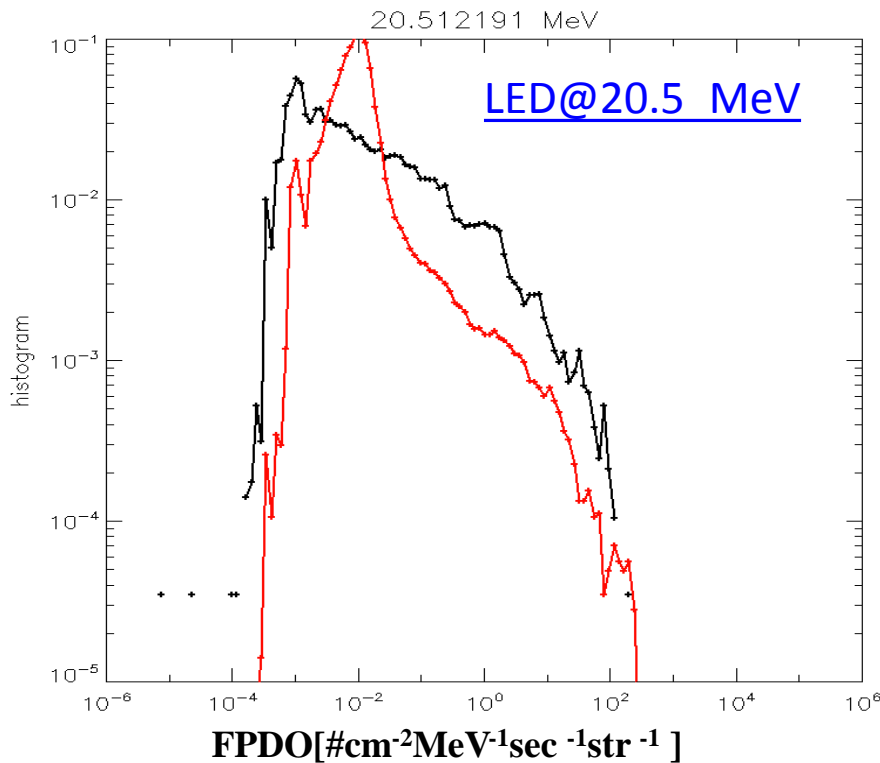# LED failure II

Sorted values of concurrent measurements

LED failure III
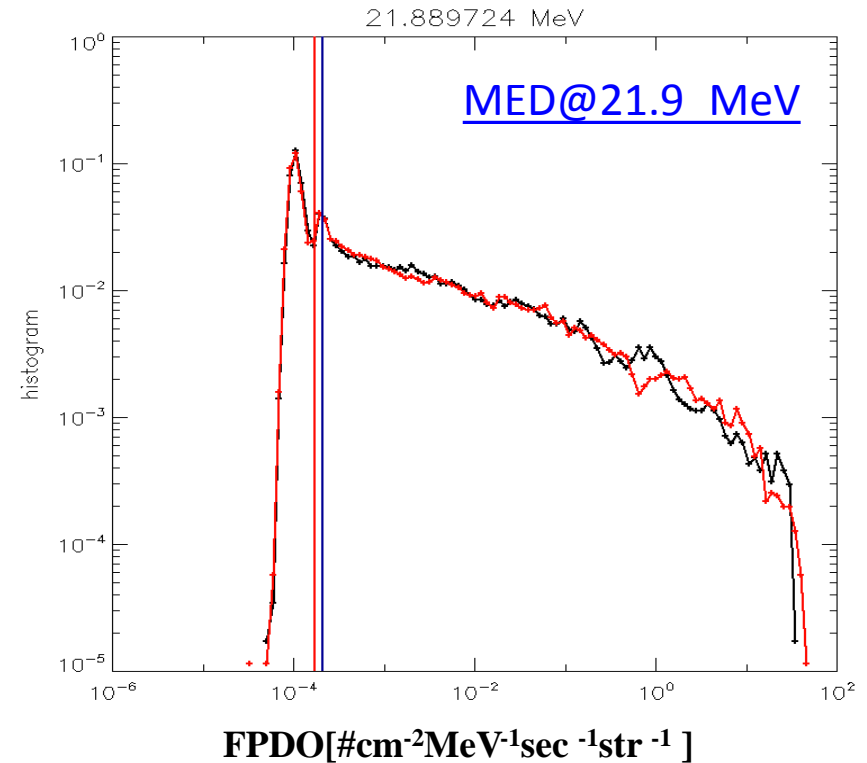
Correct LED data after April 1984

Inter-calibrate LED after the failure onset using:

- the LED data before the onset

- the MED lowest energy channel as a intermediary channel

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IMP8/GME/LED inter-calibration

MED@21.9_MeV

after & before 04/84

21.9_MeV

21.9_MeV

bin i

bin j

LED@15_MeV

after & before 04/84

LED@15_MeV

after & before 04/84

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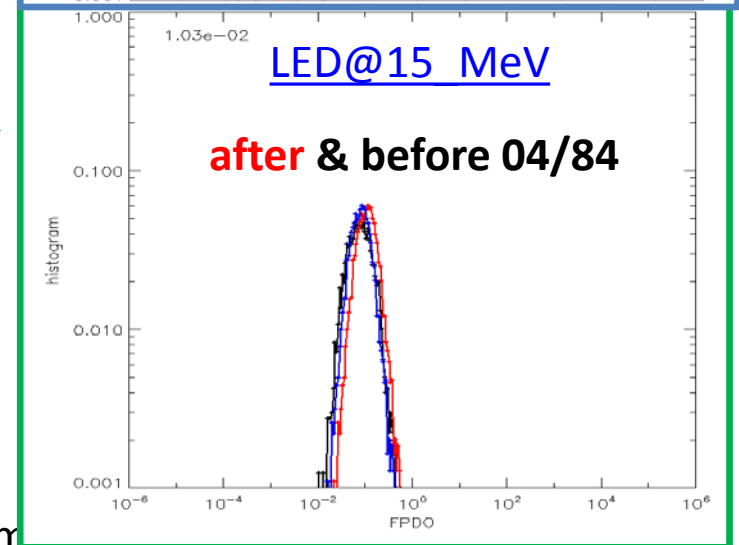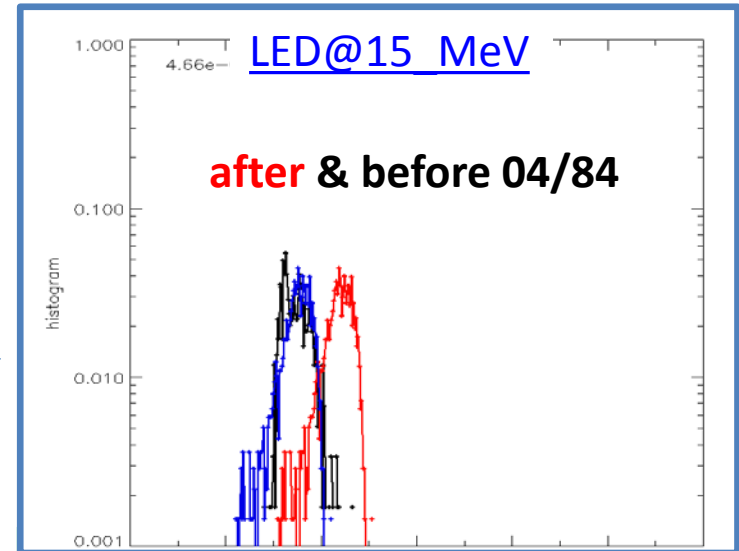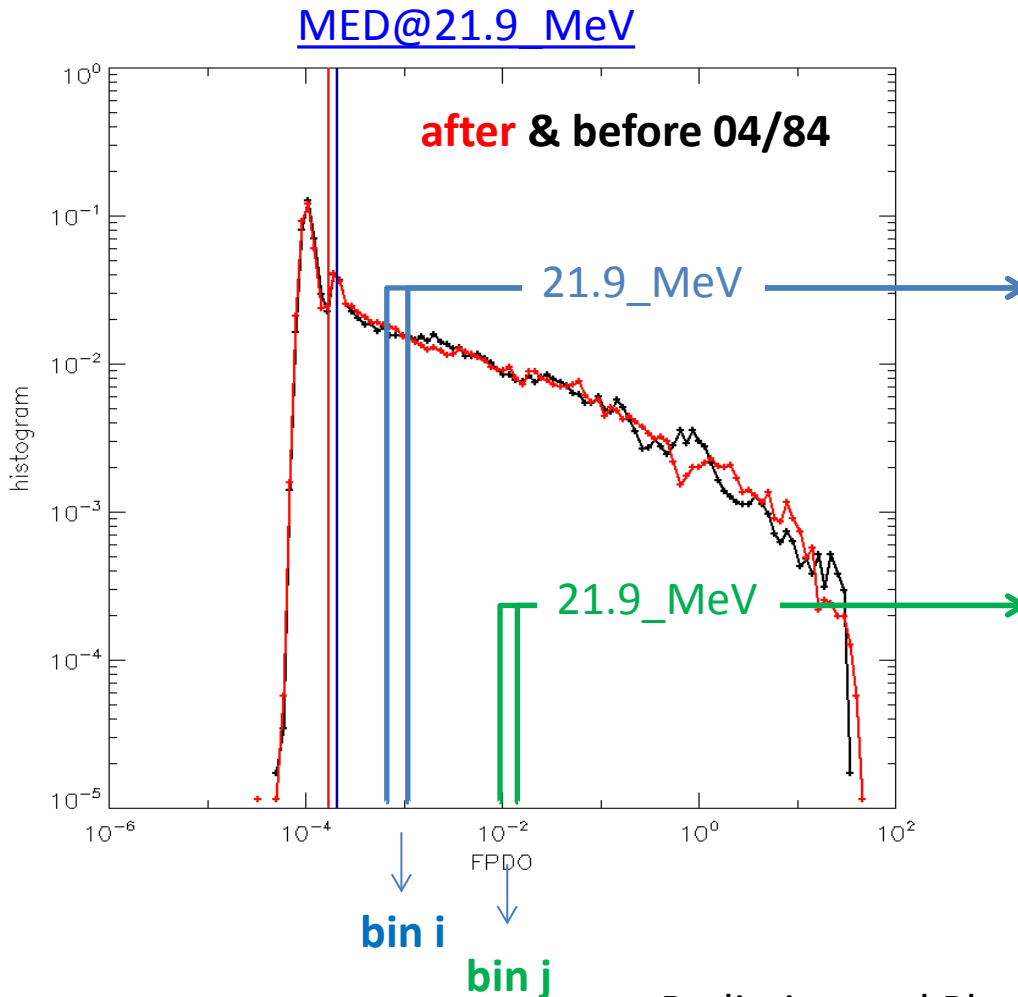
Non-linear inter-calibration function
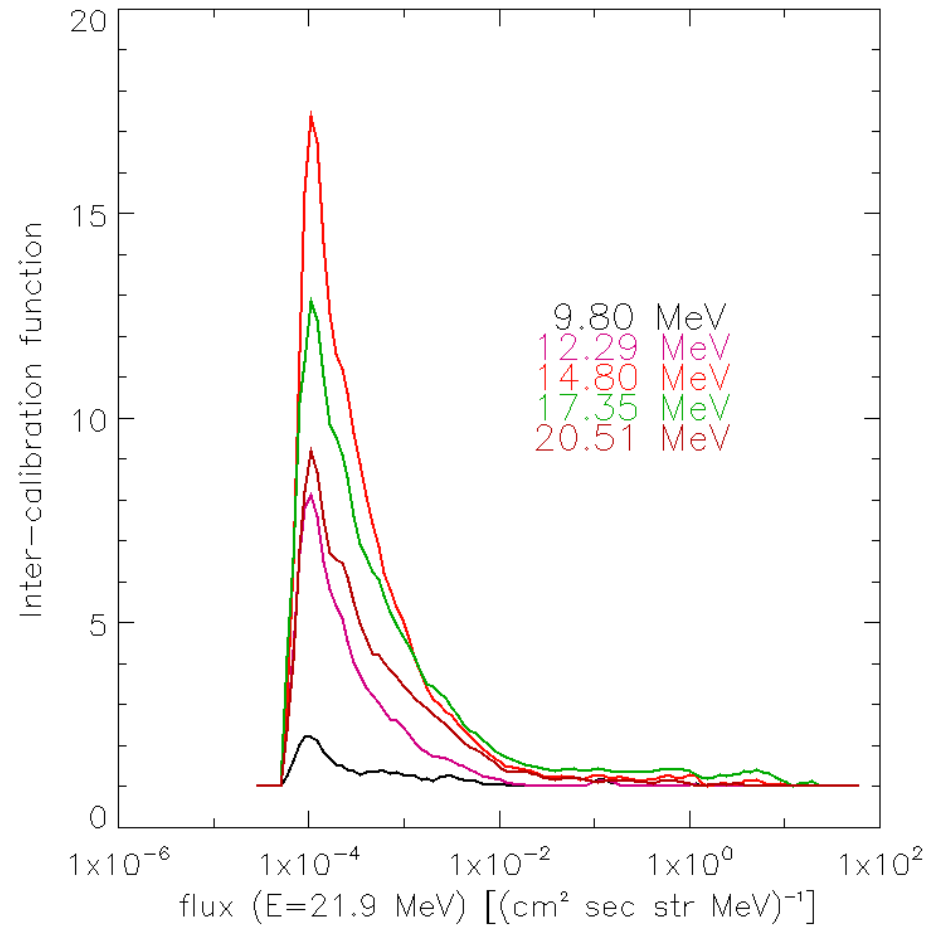
IMP8/GME/LED inter-calibration

Mean spectra of concurrent measurements

IMP8/GME/LED inter-calibration
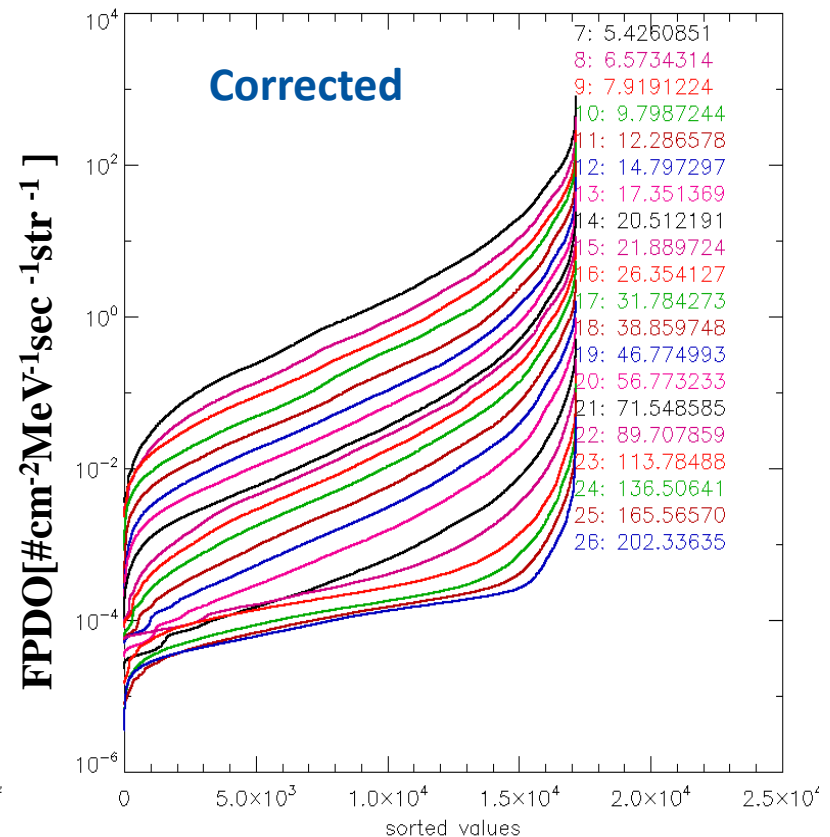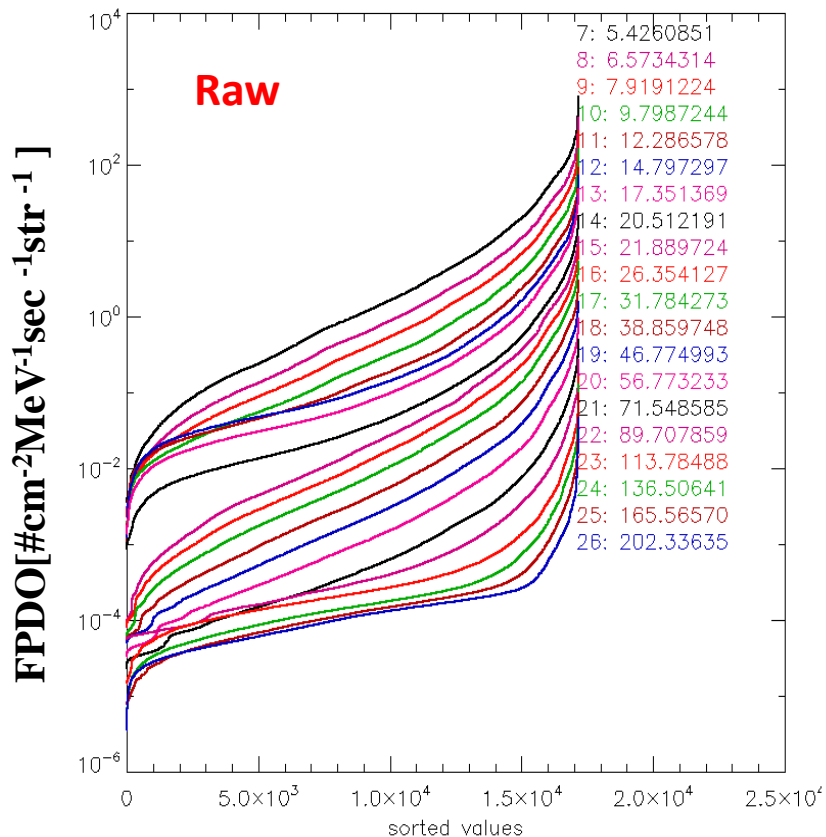
GOES/EPS data

NOAA GOES measurements:

- **Serve as basis for real-time alerts and warnings of hazardous environmental conditions by many operators;**
- **Provide long-term database of environmental conditions;**
- **Are distributed in real-time to various Space Weather Services**
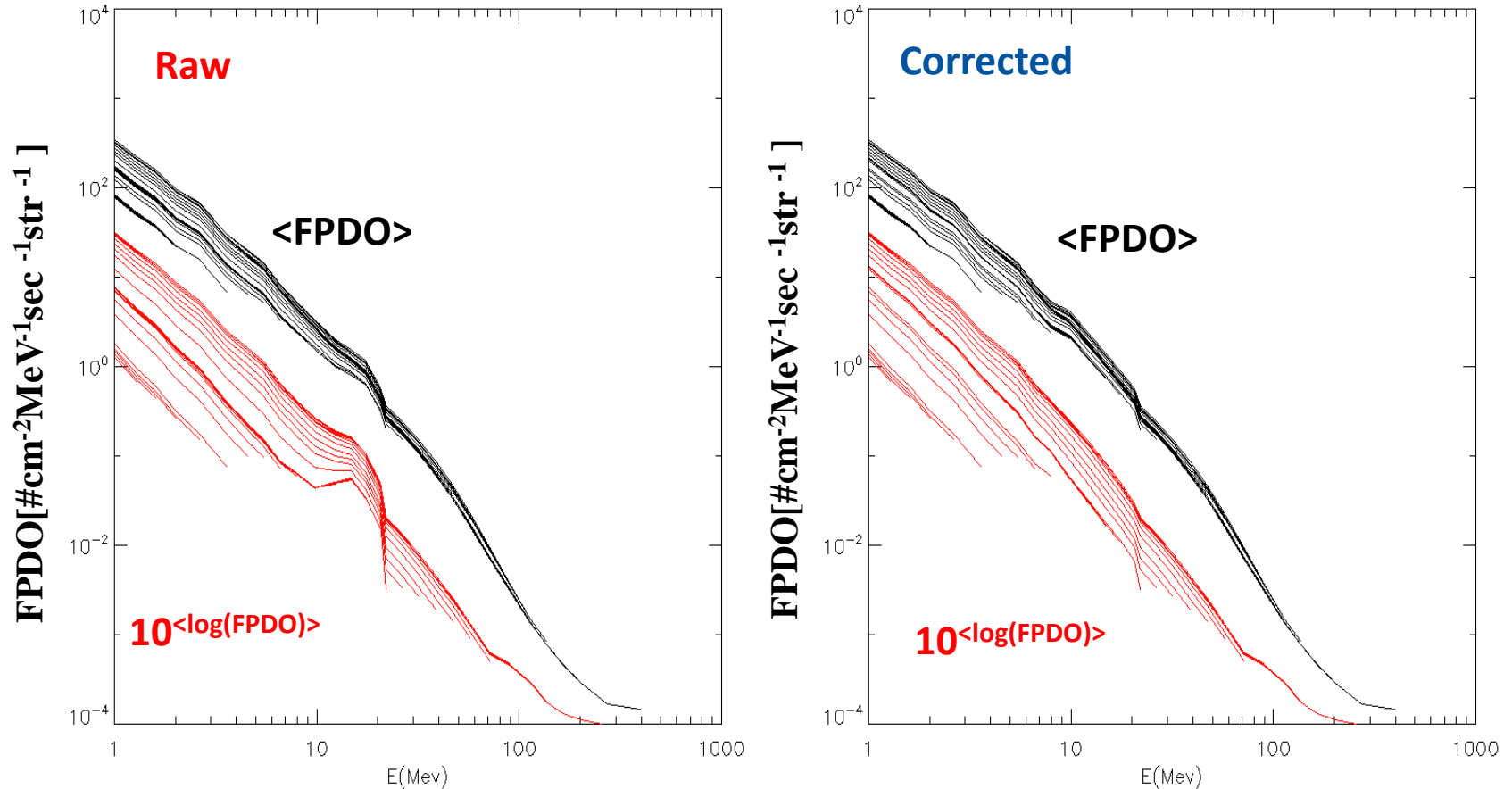- **Are used to produce the "Solar Radiation Storm" NOAA Scale**

Channel name	EPS-2 E_{nom} [MeV]
P2	6.0 [4.0–9.0]
P3	11.6 [9.0–15.0]
P4	24.5 [15–40.0]
P5	56.6 [40–80]
P6	115 [80–165]
P7	287 [165–500]

Have wide energy bins!

GOES/EPS/P2-7 calibration

Determine the energy ranges of the proton flux particles measured by GOES/EPS (according to data) (not the fluxes measured by given energy channels)

- **Re-bin IMP8/GME over an ultra dense grid within an energy range:** $E=15\text{-}400 \; MeV$

- **Fit GOES channels measurements with the re-binned IM8/GME data** $Y_{GOES} = A_{fit}(E) + B_{fit}(E)$

- **Evaluate the behavior of the fit coefficients along the energy grid using f.ex.:**

$$\delta B_{fit}(E) = |(B_{fit}(E) - 1)|$$
$$C_{fit}(E) = \sqrt{A_{fit}(E)^2 + \delta B_{fit}(E)^2}$$

GOES08/EPS-2 energies

GOES08/EPS-2 energy bins
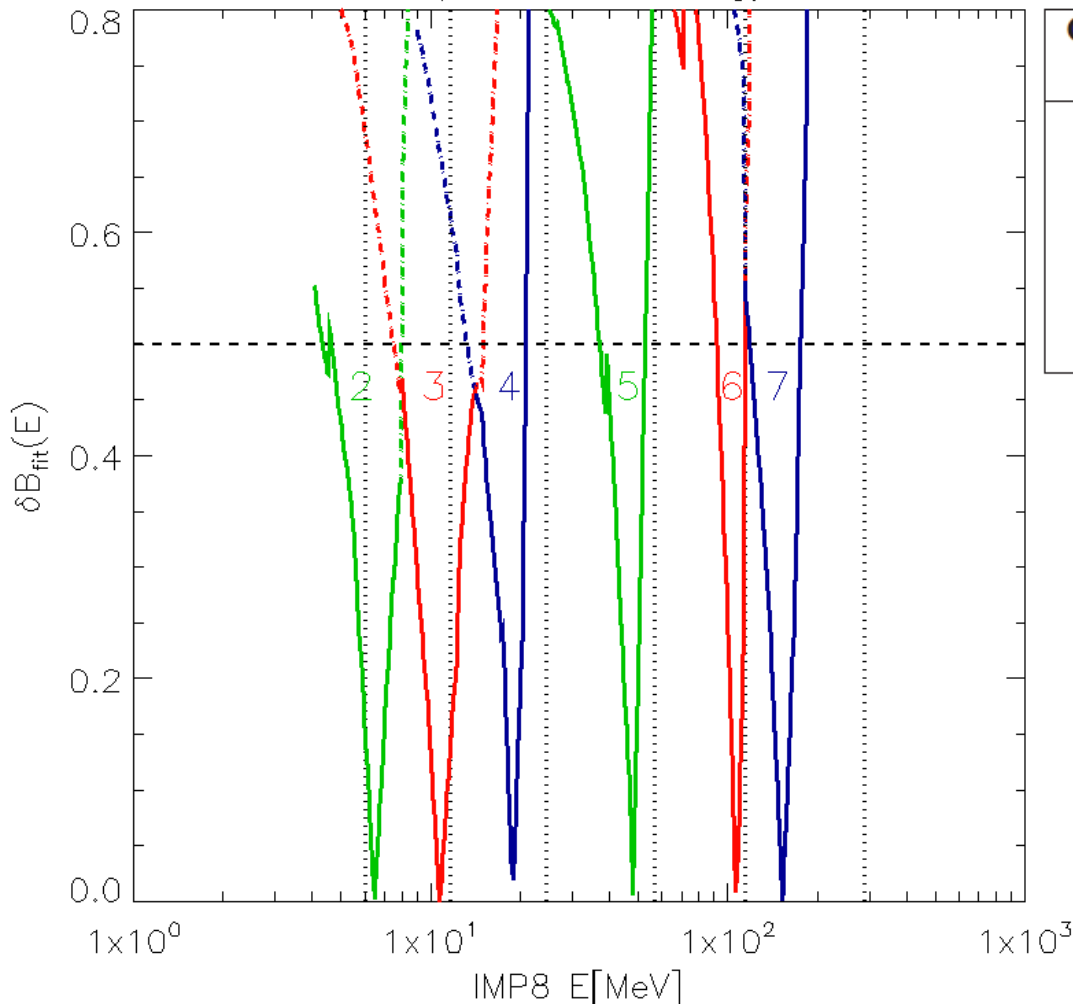
Channel name	EPS-2 E_{nom} [MeV]	GOES-8 E_{eff} [MeV]
P2	6.0 [4.0–9.0]	6.05 [4.0–7.9]
P3	11.6 [9.0–15.0]	10.6 [7.4–15.0]
P4	24.5 [15–40.0]	19.0 [13.3–21.3]
P5	56.6 [40–80]	47.8 [37.0–53.6]
P6	115 [80–165]	107. [91.5–113]
P7	287 [165–500]	153. [119–179]

Sandberg et al, GRL (Submitted)

Radiation and Plasma Monitoring Workshop
ESTEC 13-14 May 2014

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GOES08/EPS-2 spectrum
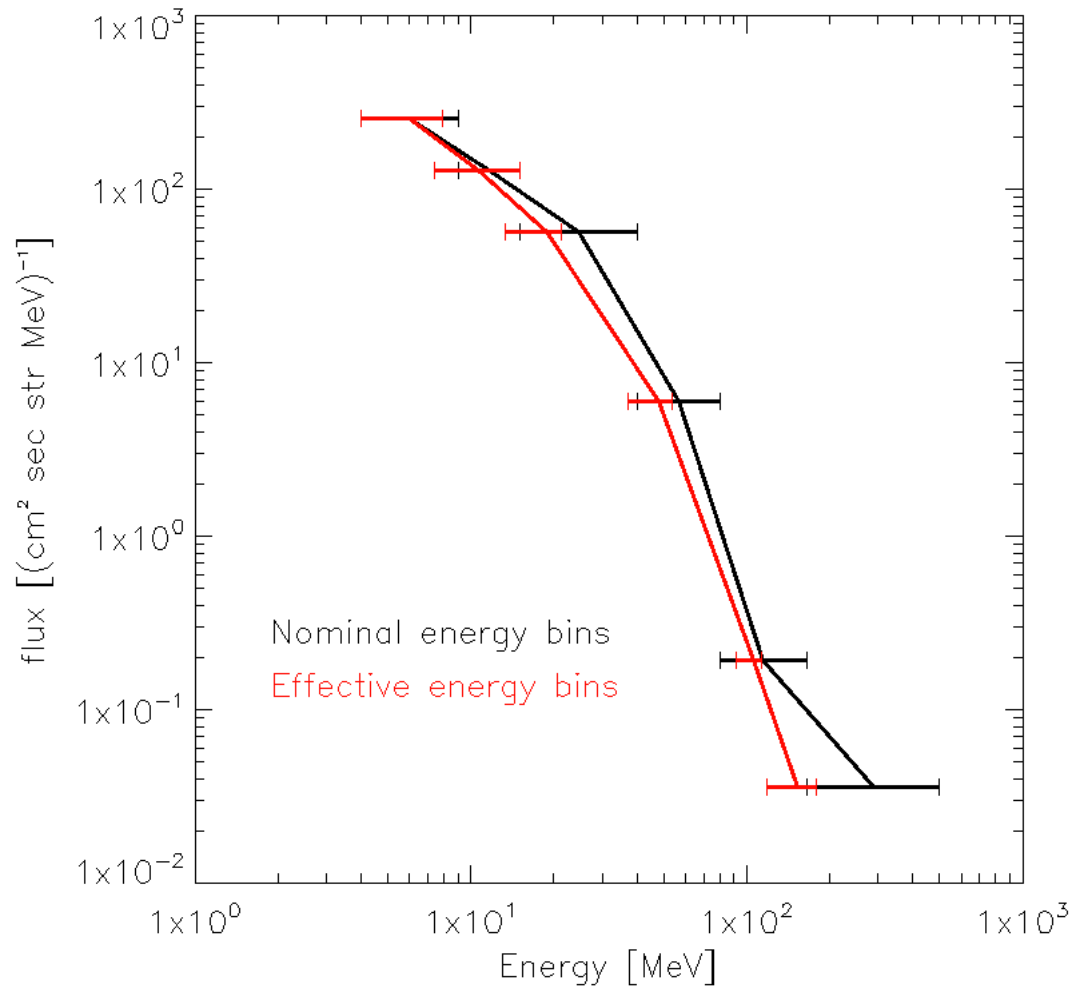
Energy range of GOES-8/EPS/P7

GOES08/EPS/P7: E_{eff}=152.92 MeV
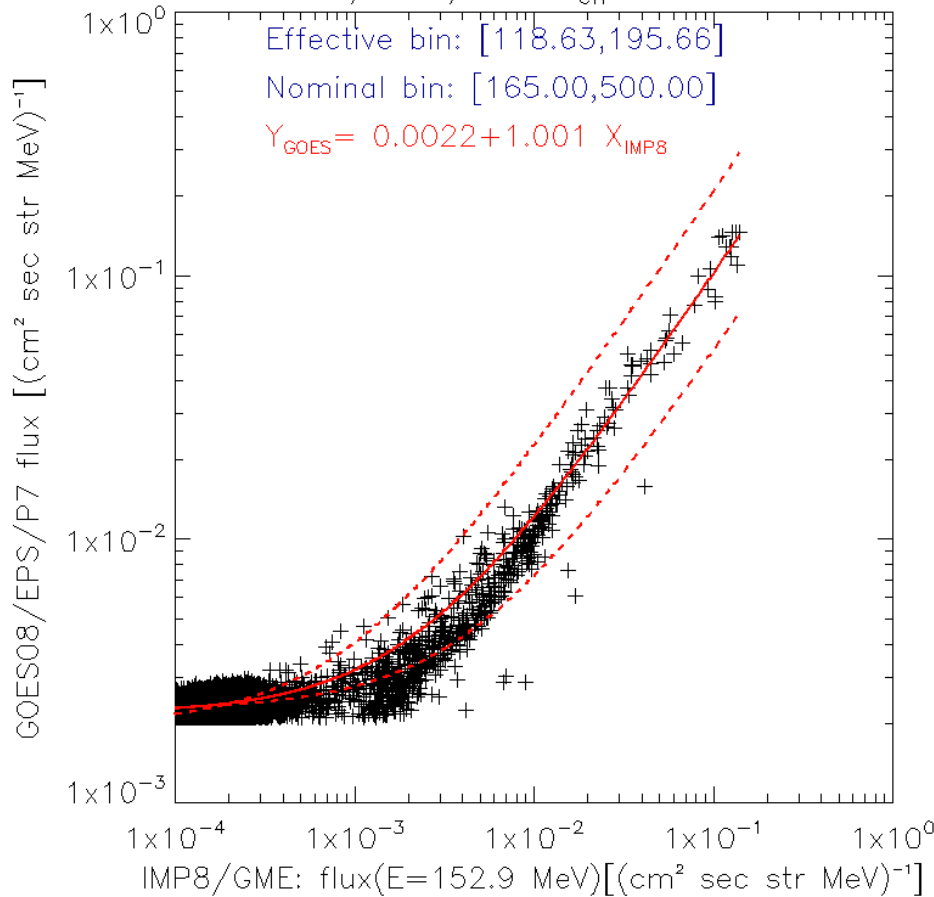
Effective bin: [118.63,195.66]
Nominal bin: [165.00,500.00]

Y_{GOES}= 0.0022+1.001 X_{IMP8}

Channel name	EPS-2 E_{nom} [MeV]	GOES-8 E_{eff} [MeV]
P2	6.0 [4.0–9.0]	6.05 [4.0–7.9]
P3	11.6 [9.0–15.0]	10.6 [7.4–15.0]
P4	24.5 [15–40.0]	19.0 [13.3–21.3]
P5	56.6 [40–80]	47.8 [37.0–53.6]
P6	115 [80–165]	107. [91.5–113]
P7	287 [165–500]	153. [119–179]

Table 3.15
Summary of EPS/HEPAD Channel Response Factors

| Channel	Particle Energy (MeV)	GE_0 (cm^2 sr MeV)	Particle Energy Range (MeV)
P2	6.5	0.252	4.2 - 8.7
P3	11.6	0.325	8.7 - 14.5
P4	30.6	5.21	15 - 40
P5	63.1	14.5	38 - 82
P6	165.	129.	84 - 200
P7	433.	839.	110 - 900

Sellers & Hansen,   SPIE 2812/353, (1996)

ESA Standard Radiation Environment Monitor

- Charged particle detector based on three solid state *Si* crystals
- Detects high-energy charged particles: e^- E_e>1 MeV, p^+: E_p>10 MeV
- Monitors spacecraft radiation environment
- Provides functions related to space weather hazards for the host spacecraft and its payload
- Provides data associated to various physical processes.
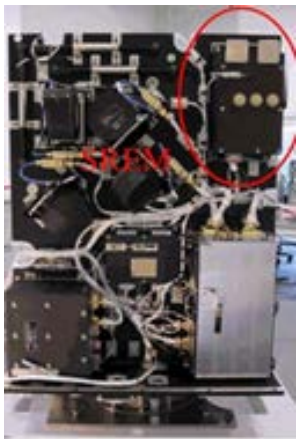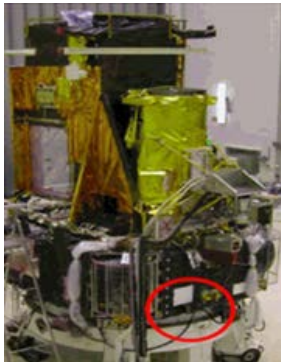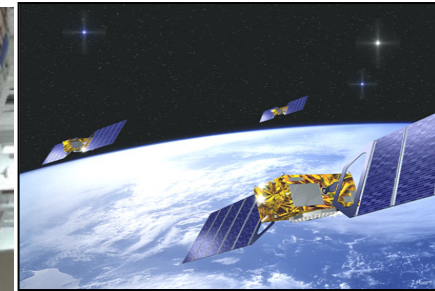
GIOVE-B
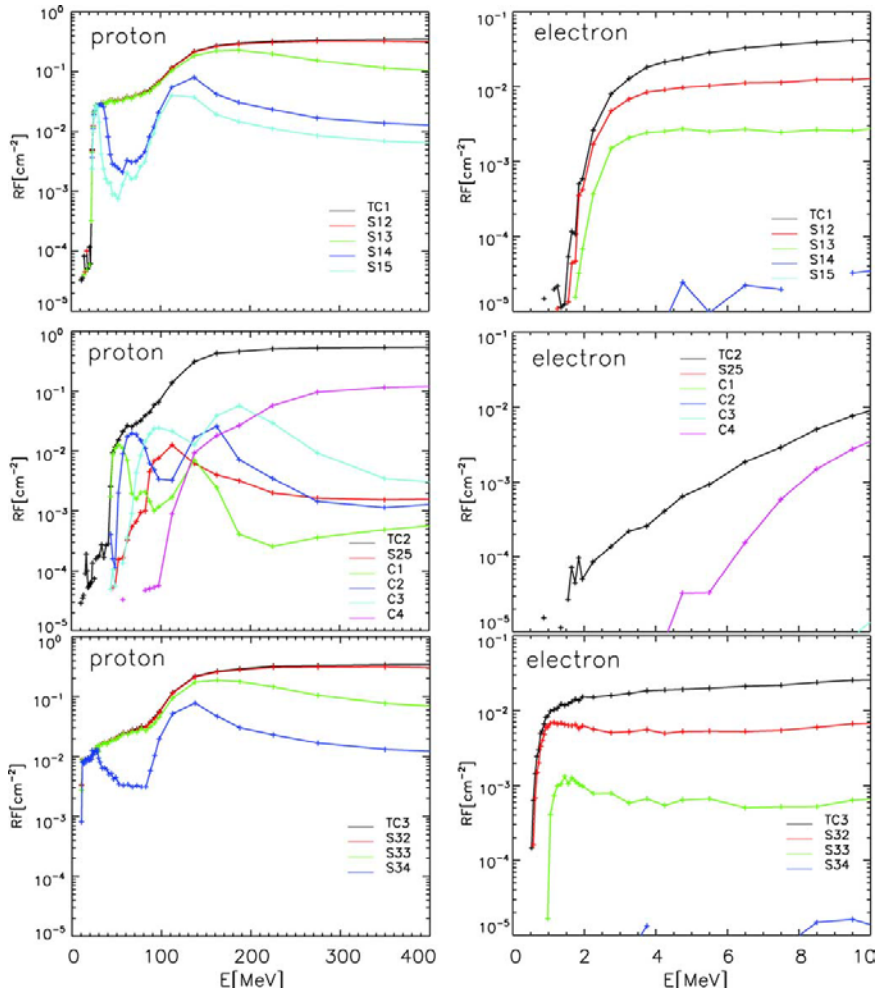
INTEGRAL

ROSETTA

HERSCHEL

PLANCK

PROBA-1

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ESA SREM

SREM	Proton Energy	[MeV]	Electron Energy	[MeV]
Bin	E_{min}	E_{max}	E_{min}	E_{max}
TC1	27	∞	2.00	∞
S12	26	∞	2.08	∞
S13	27	∞	2.23	∞
S14	24	542	3.20	∞
S15	23	434	8.18	∞
TC2	49	∞	2.80	∞
S25	48	270	–	–
C1	43	86	–	–
C2	52	278	–	–
C3	76	450	–	–
C4	164	∞	8.10	∞
TC3	12	∞	0.80	∞
S32	12	∞	0.75	∞
S33	12	∞	1.05	∞
S34	12	∞	2.08	∞

SREM counts-to-fluxes
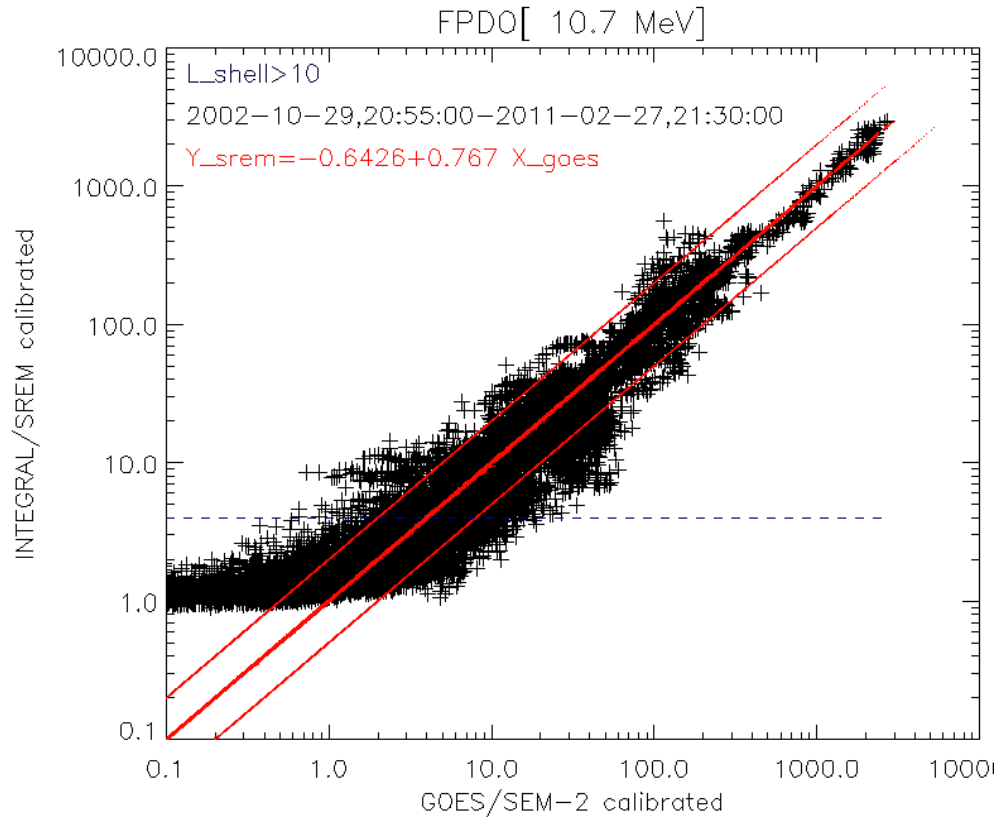

INTEGRAL/SREM
January 20, 2005, 12:00 UT
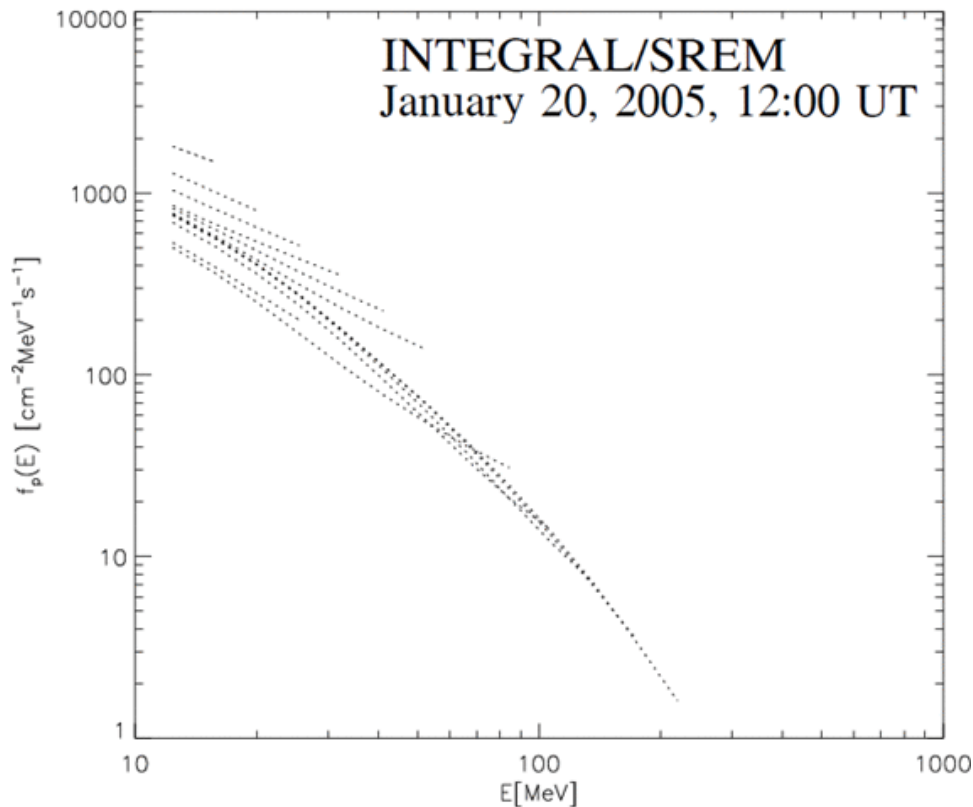
$$C_i = \sum_{q=p,e} \int_0^\infty f_q(E) RF_{i,q}(E) dE$$

$$\begin{bmatrix} \mathbf{RF} \\ \sqrt{\tau}\mathbf{R} \end{bmatrix} \cdot \overline{\mathbf{f}} = \begin{bmatrix} \mathbf{C} \\ \mathbf{0} \end{bmatrix}$$

$$\mathbf{R} = \begin{bmatrix} -1 & 1 & 0 & \cdots & \cdots & 0 & 0 & \cdots & \cdots & \cdots & \cdots & 0 \\ 1 & -2 & 1 & 0 & \cdots & 0 & 0 & \cdots & \cdots & \cdots & \cdots & 0 \\ 0 & 1 & -2 & 1 & 0 & 0 & 0 & \cdots & \cdots & \cdots & \cdots & 0 \\ \vdots & 0 & \ddots & \ddots & \ddots & \ddots & 0 & \cdots & \cdots & \cdots & \cdots & \vdots \\ 0 & 0 & 0 & 1 & -2 & 1 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & -1 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & -1 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 1 & -2 & & 0 & 0 & 0 \\ \vdots & \cdots & \cdots & \cdots & \cdots & 0 & \ddots & \ddots & \ddots & \ddots & 0 & \vdots \\ 0 & \cdots & \cdots & \cdots & \cdots & 0 & 0 & 0 & 1 & -2 & 1 & 0 \\ 0 & \cdots & \cdots & \cdots & \cdots & 0 & 0 & 0 & 0 & 1 & -2 & 1 \\ 0 & \cdots & \cdots & \cdots & \cdots & 0 & 0 & \cdots & \cdots & 0 & 1 & -1 \end{bmatrix}$$
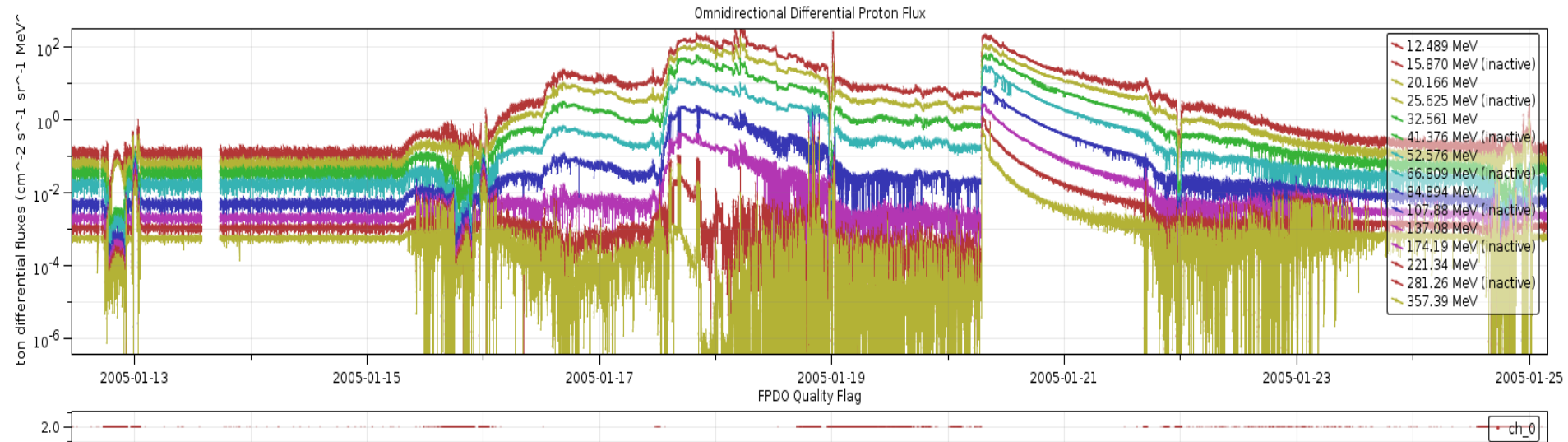
Sandberg et al, IEEE TNS 59, 1105 (2012)

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INTEGRAL/IREM vs calibrated GOES

FPD0[10.7 MeV]

L_shell>10
2002-10-29,20:55:00-2011-02-27,21:30:00
Y_srem=-0.6426+0.767 X_goes

Energy [MeV]	SREM/SVD scaling factor	Threshold [cm^{-2} s^{-1} sr^{-1} MeV^{-1}]
10	0.77	4.00
20	0.97	1.00
50	1.14	0.02
100	1.51	0.01
150	1.42	0.004

A typical profile

Omnidirectional Differential Proton Flux

FPDO Quality Flag

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Conclusions

- **A series of cross-calibration studies for solar proton monitors have been presented**

- **A non-linear inter-calibration function for the gold reference "IMP8/GME/LED" dataset was derived**

- **The energy range values of the GOES/EPS channels were determined through a new calibration scheme**

- **The SVD-derived SREM fluxes are in very good agreement with GME calibrated GOES/EPS data**

- **Opportunities for calibrating proton detectors with IMP8/GME through GOES/EPS**

- **Calibrated datasets and calibration tools will be integrated in SEPEM**

FORecasting Solar Particle Events and Flares

Forecasted flare characteristics for active regions

IAASARS

Input Parameters
Flare magnitude
AR longitude
(CME width; velocity)

Nowcasting
Actual flare
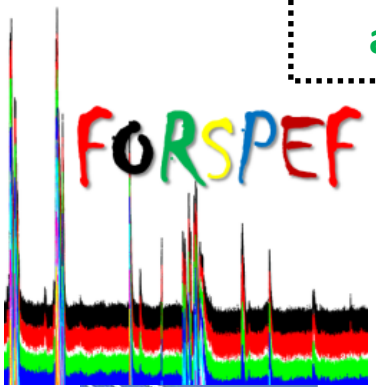**and CME data**

DATABASE
1984-2013

Extensive SEP Database GOES calibrated data ; >330 events

Flares >M1.0 CME width CME velocity

PDF of selected SPE characteristics for given flare
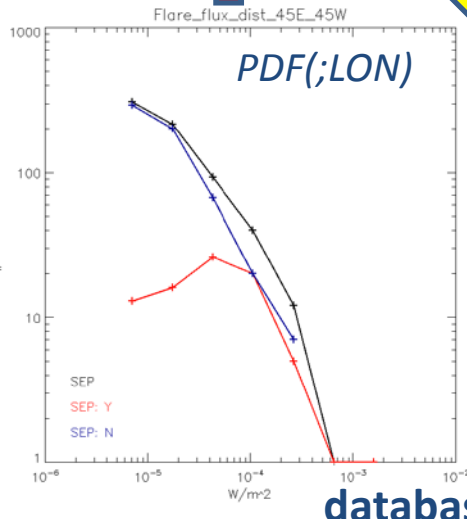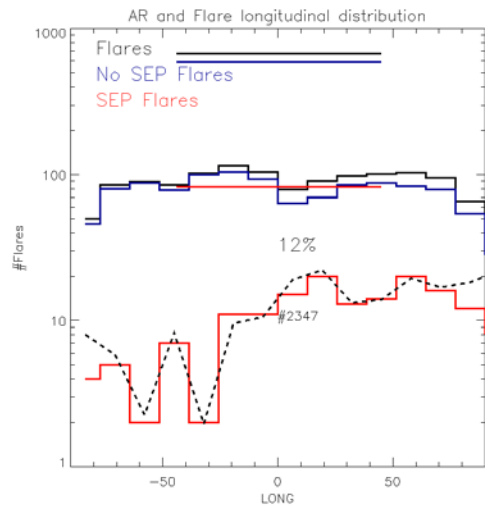
Output
Probabilities of SEP occurrence
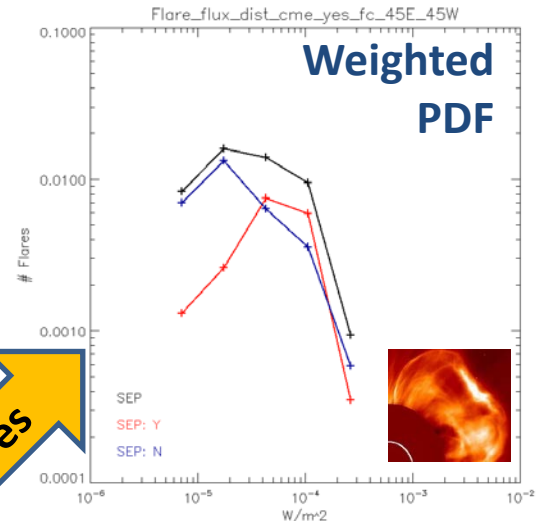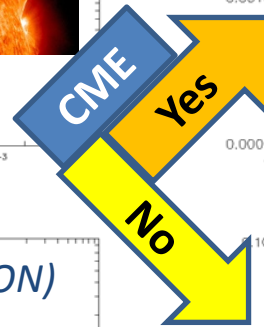SEP characteristics

FORSPEF

A. Anastasiadis, I. Sandberg, A. Papaioannou, M. Georgoulis,
G. Tsiropoula, K. Tziotziou, T. Katsiyannis

eesa ESTEC

SPE forecasting module

Flare forecast

Probability for occurence of flare in AR:#2347 LON=45E_45W with magnitude > 10^{-6} is 0.25

AR and Flare longitudinal distribution

Flares
No SEP Flares
SEP Flares

12%

#2347

Weighted PDF

Flare_flux_dist_fc_45E_45W

SEP
SEP: Y
SEP: N

Weighted PDF

Flare_flux_dist_cme_yes_fc_45E_45W

SEP
SEP: Y
SEP: N

CME

Yes

No

PDF(;LON)

Flare_flux_dist_45E_45W

SEP
SEP: Y
SEP: N

database

Weighted PDF

Flare_flux_dist_cme_no_fc_90E_90W

SEP
SEP: Y
SEP: N

FORSPEF

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