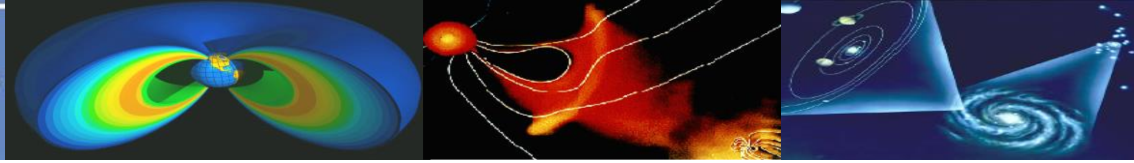


HERMES project

Hellenic **E**volution to **R**adiation Data Processing and **M**odelling of the **E**nvironment in **S**pace

IASA: Prof. I.A. Daglis (Project Manager), I. Sandberg (Technical Manager), C. Papadimitriou, A. Tsigkanos, S. Aminalragia-Giamini, G. Provatas, O. Giannakis & C. Katsavrias

ESA/ESTEC contract 4000112863/14/NL/HB
Funded by Science Core Technology Programme (CTP)

ESA: P. Jiggens (ESA technical officer)

ESTEC Final Presentation Days: May 2018

Overview

- Team
- Acknowledgments
- HERMES in a slide
- Tasks
- Work performed & Results (selected)

Kick-Off: February 2015
Final Presentation: May 2018
Project closure: - July 2018

HERMES project in a slide

- Collect, clean, evaluate, cross-calibrate a large amount of radiation datasets
- Store data in HERMES ODI database
- Perform numerical calibration for 3 radiation monitors
- Evaluate ESA SEPEM RDS 2.x, Optimize ESA SEPEM VTM performance
- Develop new probabilistic approach for radiation belt modelling (TREPEM)
- Develop a new modelling approach for SEP radiation environment (VESPER)
- Create a unified/modular European Space Radiation Model (ESPREM)
  - Integrate Magnetospheric Shielding Model (MSM)
  - DLR Galactic Cosmic Ray Model
- Develop a modular Radiation Effects Modelling System (ESPREM system)
  - Integrate a series of effect tools

The Tasks

- Task 1: Radiation data processing & calibration
- Task 2: Radiation Belt modelling
- Task 3: Solar Energetic particle modelling
- Task 4: Combined radiation modelling (& effects)
- Task 5: Improvements, Verification, Validation & Update

HERMES db: Open Data Interface

- Data:
  - Some data migrated from SRREMs DB
  - New datasets recreated from scratch to produce well-formed CDF files and correct metadata/units
- HERMES db based on ODI: a Database system for downloading, processing and storing radiation environment data based on MySQL
  - Includes an assortment of tools and utilities to use and extend
  - Server software for ingesting, parsing, downloading data and more
  - Client libraries for getting data natively in most common programming languages
  - Excellent for the HERMES use case!
- UNILIB
  - Fortran UNILIB library with custom MATLAB wrapper for integration with HERMES software
  - NOTE: current versions of ODI can run UNILIB automatically, but it is still a performance bottleneck when ingesting large amounts of historical data.

HERMES datasets

Dataset	Omnidirectional Fluxes	Unilib magnetic coordinates	Quality flags
azur_ei_88_l1_v01	N	N	N
crres_mea_l1_v01	Y	N	N
giovea_merlin_l1_v01	N	N	N
gioveb_srem_hermes_l2_v02	Y	Y	Y
integral_irem_hermes_l2_v02	Y	Y	Y
polar_ceppad_l2_v01	Y	Y	N/A
proba1_srem_hermes_l2_v01	Y	Y	Y
xmm_ermd_l2_v01	Y	Y	Y
demeter_idp_l2_v01	N	N	N
rbspa_mageis_hermes_l2_v01	Y	Y	Y
rbspb_mageis_hermes_l2_v01	Y	Y	Y
rbspa_rept_hermes_l2_v01	Y	Y	Y
rbspb_rept_l3_hermes_l2_v01	Y	Y	Y
probav_ept_l1_v01	N	Y	N

Data Evaluation & Cleaning

- Temporal Coverage
- Spatial Coverage
- Spectra Distributions
- Flux Maps
- Cross-species Contaminations

***Main contributor**: C. Papadimitriou*

- Develop routines for determination of data caveats (spikes, saturation, contamination)
- Creation/ingestion of cleaned datasets to ODI (set flags on datasets)

***Main contributor**: C. Katsavrias*

Evaluation plots: examples

XMM/ERM

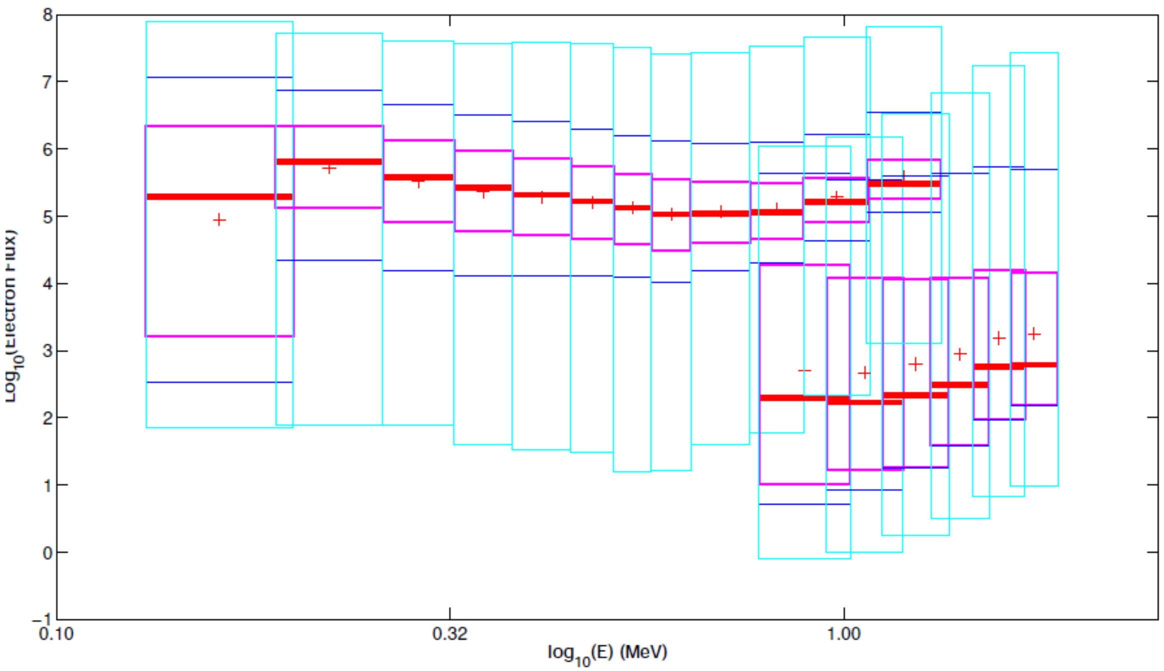


Figure 20: Boxplot for Log_10(Electron Flux).

POLAR/CEPPAD

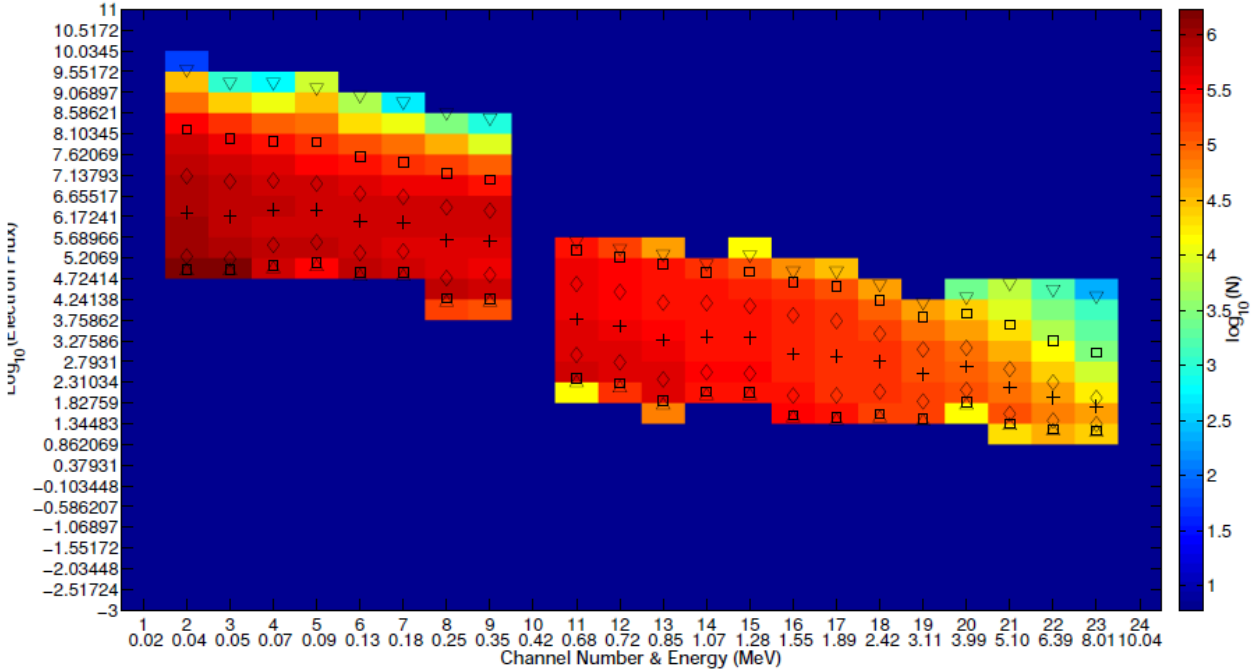


Figure 21: Color Distributions of fluxes for Log_10(Electron Flux).

Evaluation plots: examples

XMM/ERM

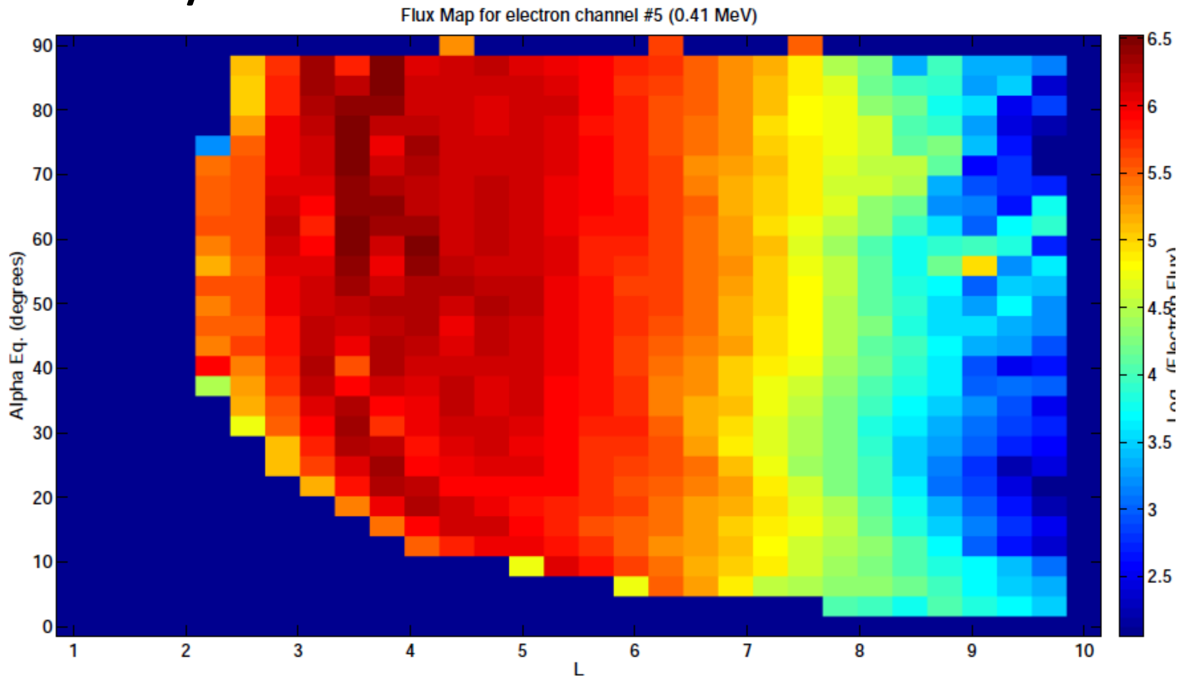


Figure 40: Flux Map for electron channel No 5.

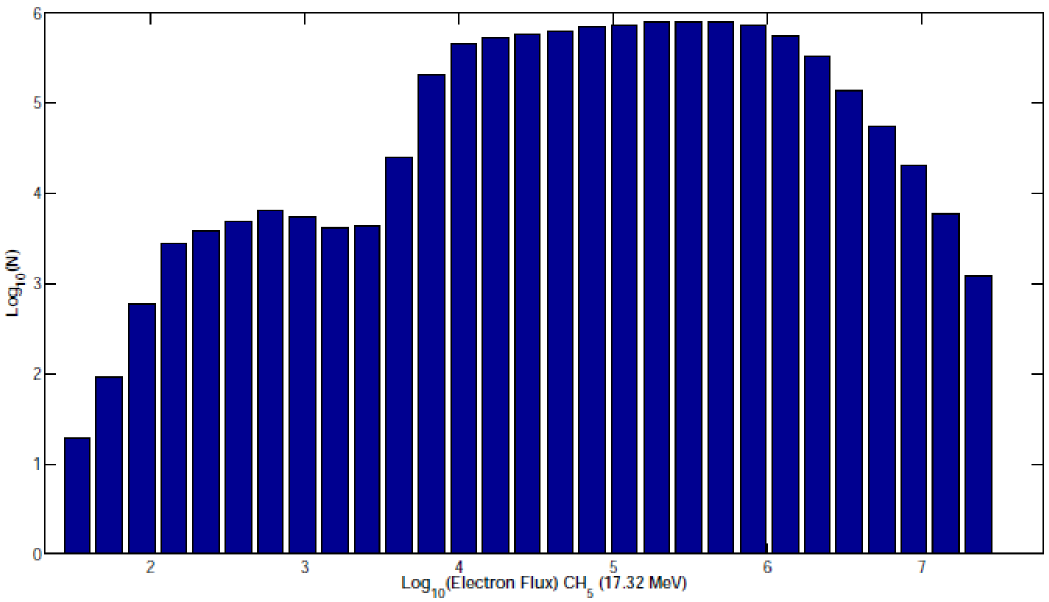
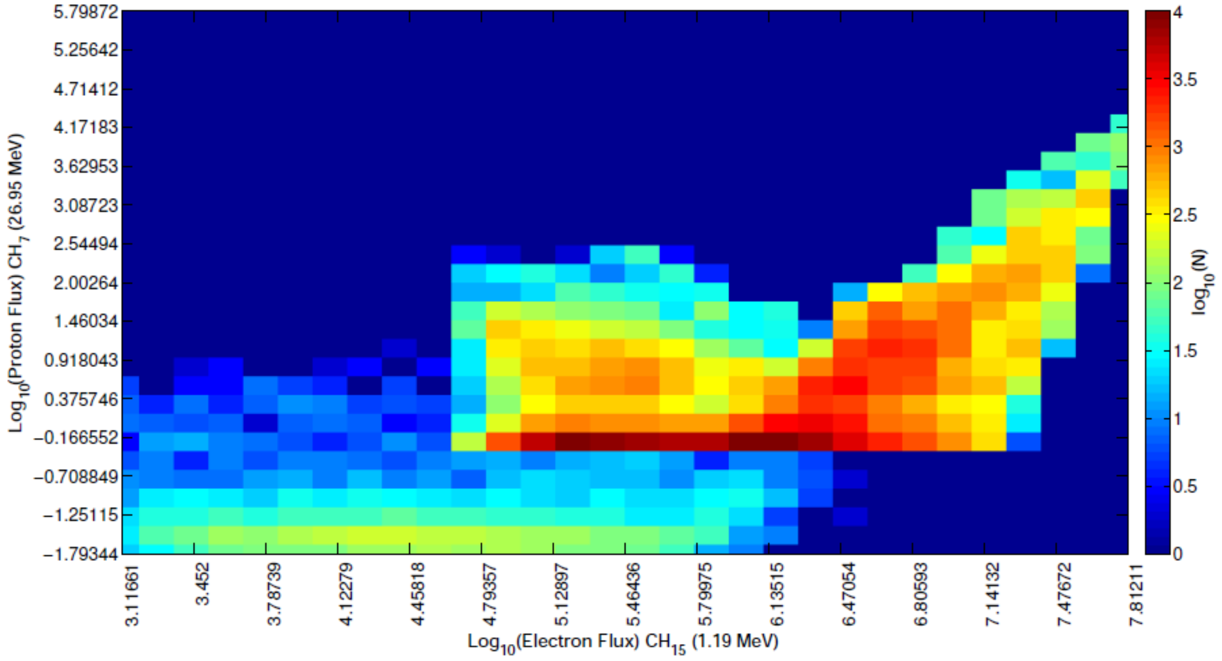


Figure 121: Histogram of flux values for fedo channel No 5.

Evaluation plots: examples

XMM/ERM



PROBA-V/EPT

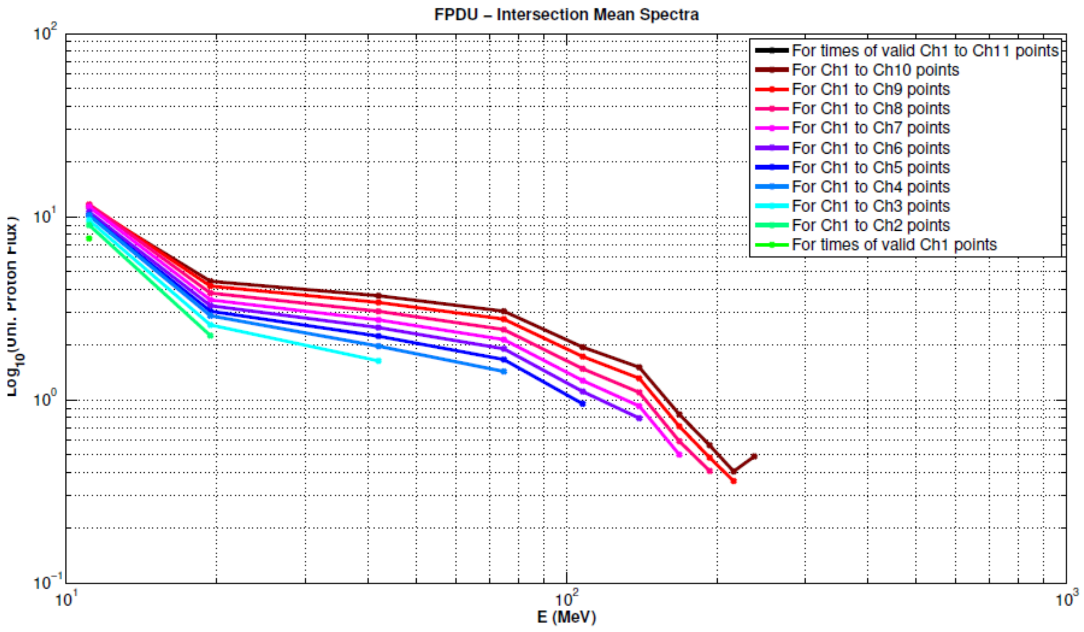


Figure 15: Intersection Mean Spectra for Log_10(Uni. Proton Flux).

Cleaning Methods

- Instrument Saturation

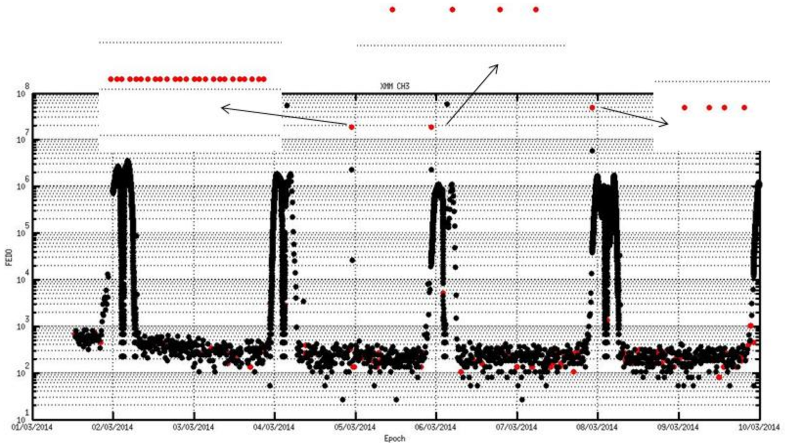
The algorithm calculates the absolute difference of neighboring data-points.

$$D1=|x(i)-x(i+1)|$$
$$D2=|x(i)-x(i-1)|$$

Then we determine a data point as instrument saturation if:

$$D1<d \text{ or } D2<d$$

where d=0.

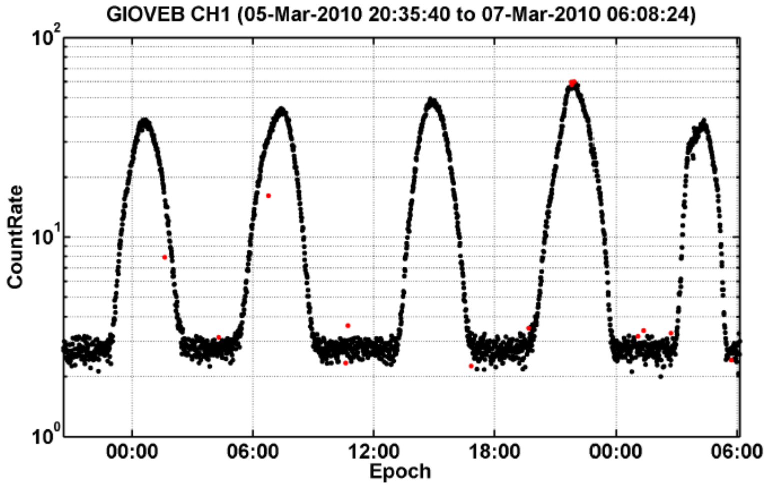


- De-spiking

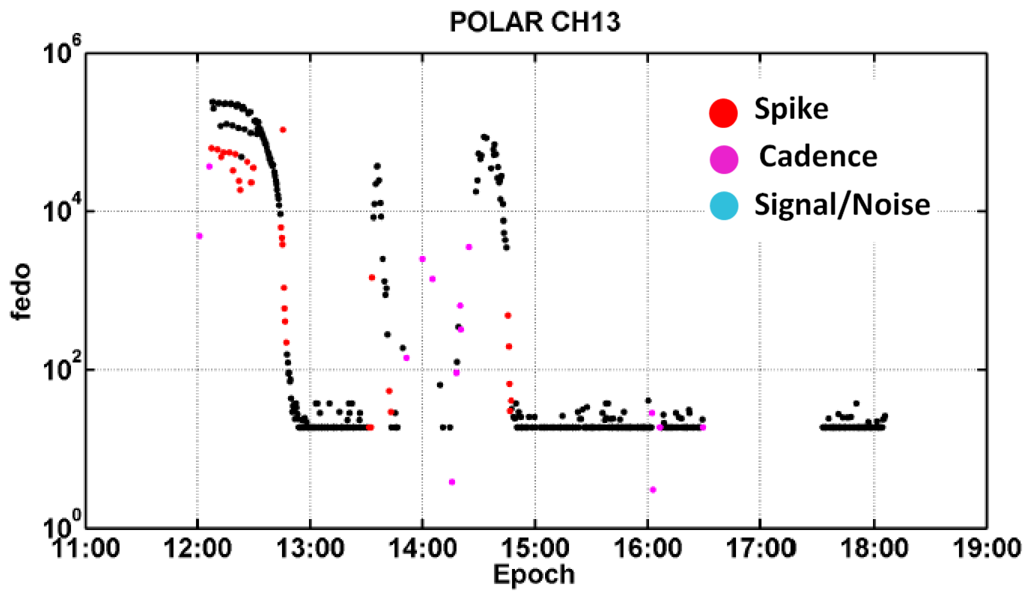
Spikes are then defined as the points, which simultaneously satisfy the following conditions:

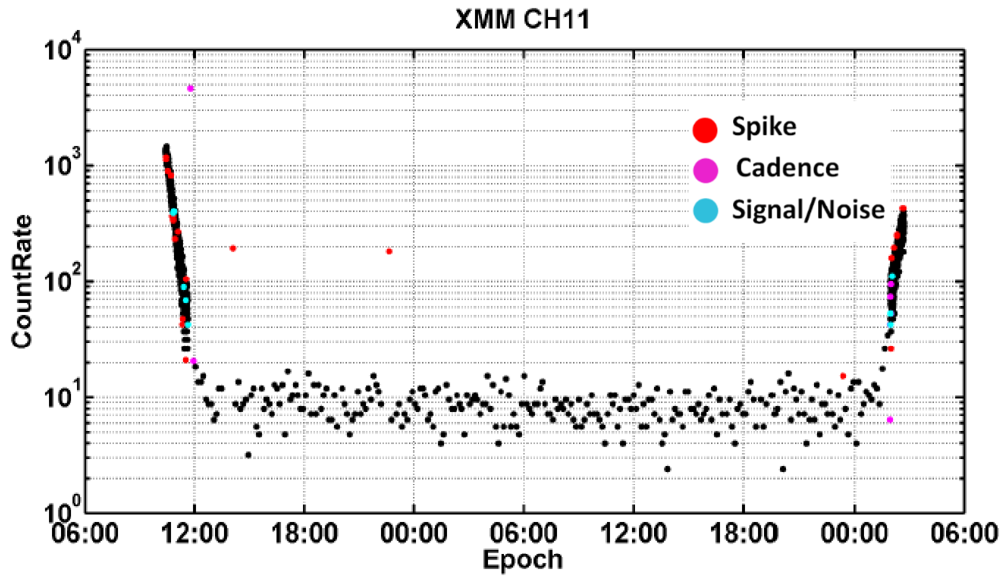
$$|x_i - \mu_i(x_i)| \,/\, \sigma_i(x_i) > (2\ln(2N))^{1/2}$$

$$4|d_i - m_i(d_i)| \,/\, (3\sigma_i(d_i)) > (2\ln(2N))^{1/2}$$



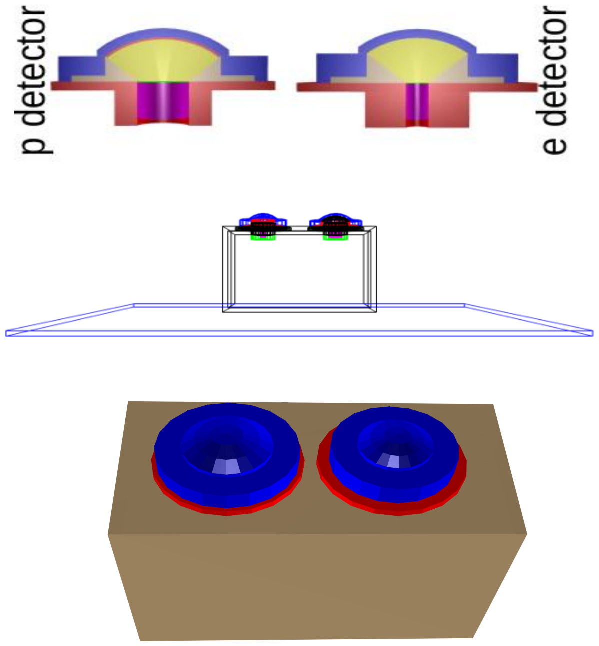
Data cleaning plots: examples



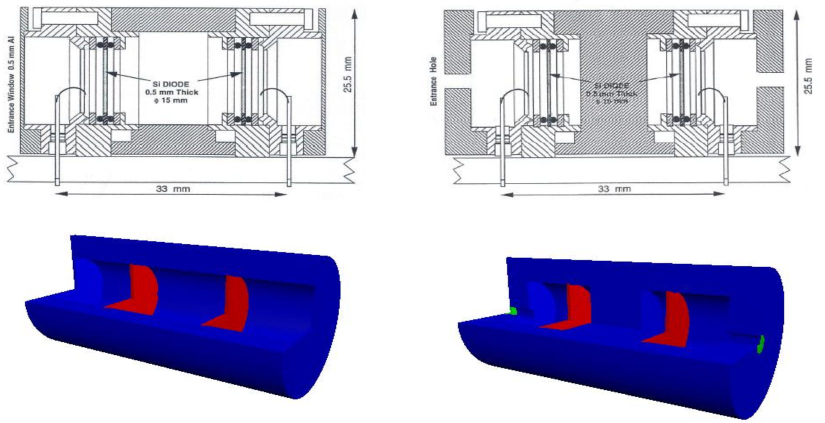


Calibration of radiation monitors

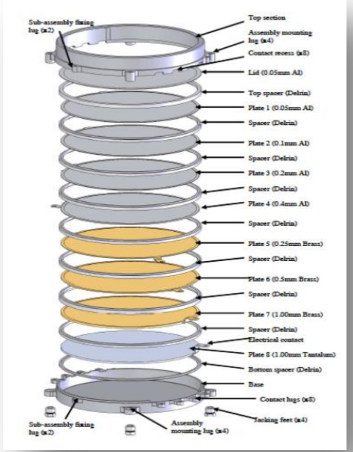
STRV-1b/REM



XMM/ERM



GALILEO/SURF



Main contributor: *G. Provatas*

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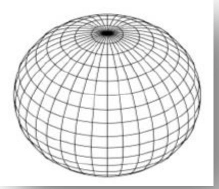
Calibration set-up

$$C = \int_0^\infty \int_0^{2\pi} \int_0^\pi F(\theta,\phi,E)R(\theta,\phi,E)sin\,(\theta)\,d\theta d\phi dE$$

$$C(E) = \sum_{i=1}^{614} F_i R_i \iint_{s_i} sin(\theta) d\theta d\phi dE = \sum_{i=1}^{614} F_i R_i \delta s_i$$

Responses with angular resolution of **δθ=δϕ=10º** for 614 different directions



$$R_i = \frac{C_i}{N_i}\pi r^2 \quad [cm^2]$$

Planar source at each direction

$$F_i = \frac{N_i}{\pi r^2}[cm^{-2}\cdot s^{-1}\cdot MeV^{-1}]$$

Electrons: 100 keV – 10 MeV
Protons: 10 MeV – 1 GeV

- **Geant4 v. 9.6 patch-03**
- **GRAS v. 03-03-r1561**

- **ROOT v. 5.34/20**

$$R_{4\pi}(E_j) = \frac{1}{4\pi}\sum_{i=1}^{614} R(\theta_i,\phi_i,E_j)\delta s_i$$

$$R(\theta_i,\phi_i) = \frac{1}{100}\sum_{j=1}^{100} R(\theta_i,\phi_i,E_j)$$

Analysis of simulation output

Geometry model of the instruments

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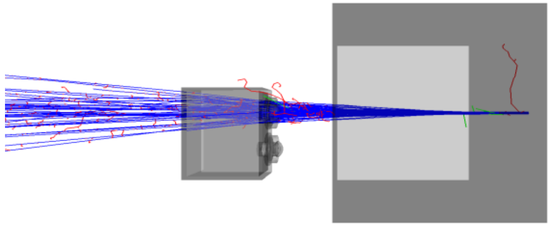
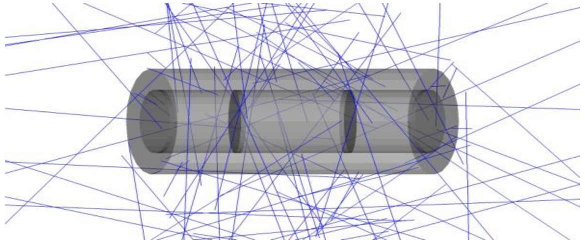
Calibration set-up: Validation

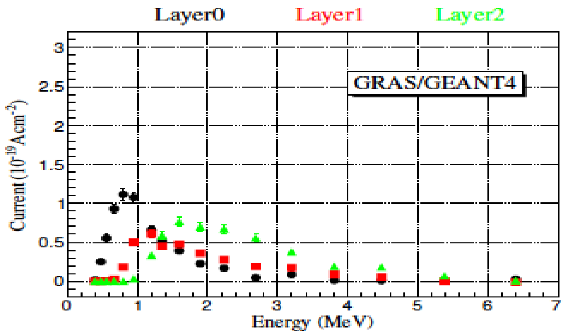
- **STRV-1b/REM:** The calibration measurements at PSI using proton beams were reproduced



- **XMM/ERM:** Derived transfer matrix compared with reported results



- **MERLIN/SURF:** Charging currents obtained with GRAS/Geant4 compared with DICTAT results.



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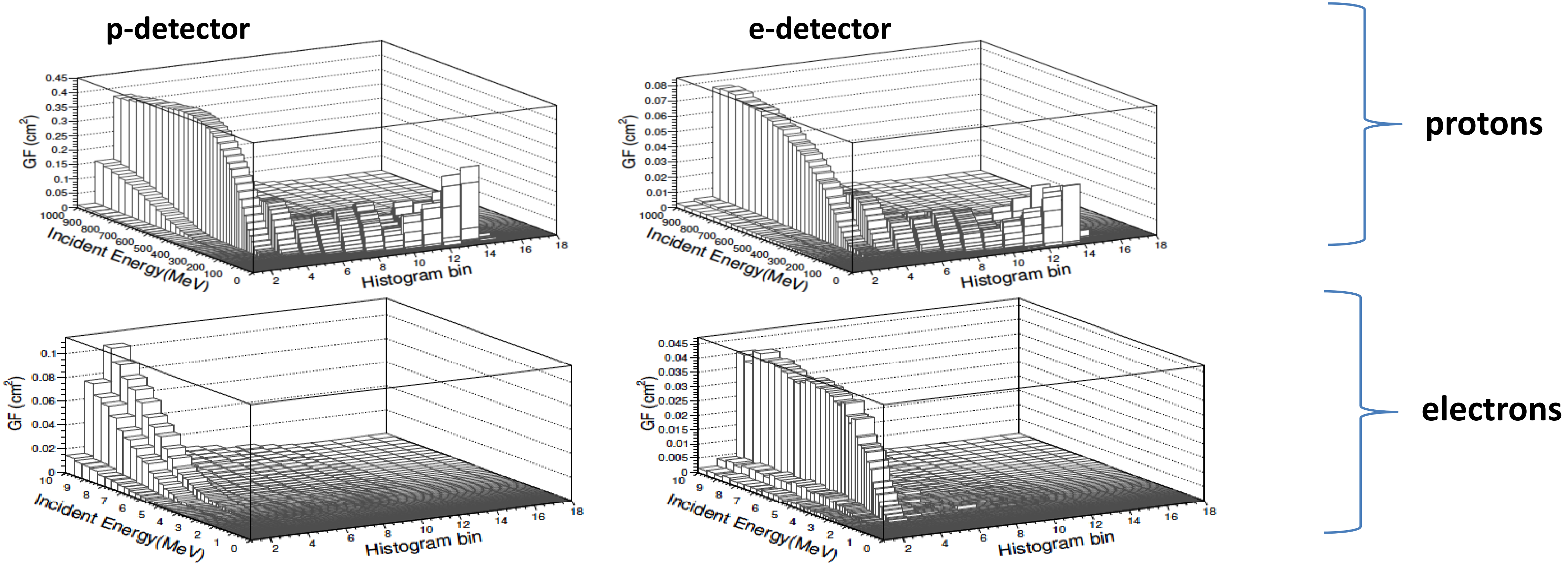
REM: omni-directional responses

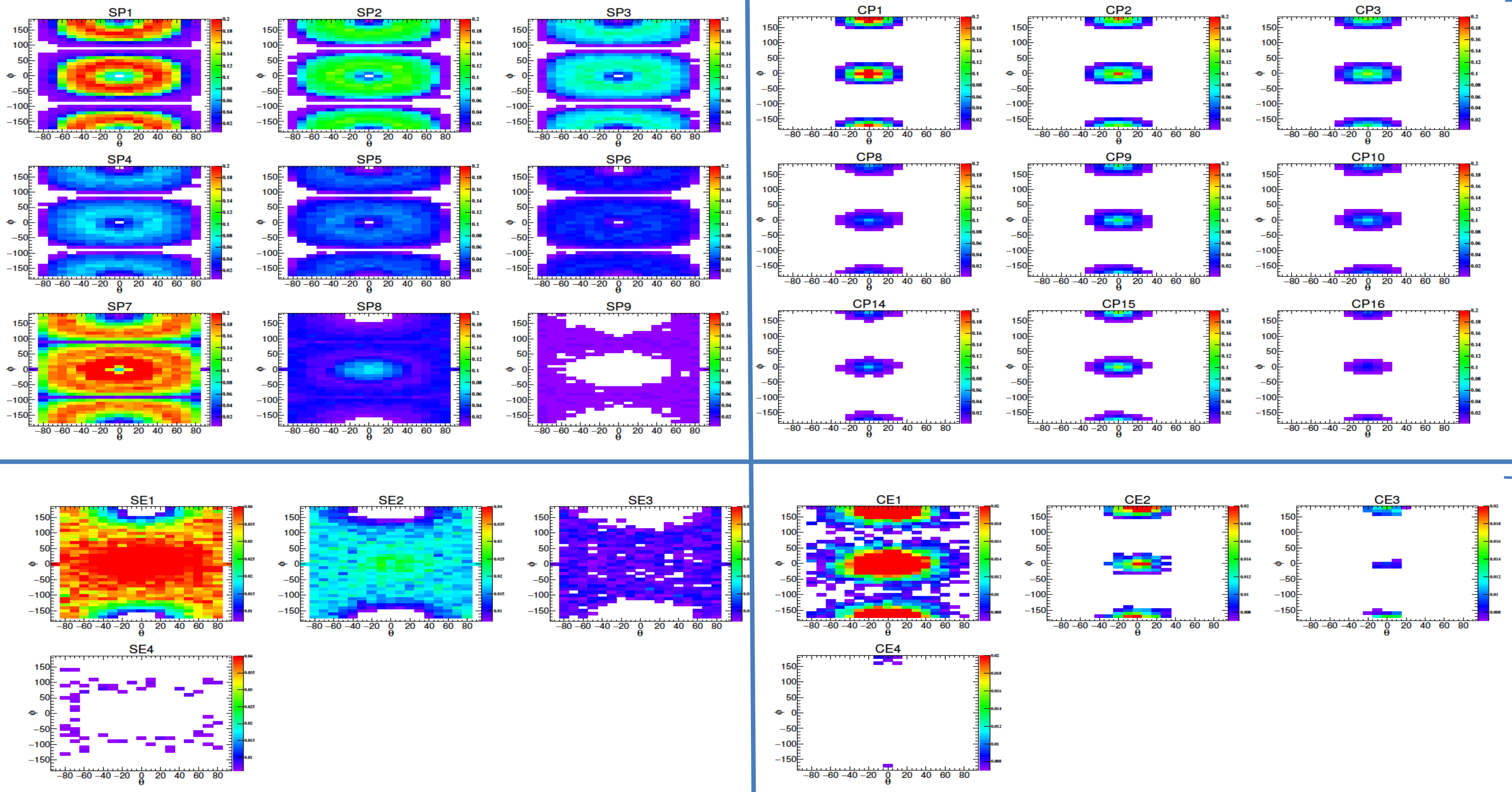


- p/e are detected within the 15 channels, the 16th channel can detect heavier particles.
- p-detector's GFs are greater than e-detector's.
- protons can contribute in all 15 channels detections → no pure e-counters
- electrons are counted within the first 2 channels only → poor energy resolution

XMM/ERM/HE: directional responses

single

coincidence



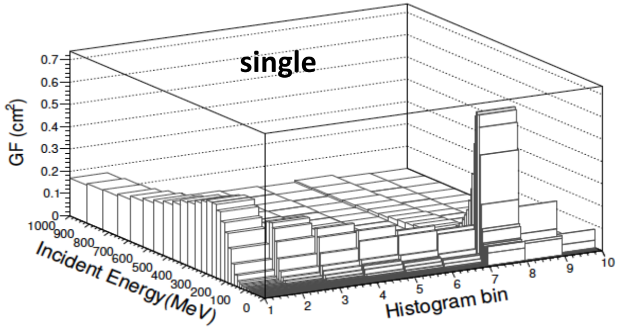
protons

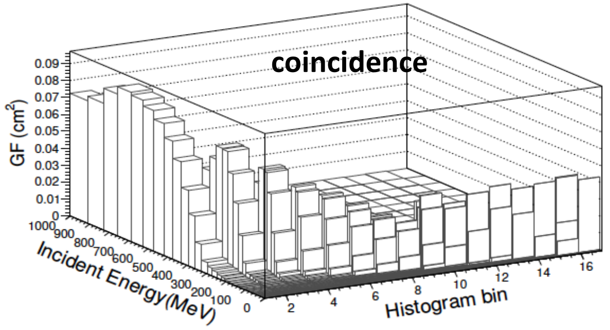
electrons

XMM/ERM: omni-directional responses

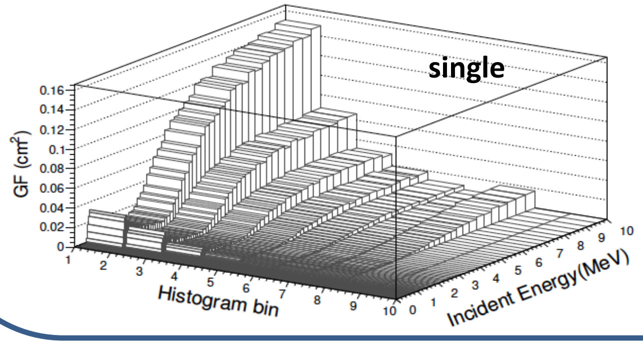
HE unit

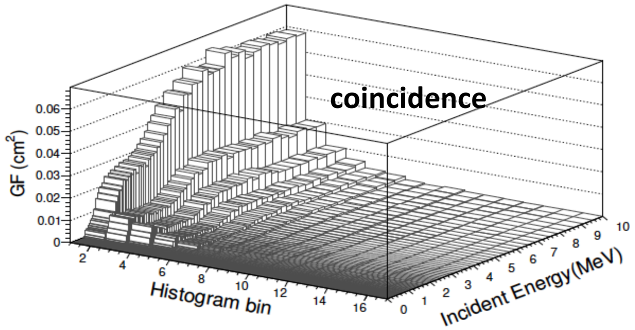
protons





electrons



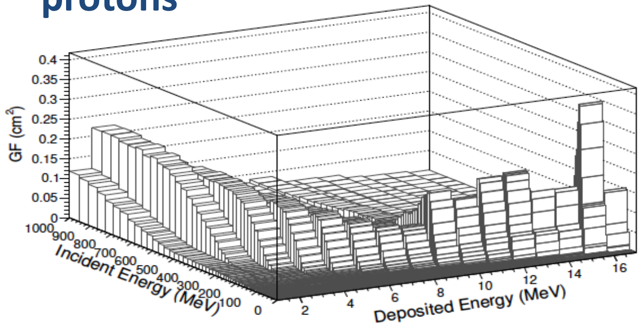


Protons are detected in all channels
In singles mode protons are mainly detected through the lateral shielding.
The peak at channel #7 corresponds to p from forward directions that are stopped in the first diode it encounter.

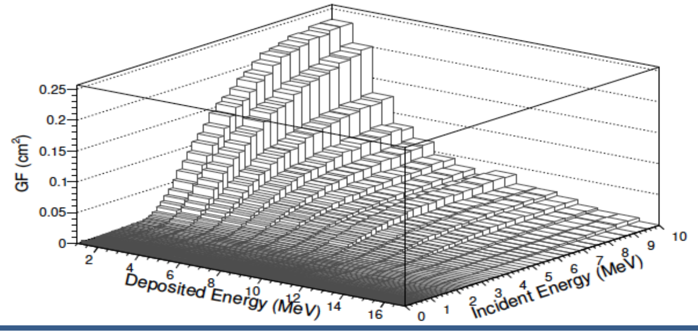
Electrons are detected in the first 3 channels.
In single mode electrons are detected from lateral as well as axial directions.
In coincidence mode only electrons from front or back directions are measured.

LE unit

protons



electrons



The response to protons is similar to the HE single responses, with the peak in the low incident energy shifted to higher energies (>20 MeV), due to the thicker Al shield.
The response to electrons below 2 MeV is negligible.

Data unfolding

$$C_i = \sum_{q=p,e} C_{i,q} = \sum_{q=p,e} \left[\int_0^{\infty} f_q(E) RF_{i,q}(E) dE \right]$$

- Inverse Problem – Non-unique solution
- Success in data unfolding depends on:
  - Response Function (Calibration)
  - Quality of measurements
  - Unfolding Method

Goal: develop/update & apply unfolding methods for the counts-to-fluxes calculation

- Singular Value Decomposition Method
- Artificial Neural Networks
- Correlative Unfolding Method

Contributors: *S. Aminalragia-Giamini & I. Sandberg*

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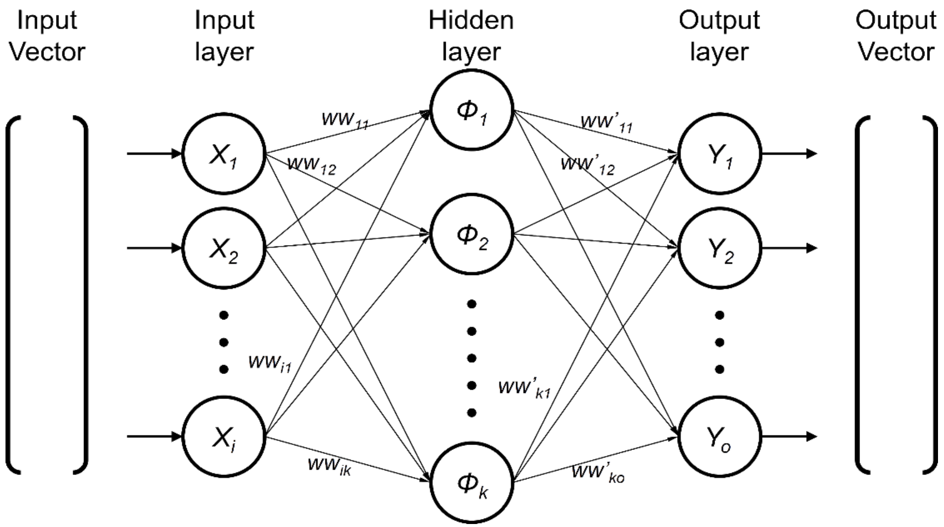
Artificial Neural Network

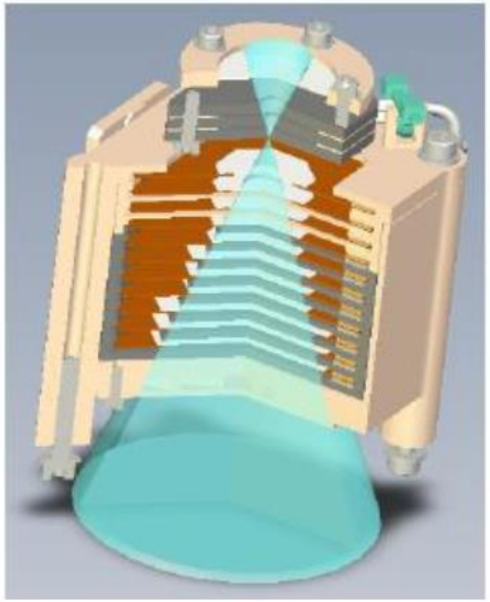
A number of interconnected collaborating neurons comprises a network which is trained by a learning algorithm using a training set.

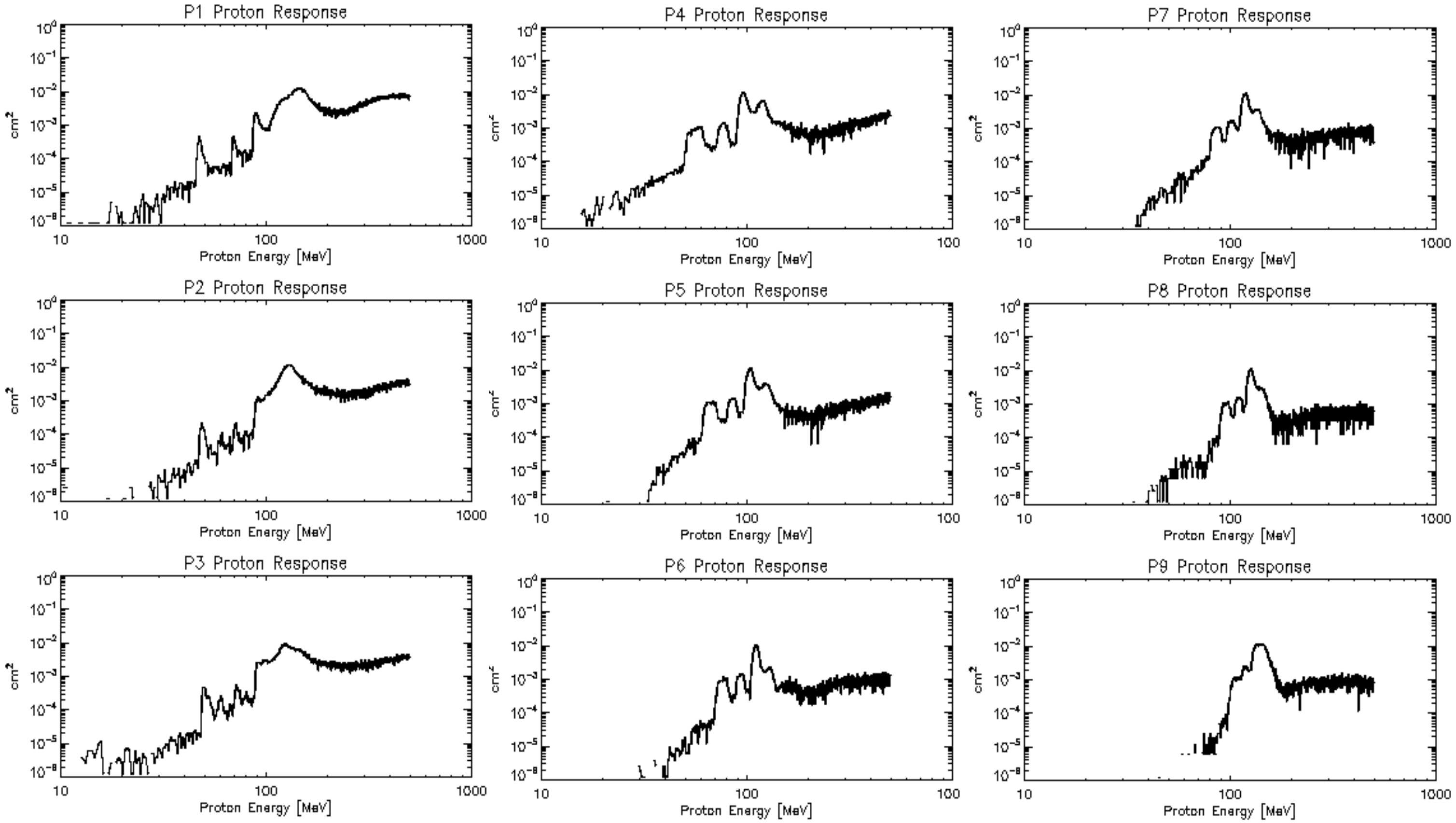


- Each node is a neuron
- Neurons are arranged into layers - one or more "hidden" layers may be exist
- Hidden layer neurons employ non-linear functions e.g. sigmoids or gaussians
- Weight factors model the strength of the neural synapses

Example: Alphasat/MFS data

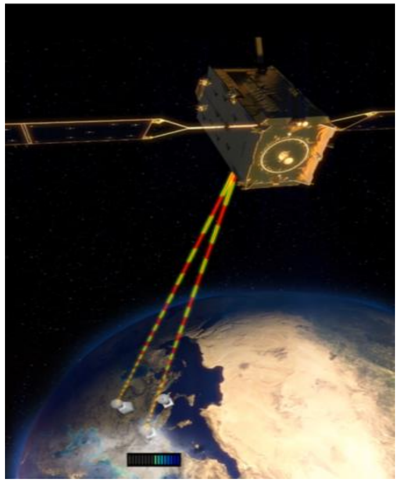
MFS provides measurements in 17 channels. The first 10 channels are the P-channels, and the last 7 the so-called E-channels

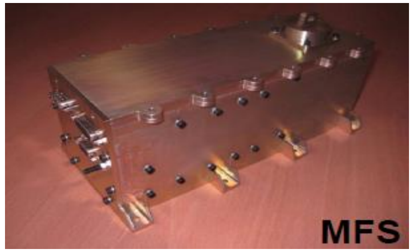


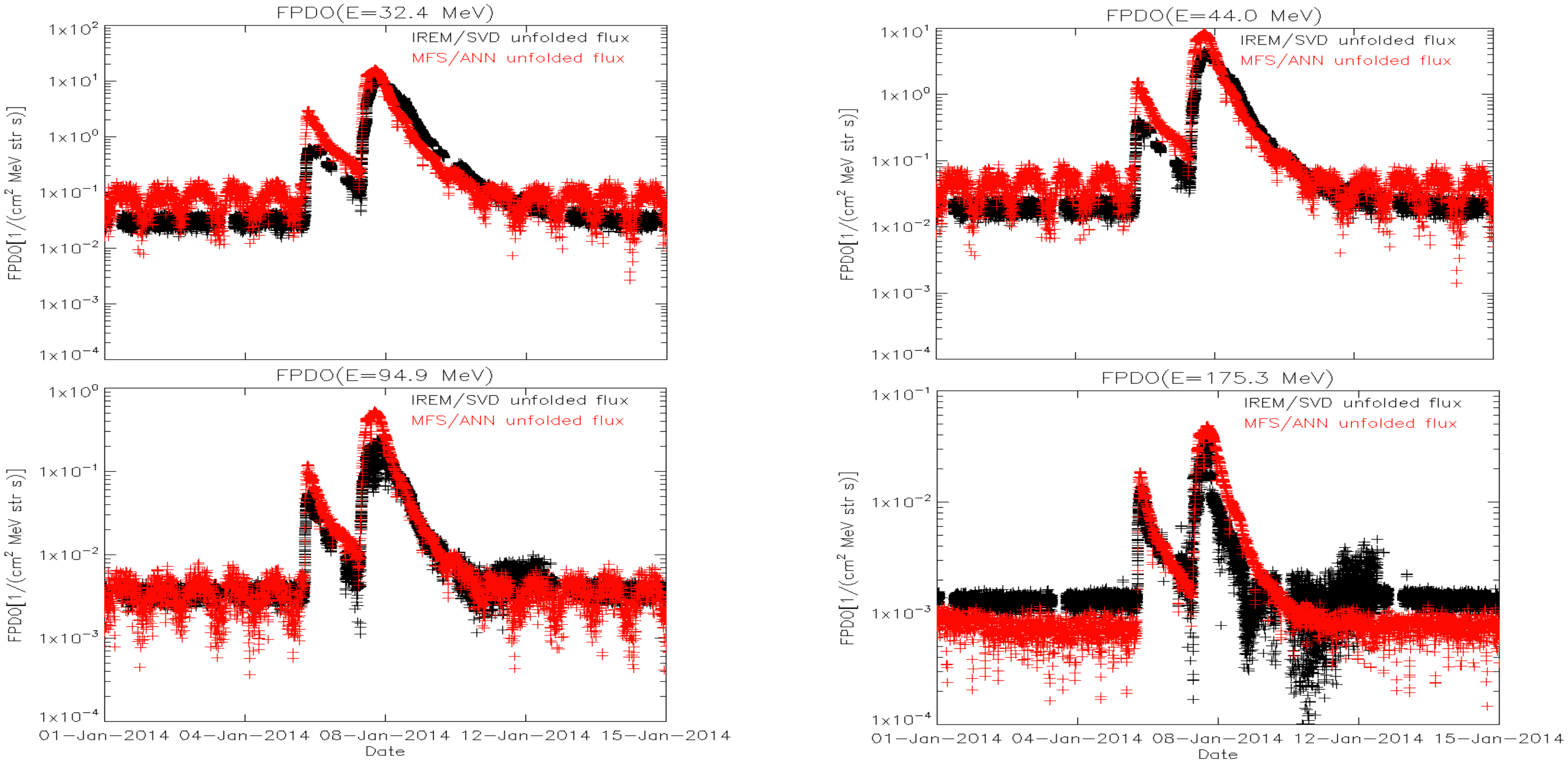


In collaboration with P. Goncalves, LIPT, Portugal

Example: Alphasat/MFS data

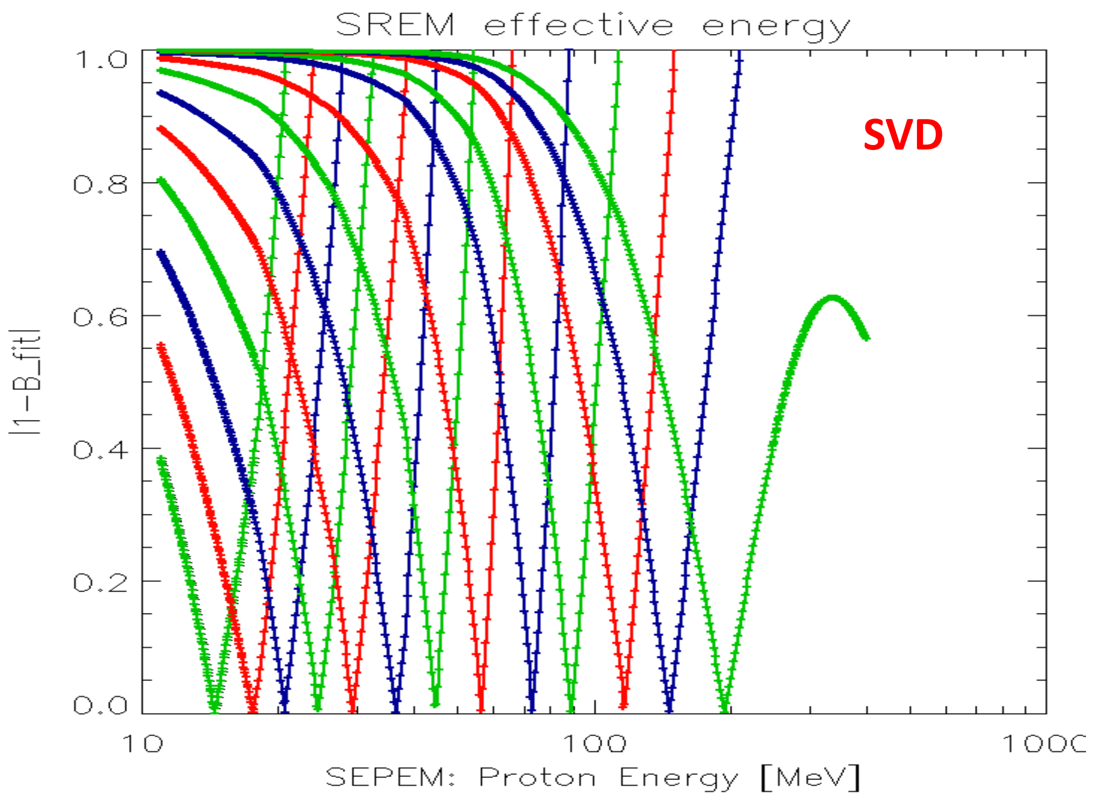


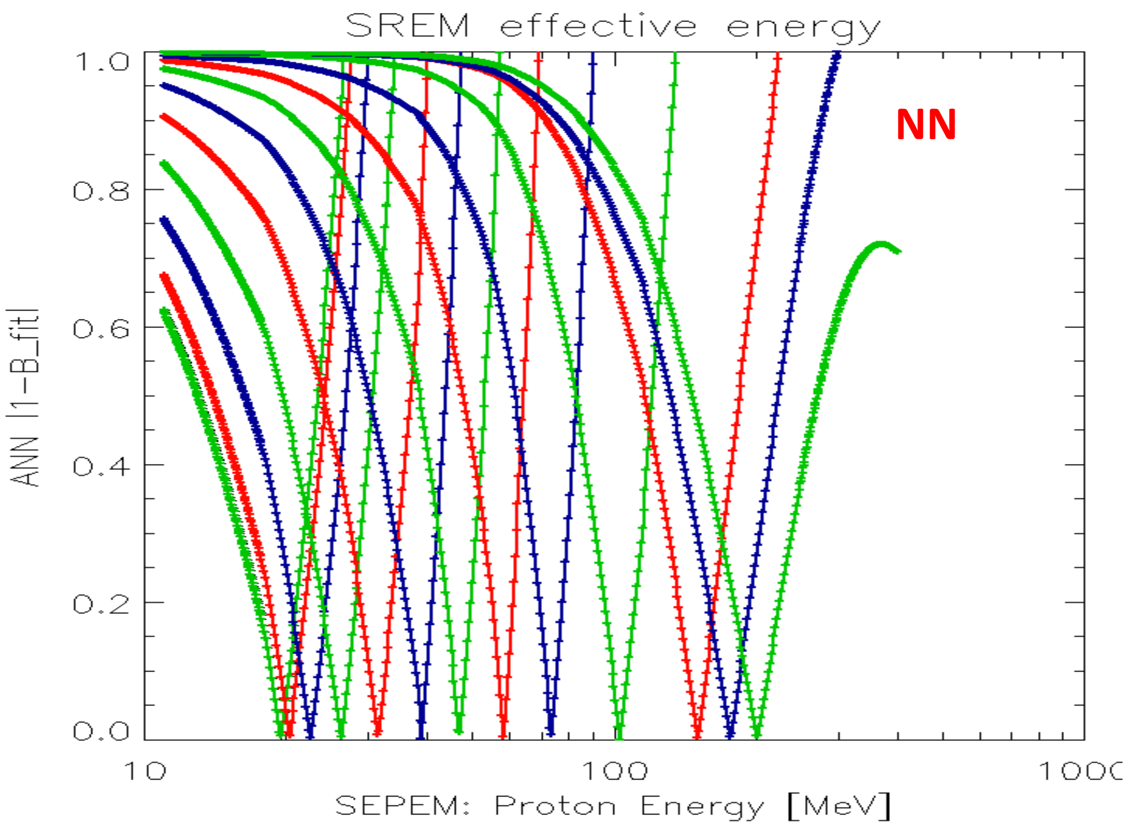




L. Arruda et al. IEEE TNS 64 (8), 2333, 2017

ESA SREM cross-calibration





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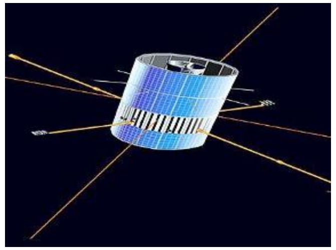
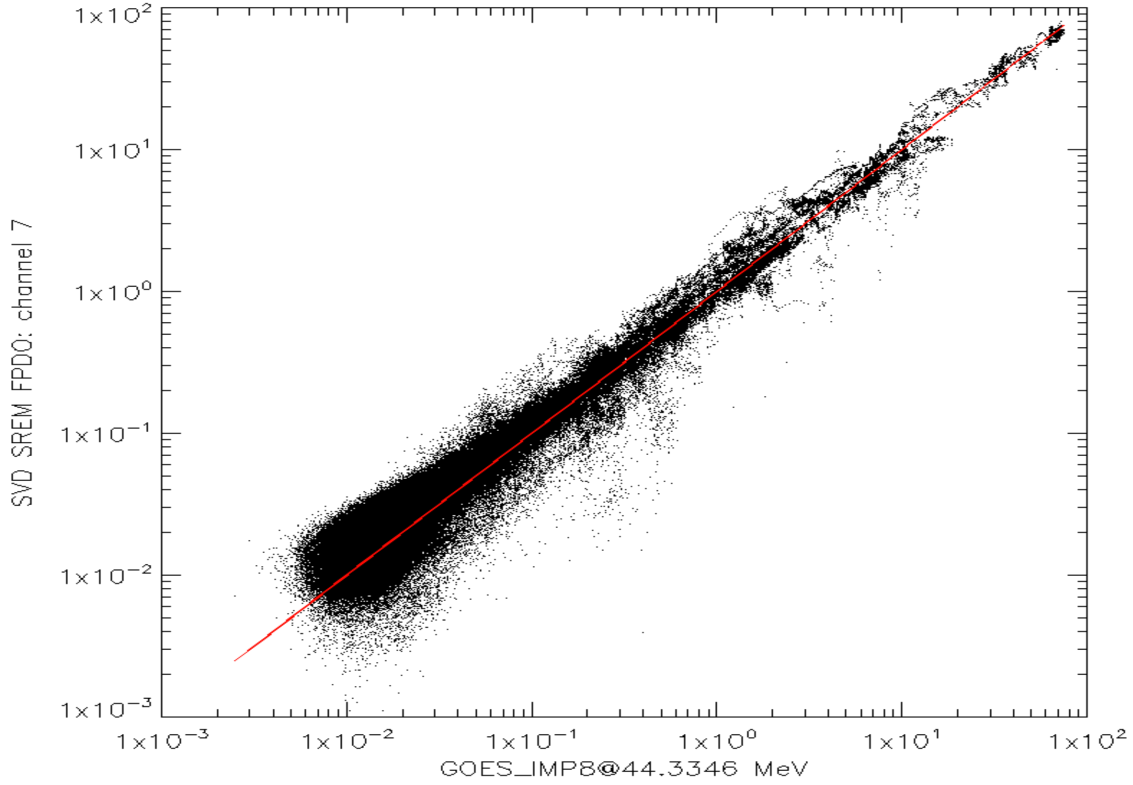
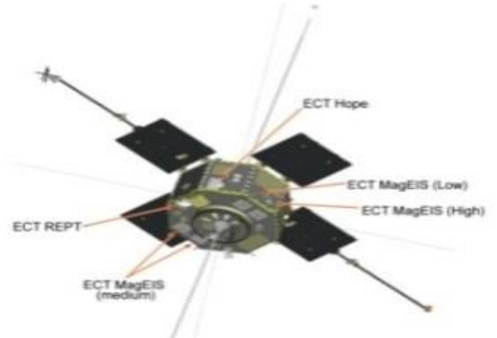
SREM SVD cross-calibration



SREM proton flux channel	Nominal unfolding energy	Effective Energy value
#1	12.4	14.50
#2	15.8	17.63
#3	20.0	20.69
#4	25.4	24.62
#5	32.3	29.31
#6	41.1	36.44
#7	52.2	44.33
#8	66.3	56.33
#9	84.3	73.16
#10	107.1	89.00
#11	136.1	116.4
#12	172.9	146.88
#13	219.7	194.9
#14	279.3	320
#15	354.8	361.3



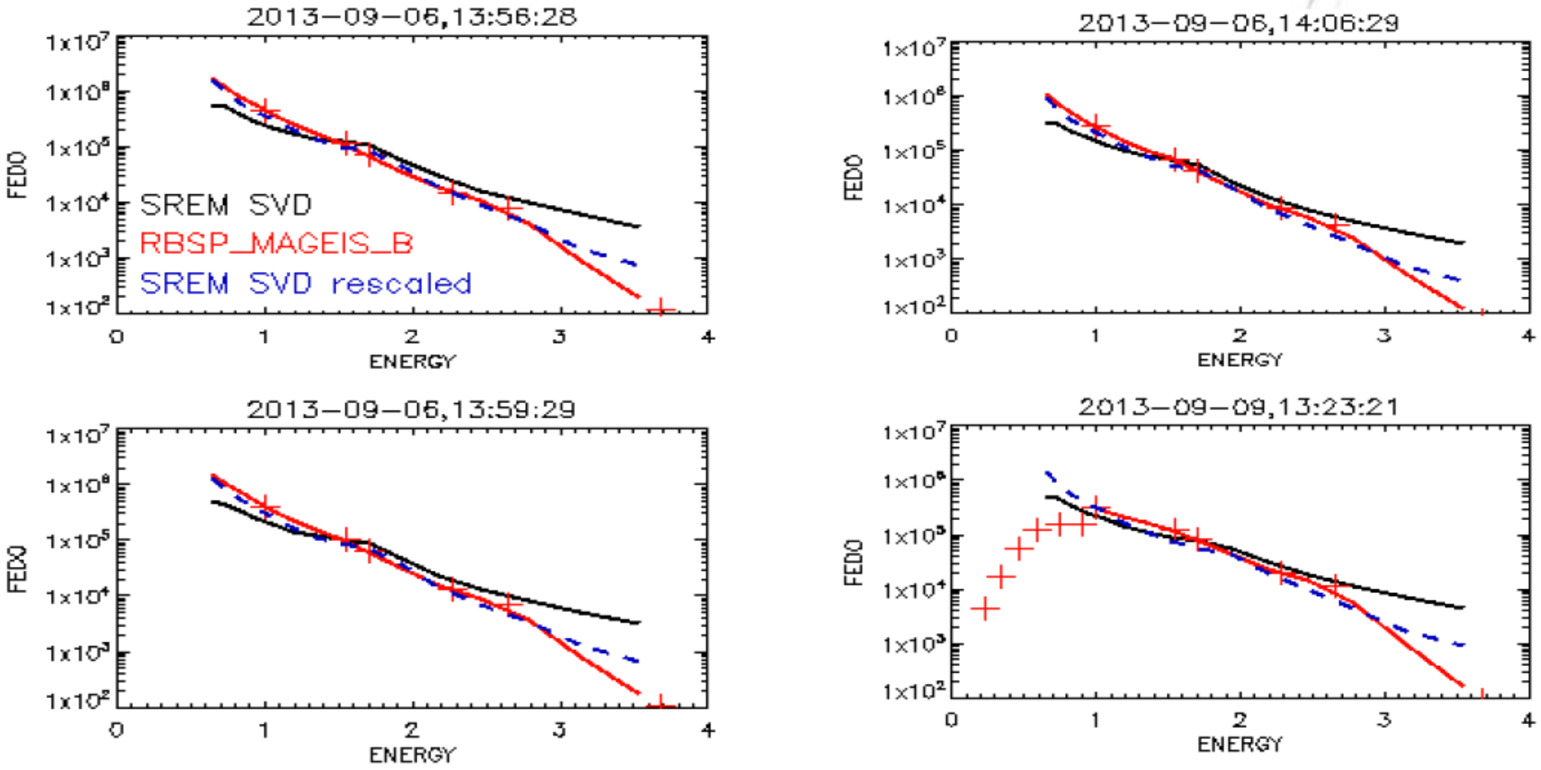
ESA SREM cross-calibration



RBSP/MagEIS
(30keV-4 MeV)

Nominal unfolding energy	Scaling Factor
0.65	2.85
0.73	2.05
0.83	1.77
0.93	1.64
1.06	1.47
1.19	1.19
1.35	0.96
1.52	0.79
1.71	0.63
1.93	0.58
2.18	0.57

3 < L* < 6 and dL* < 0.1
d (B / Beq) <0.1 and B / Beq ~ 1
4 <MLT <8 and 16 <MLT <20
dt < 1 h



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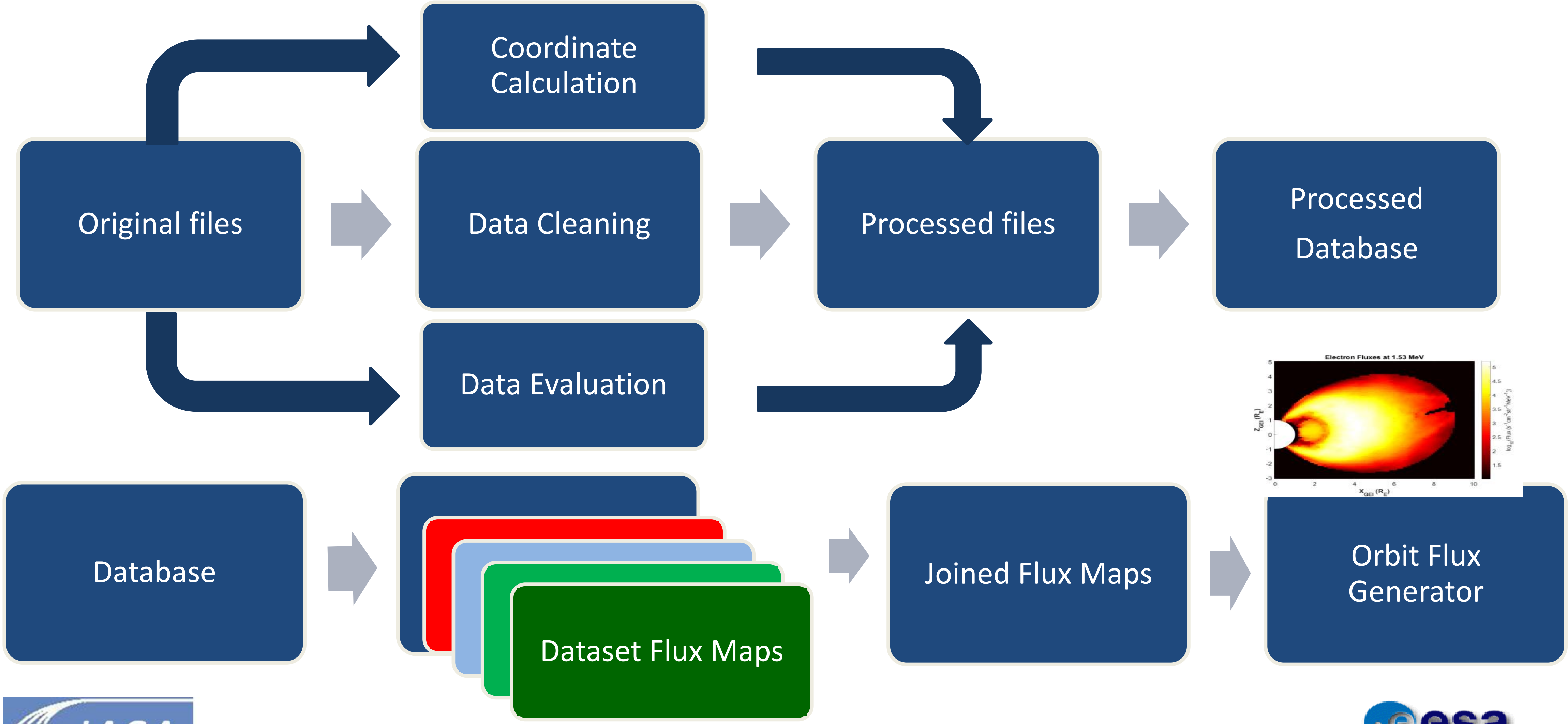
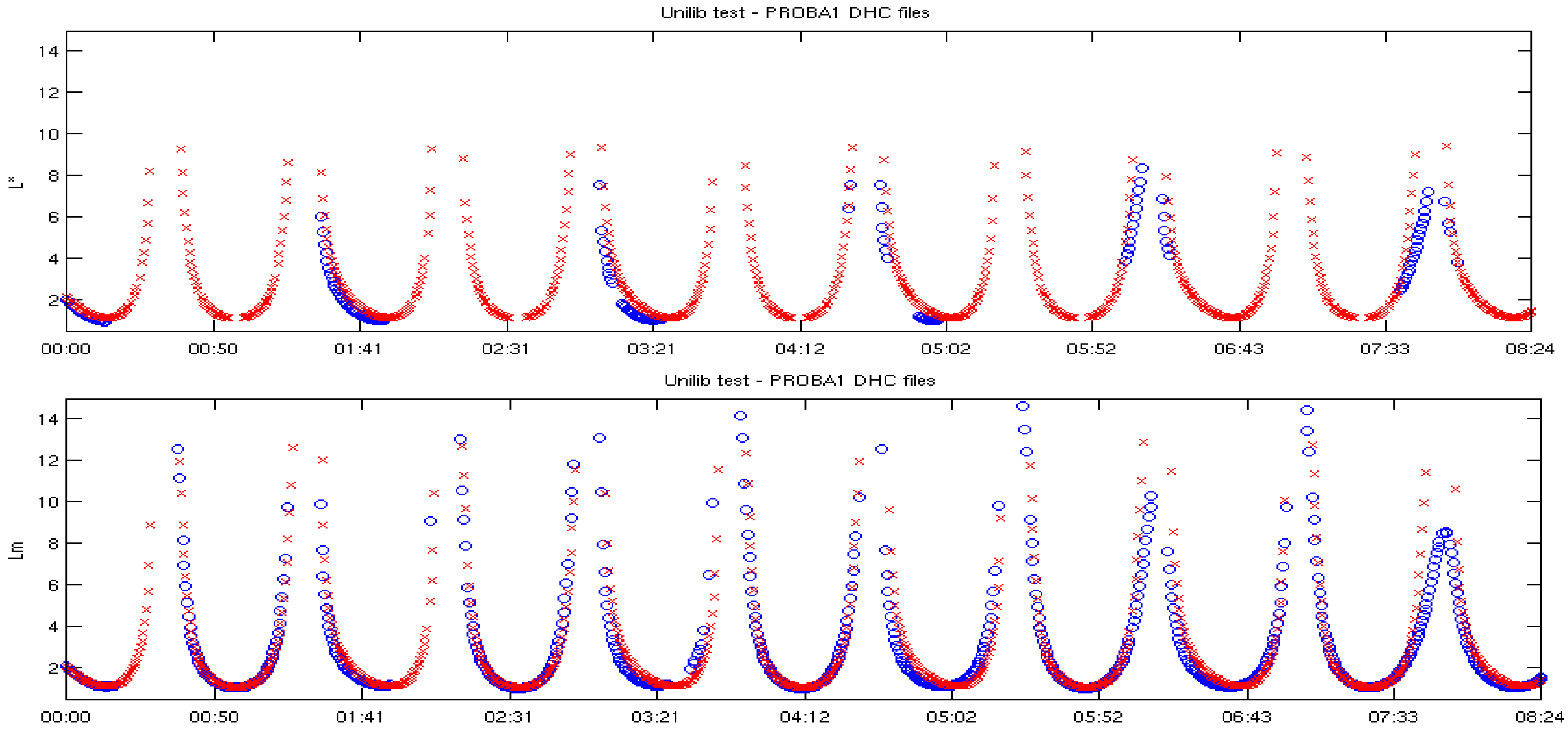
Roadmap: Radiation Belt specification model



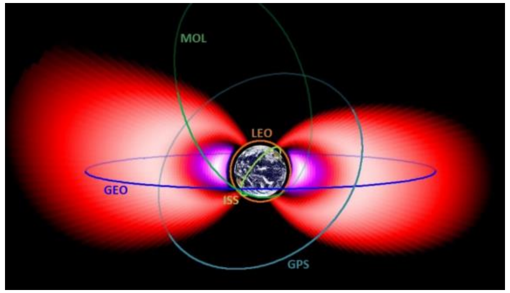
Unilib vs IRBEM



Radiation belt models

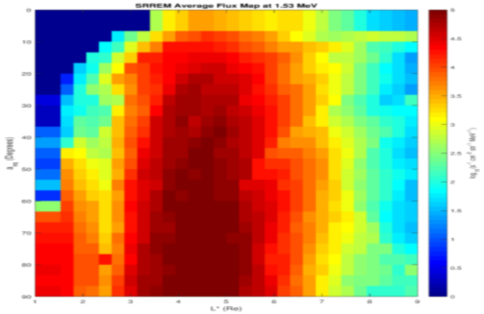
AE9/AP9

- Accumulate daily averaged flux values at each grid point
- Calculate median and 95th percentile
- Assume Weibull distribution (electrons) or log-normal distribution (protons)



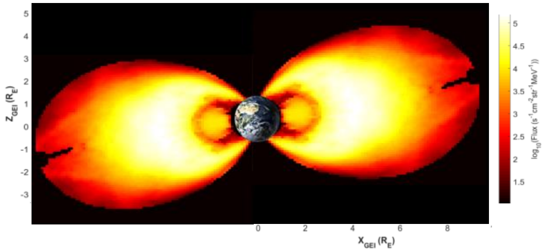
SRREM

- Construct synthetic time series (aggregating all data)
- Calculate daily averages
- Compute the histogram of the data



TREPEM

- Accumulate daily average values at each grid point
- Calculate 29 quantiles as a means to describe the distribution
- Use inverse transform sampling to generate points according to the derived distribution and compute the histograms from them



TRapped Energetic Particle Environment Model

- Purely Data driven model with a statistical approach to cover the entire distribution of fluxes at each grid point
- Produce fly-in scenarios of fluxes/fluences (average, percentile)
- Additional output: histogram of all flux/fluence values that were encountered by the satellite along its flight path
- Both e^- and p^+ models available
- I/O format compatible with AE9/AP9 (IRENE) models

IASA

Contributors: *C. Papadimitriou, I. Sandberg*

esa ESTEC

TREPEM

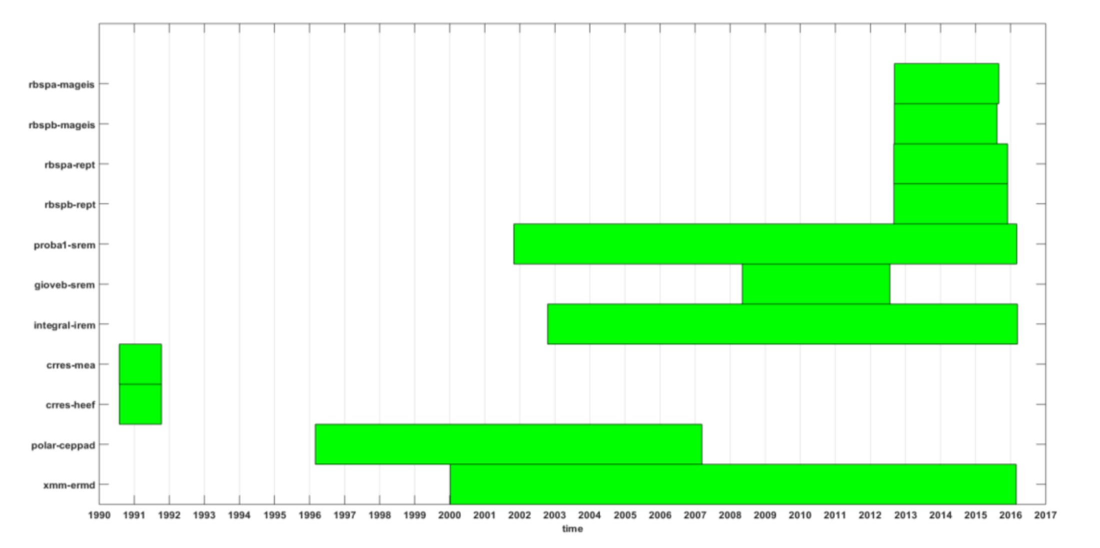
- RBSP-A MagEIS
- RBSP-B MagEIS
- RBSP-A REPT
- RBSP-B REPT
- PROBA1 SREM
- GIOVEB SREM
- INTEGRAL IREM
- CRRES MEA
- CRRES HEEF
- POLAR CEPPAD
- XMM ERMD

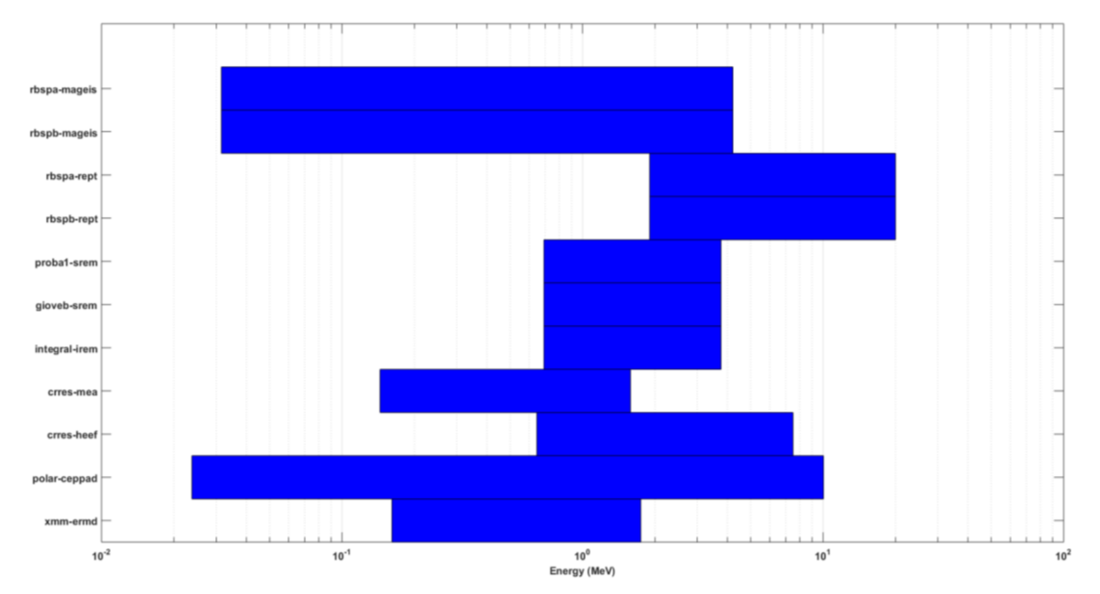
- **1st Invariant (Energy)**
  - 10 channels
    (50 keV – 10 MeV)
- **2nd Invariant (a_{eq})**
  - 27 bins (0 – 90 degrees)
- **3rd Invariant (L*)**
  - 30 bins (1 ≤ L* ≤ 10)

For each dataset:

- Assign daily averaged, omni, diff. fluxes to grid
- Save 29 quantiles as a proxy of their distribution

Merge all dataset flux maps to produce final model map





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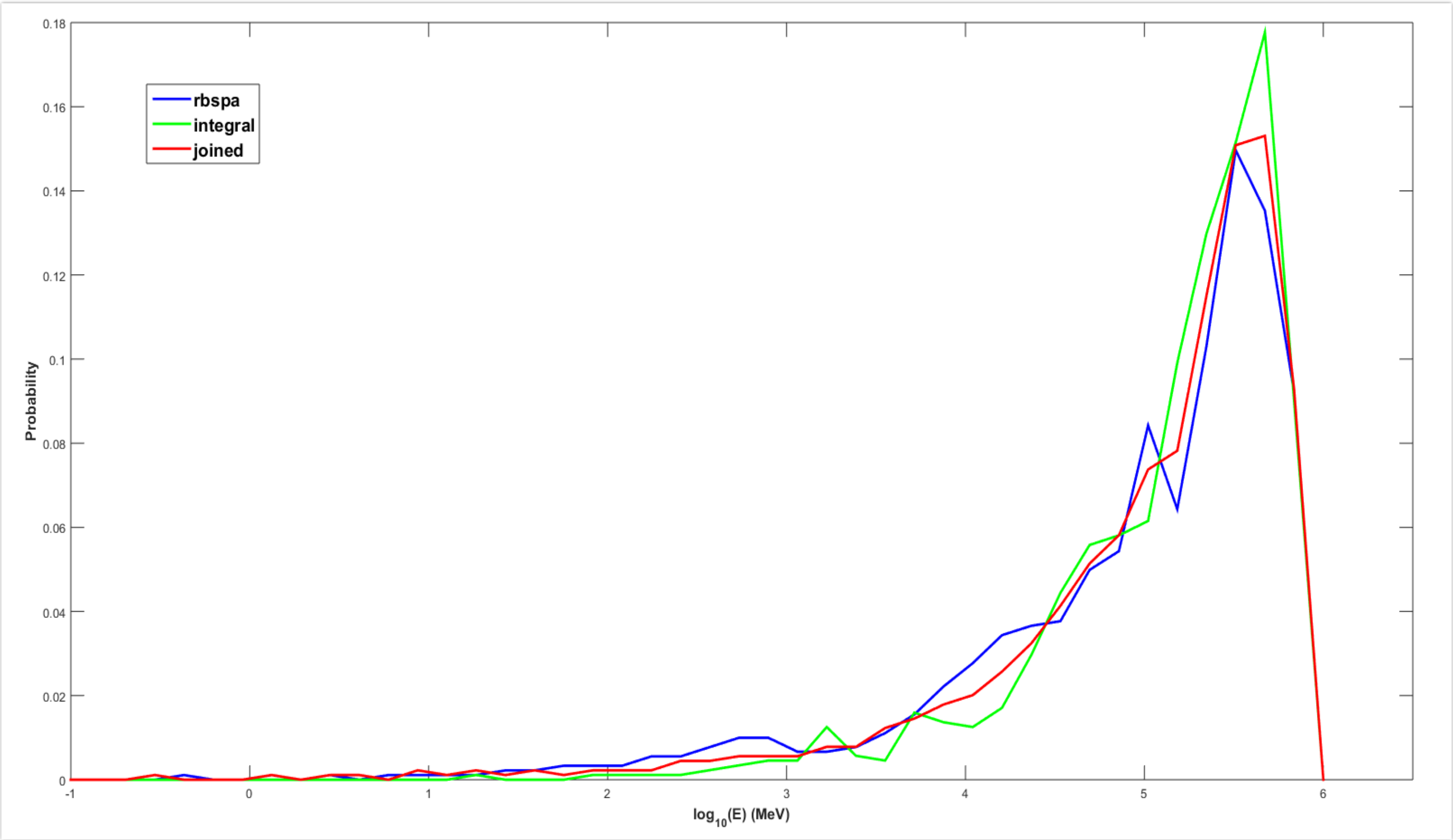
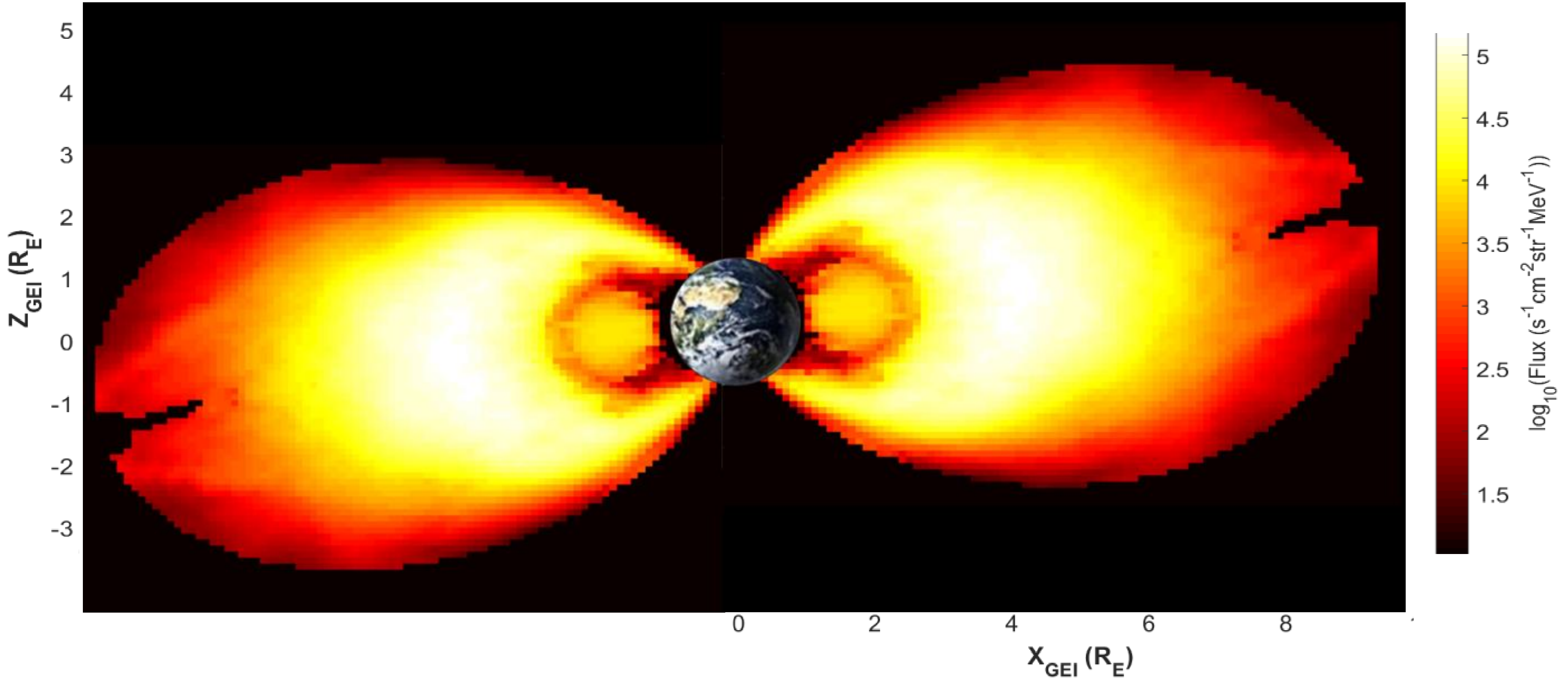
Merging Flux Maps via Inverse Sampling

Method Description

- For each grid point/energy
  - For each dataset
    - **Read quantiles** from the flux map
    - **Produce** 10,000s points via inversion sampling
  - **Join** produced points from all datasets
  - **Derive** new quantiles , mean, stdev, etc
  - Save new statistics to grid point of merged map
- **Produce** quantile-flux-map



TREPEM



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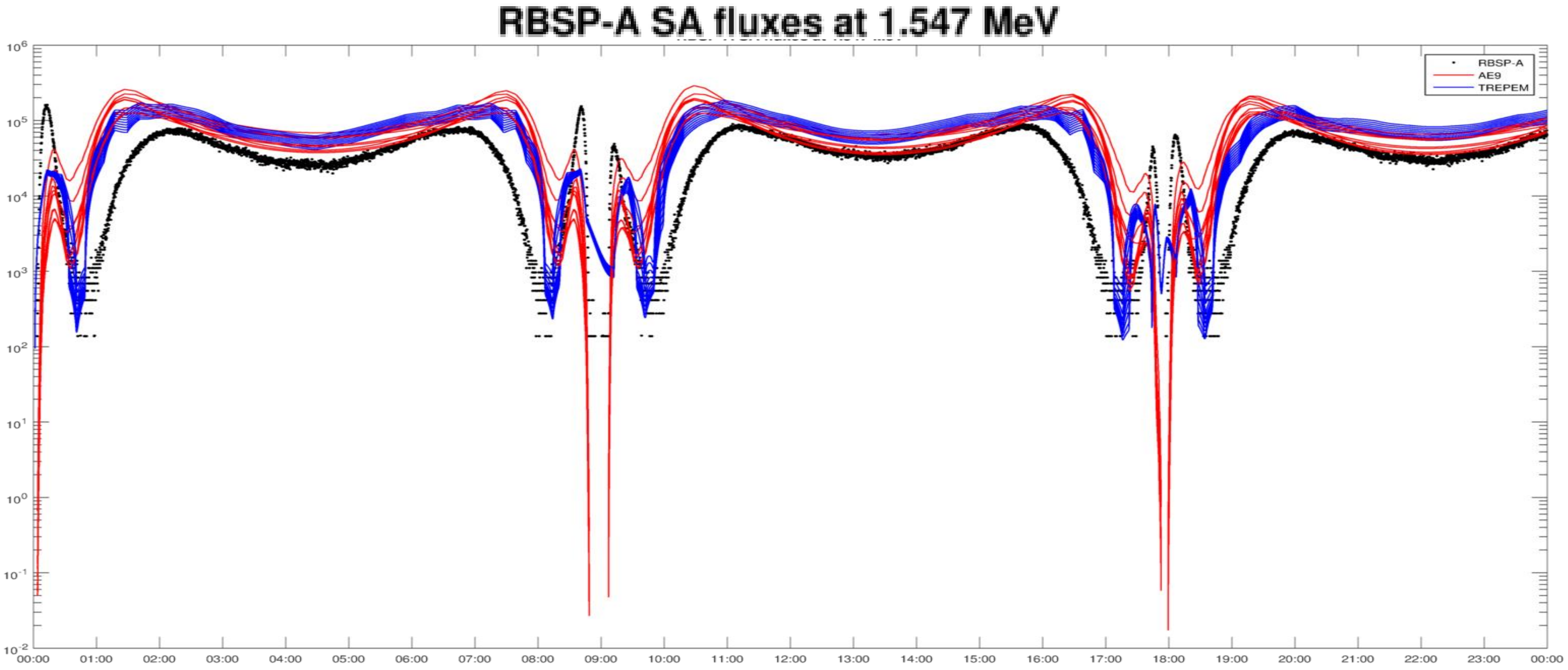
Validation Example – (near) GTO



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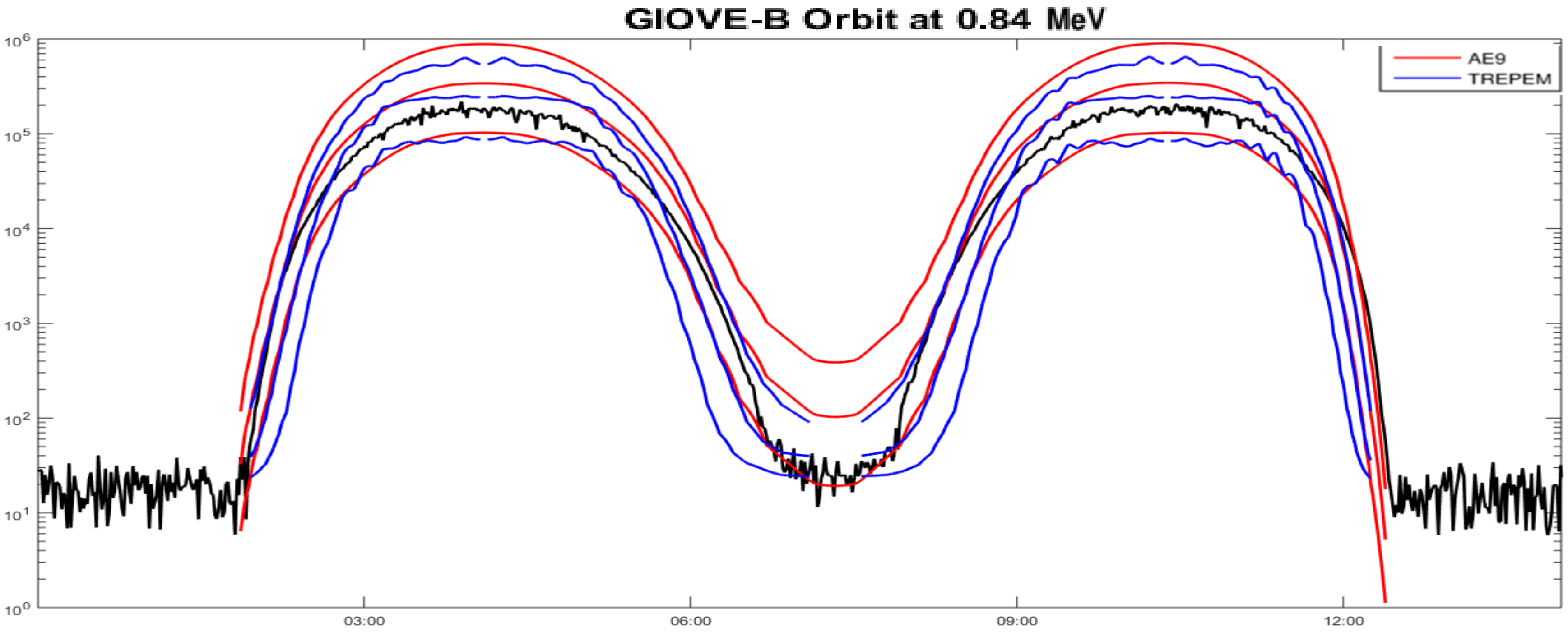
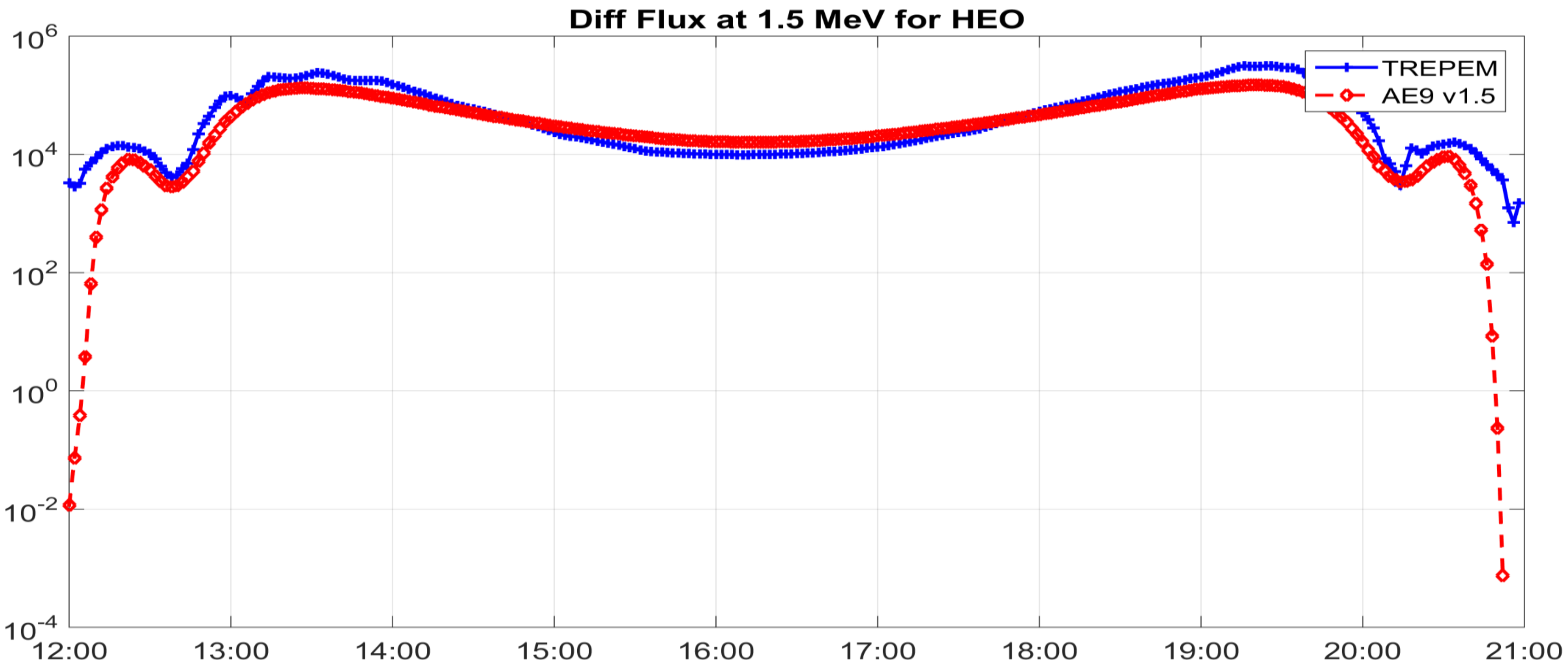
Validation Example – MEO



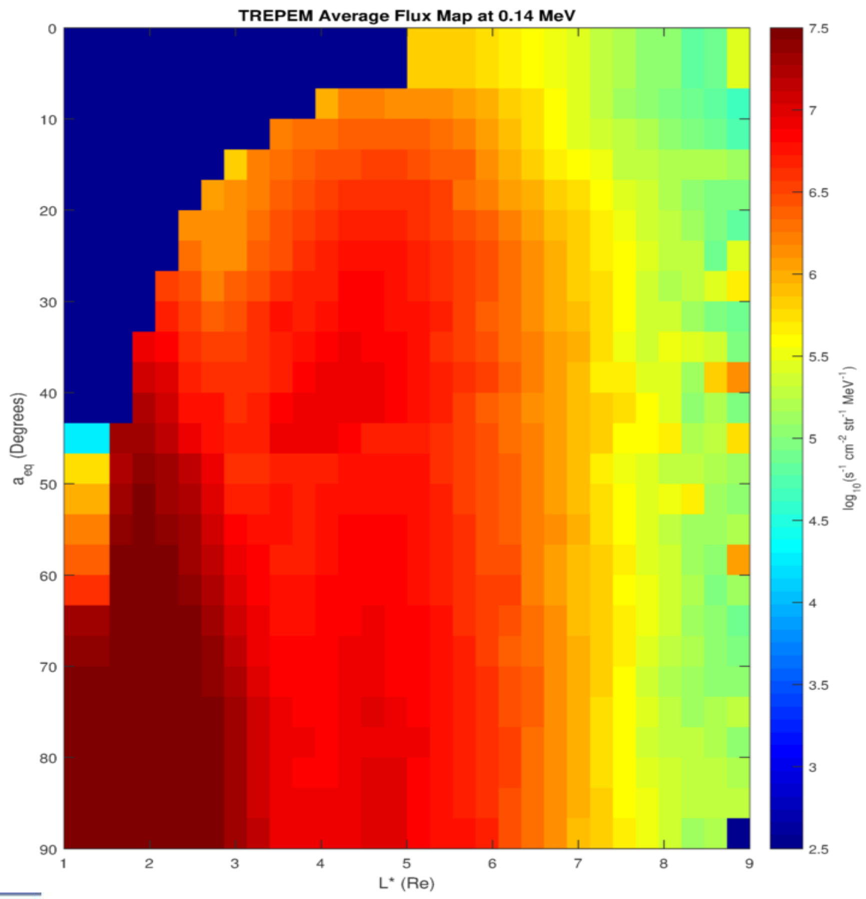
Validation Example – HEO

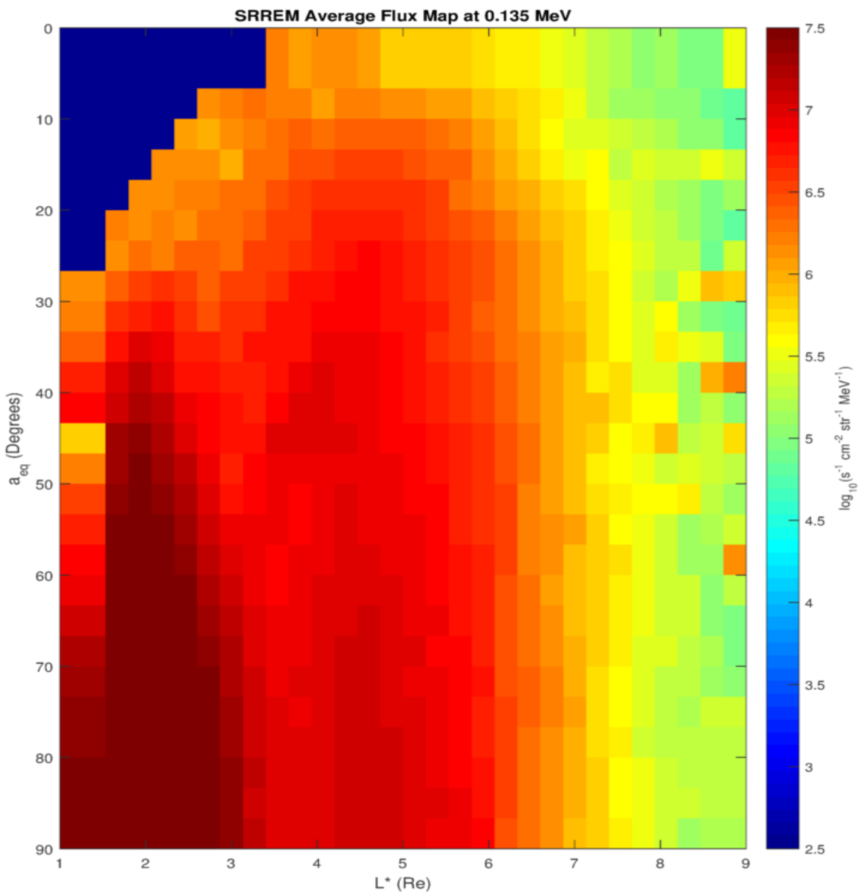


TREPEM

SRREMs

0.14 MeV

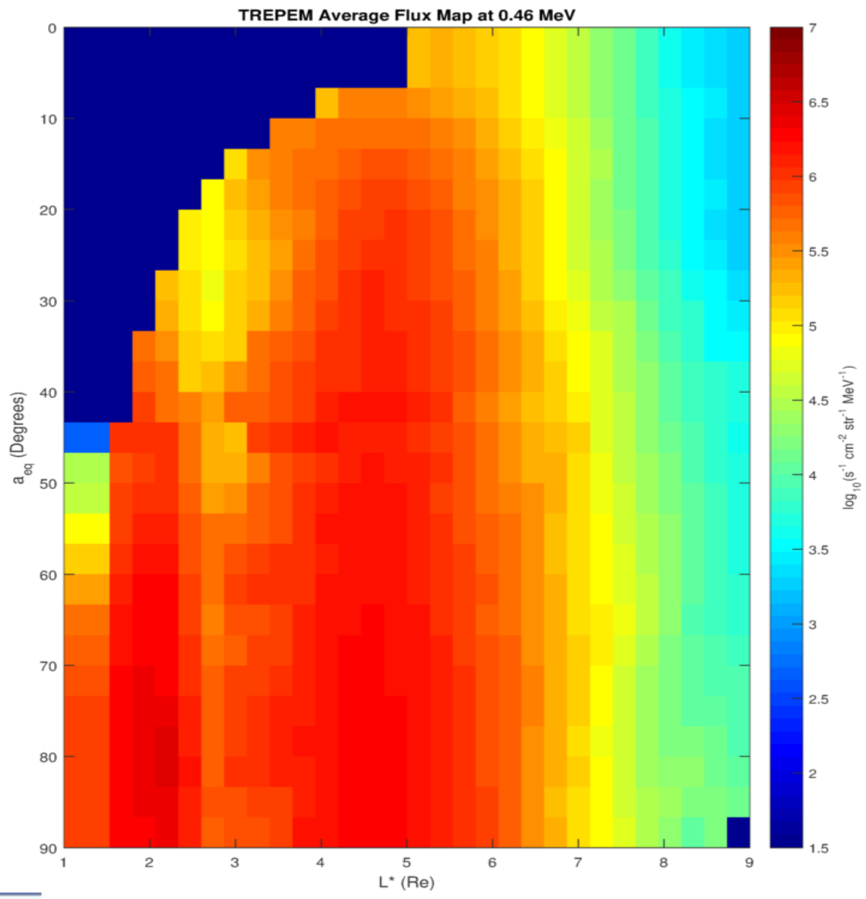


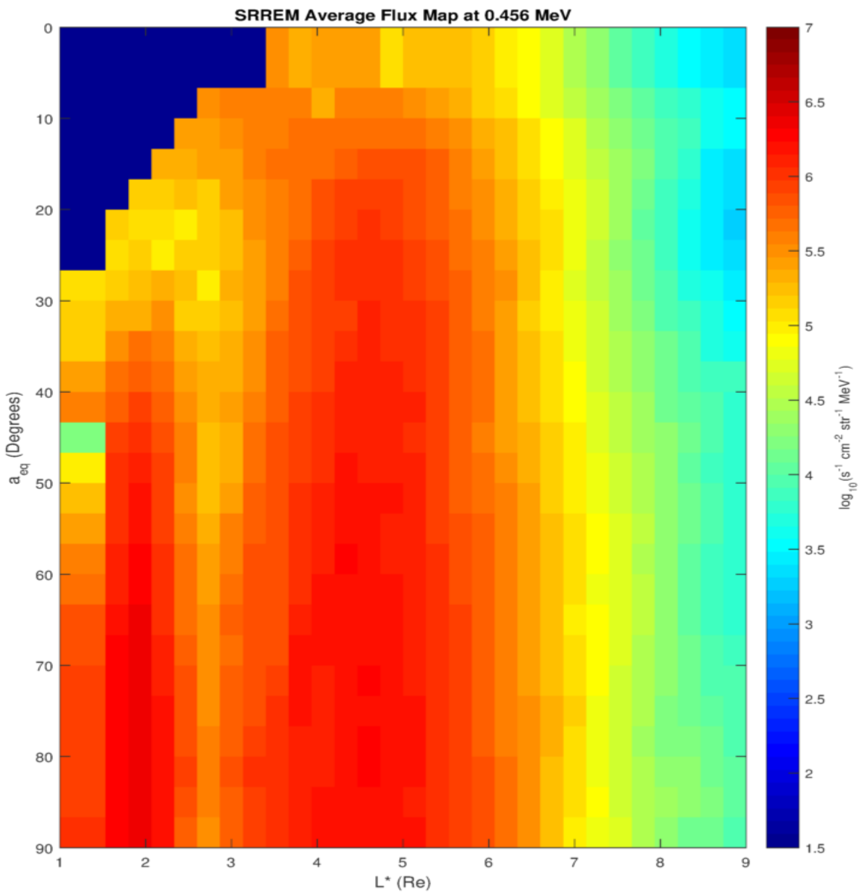


TREPEM

SRREMs

0.46 MeV





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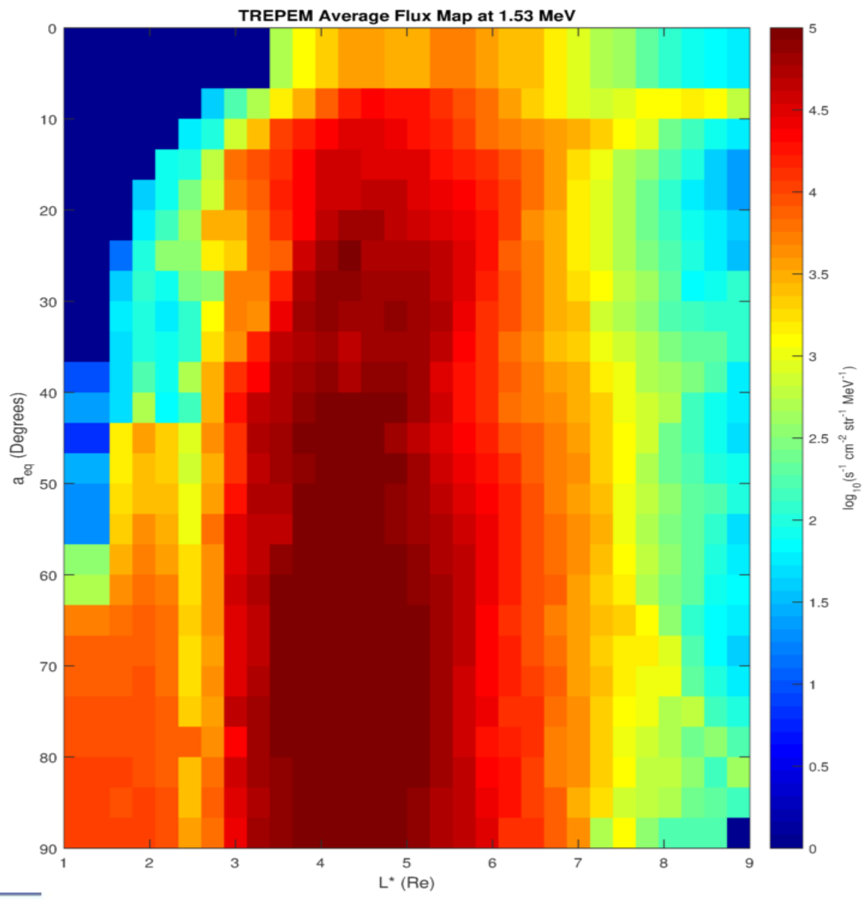
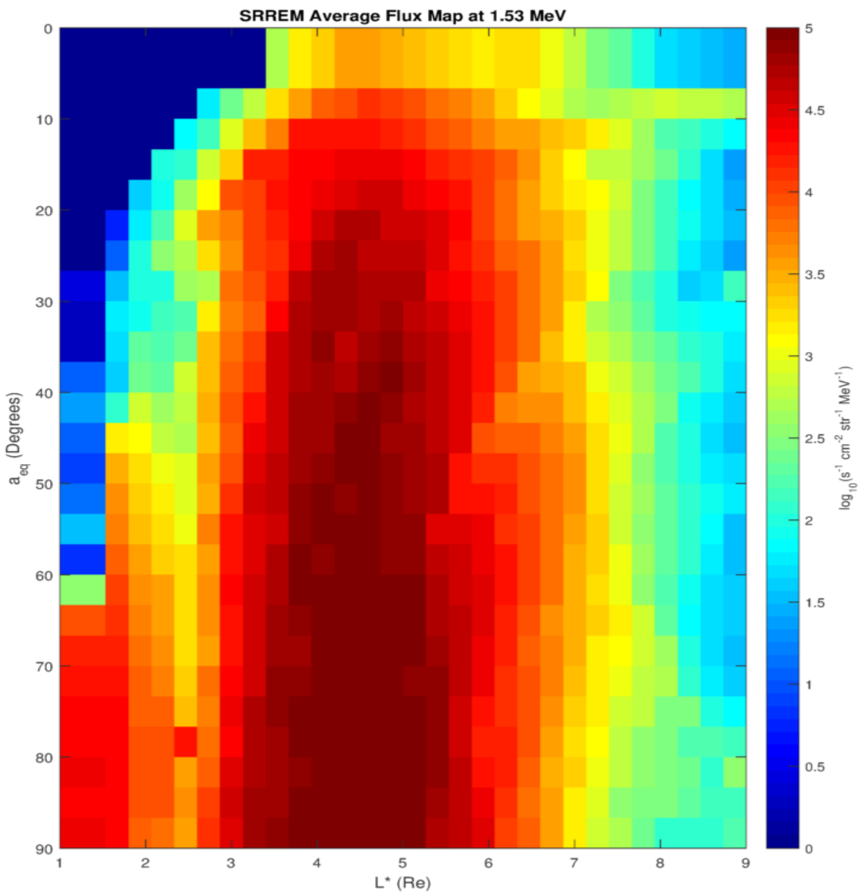
TREPEM
SRREMs

1.53 MeV

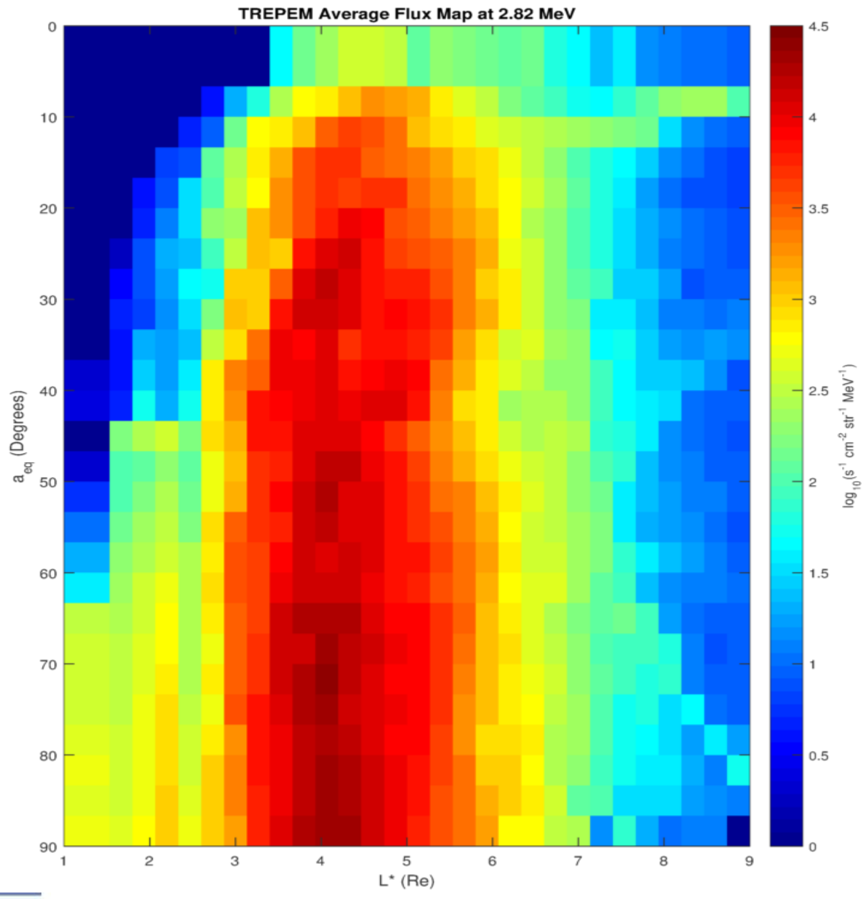


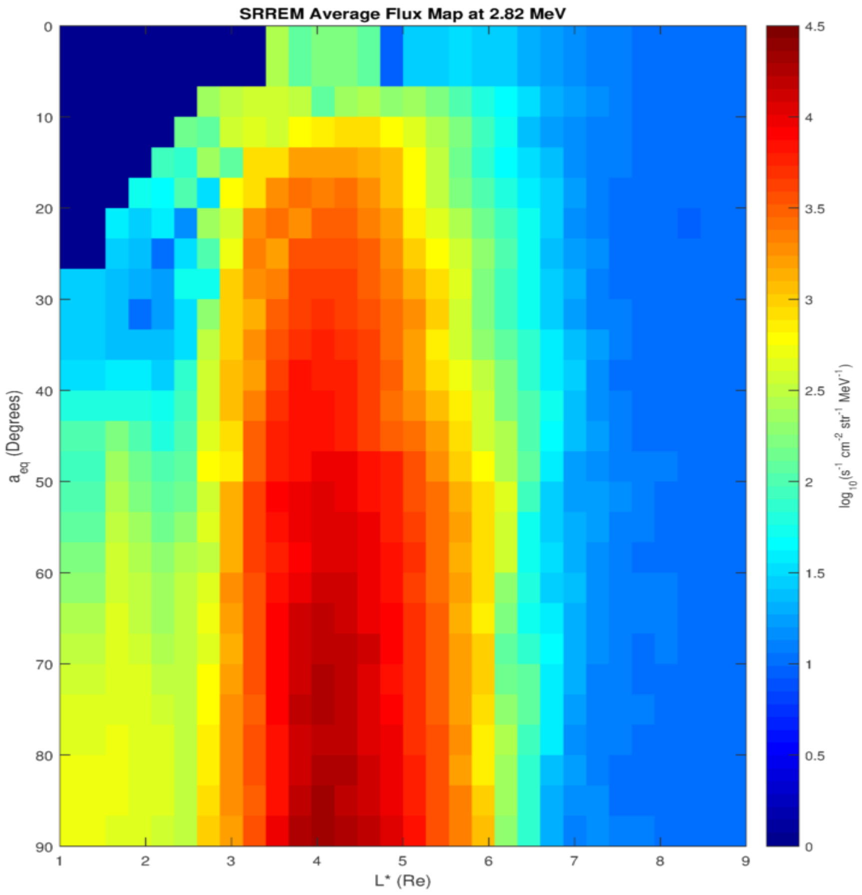


TREPEM

SRREMs

2.82 MeV





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Virtual Timelines Model (updates)

SEPEM esa

- **Routines of the VTM code were restructured resulting in the decrease of processing time by 3 times!**
- **VTM code was reconstructed to provide Spectral VTM outputs**

Virtual Timeline Model	Spectral Virtual Timeline Model
• For each energy – Impose lower limit – Get significant events for this energy – Apply Virtual Timeline – Get Output • Put all outputs together • Receive spectral (possible inconsistent) outputs	• Choose ONE energy/channel E_{VT} • Impose lower limit • Find significant events • Apply Virtual Timeline, VT • Keep the same VT and get outputs for **ALL** energies BELOW < E_{VT} • Receive spectral consistent outputs for **$E \leq E_{VT}$**

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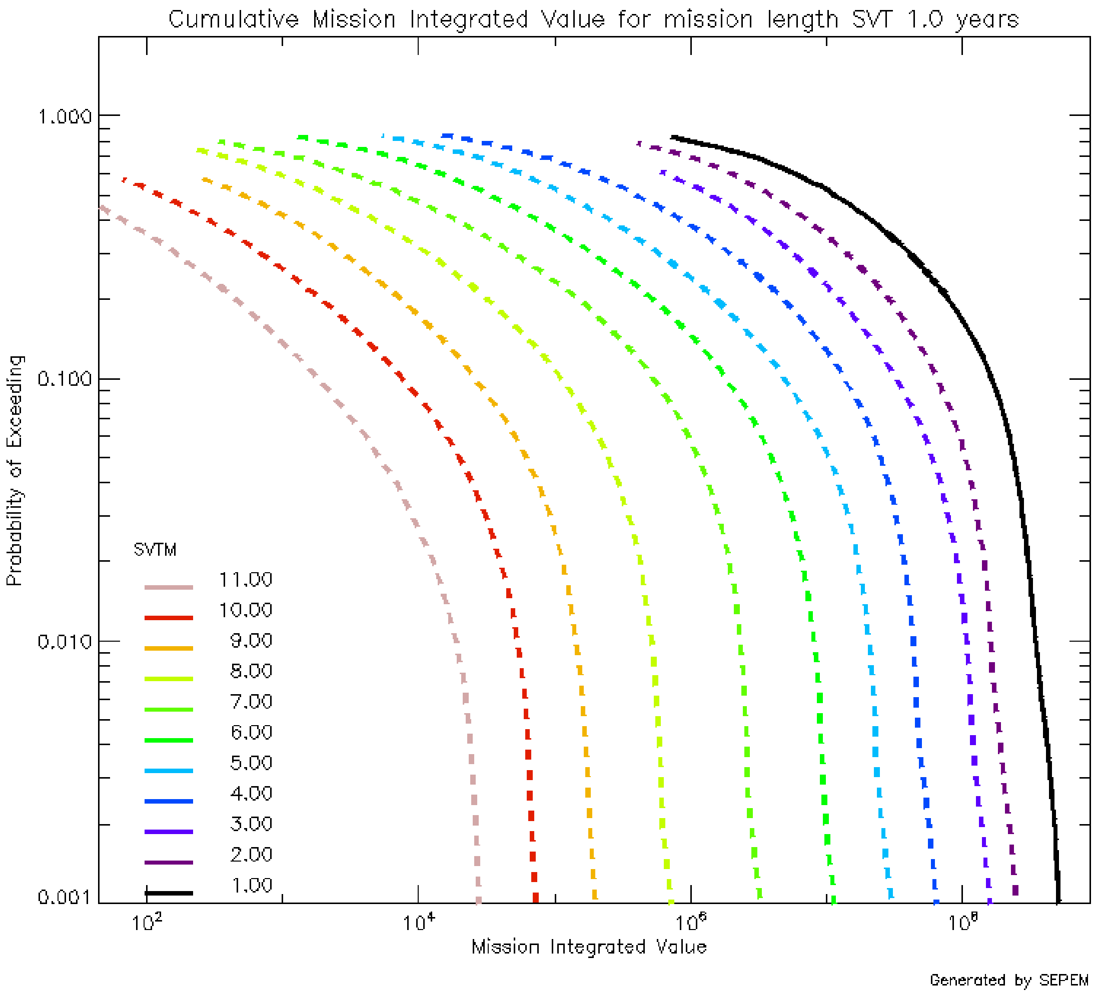
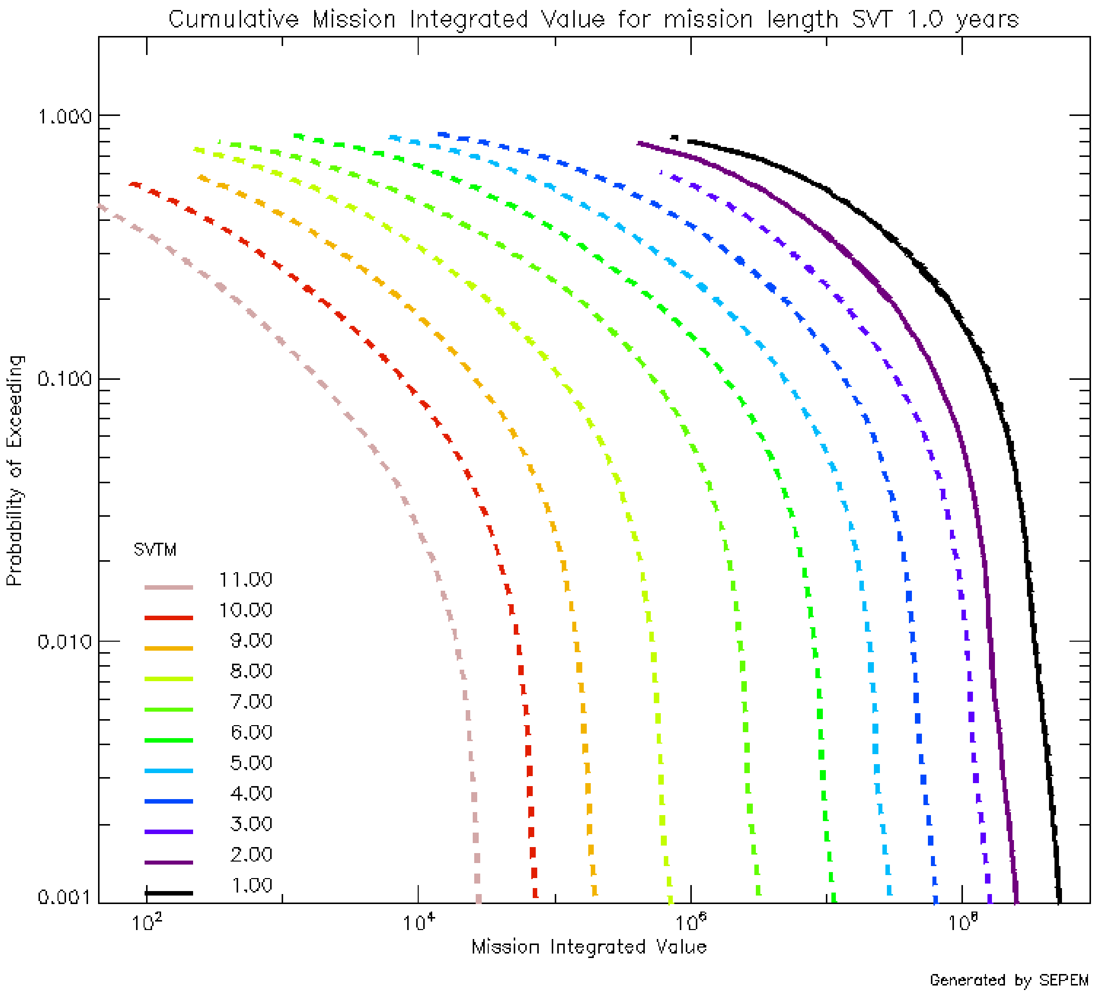
SVTM



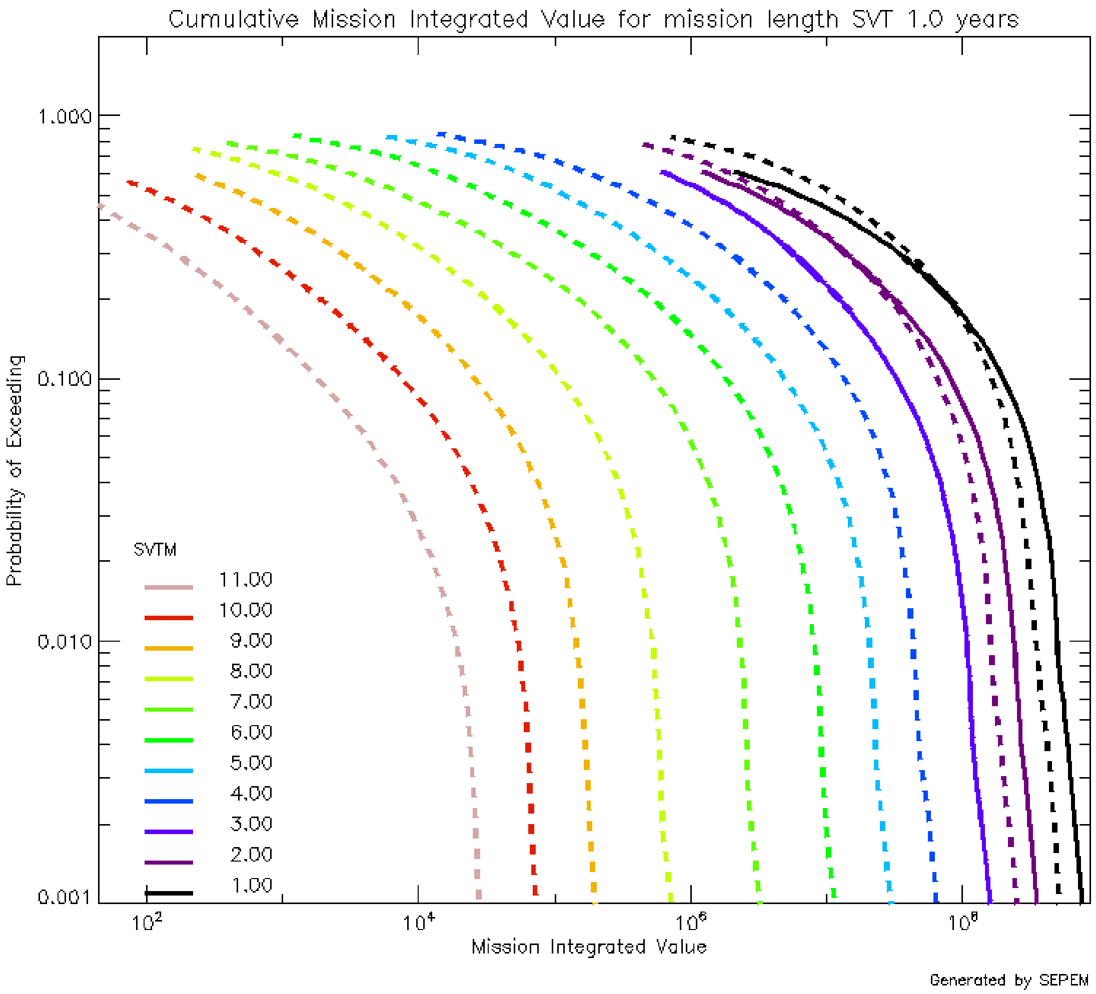
RDS 2.0: Cumulative Fluence

SVTM



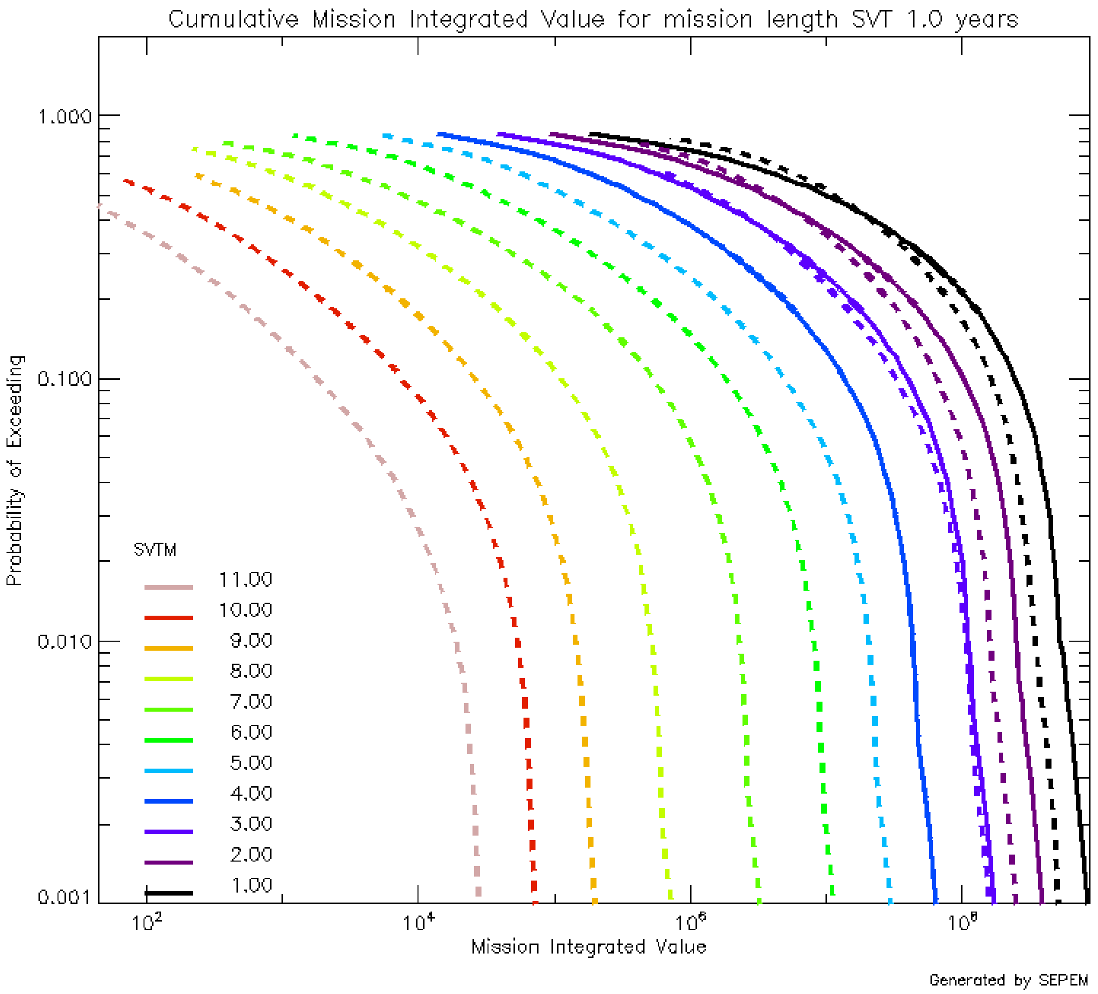
RDS 2.0: Cumulative Fluence

SVTM



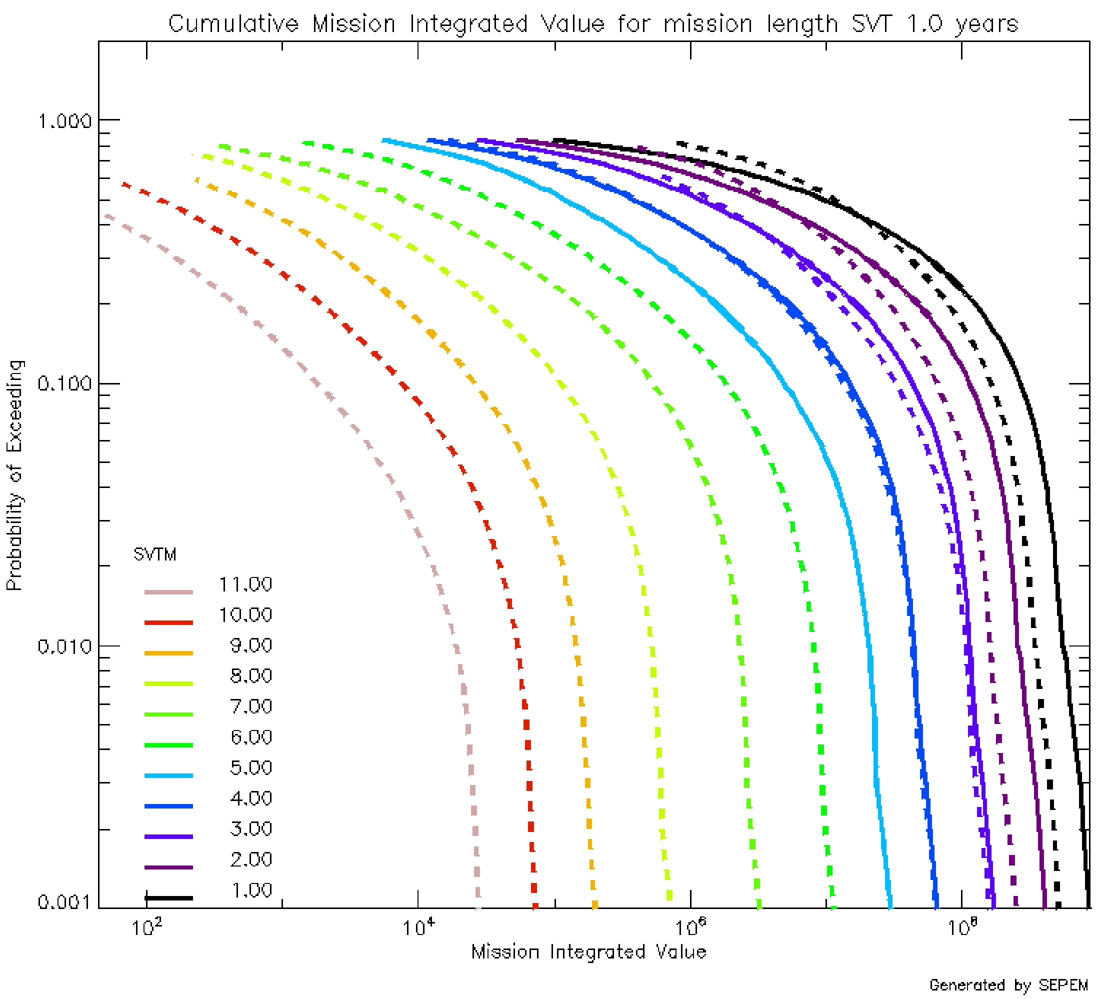
RDS 2.0: Cumulative Fluence

SVTM



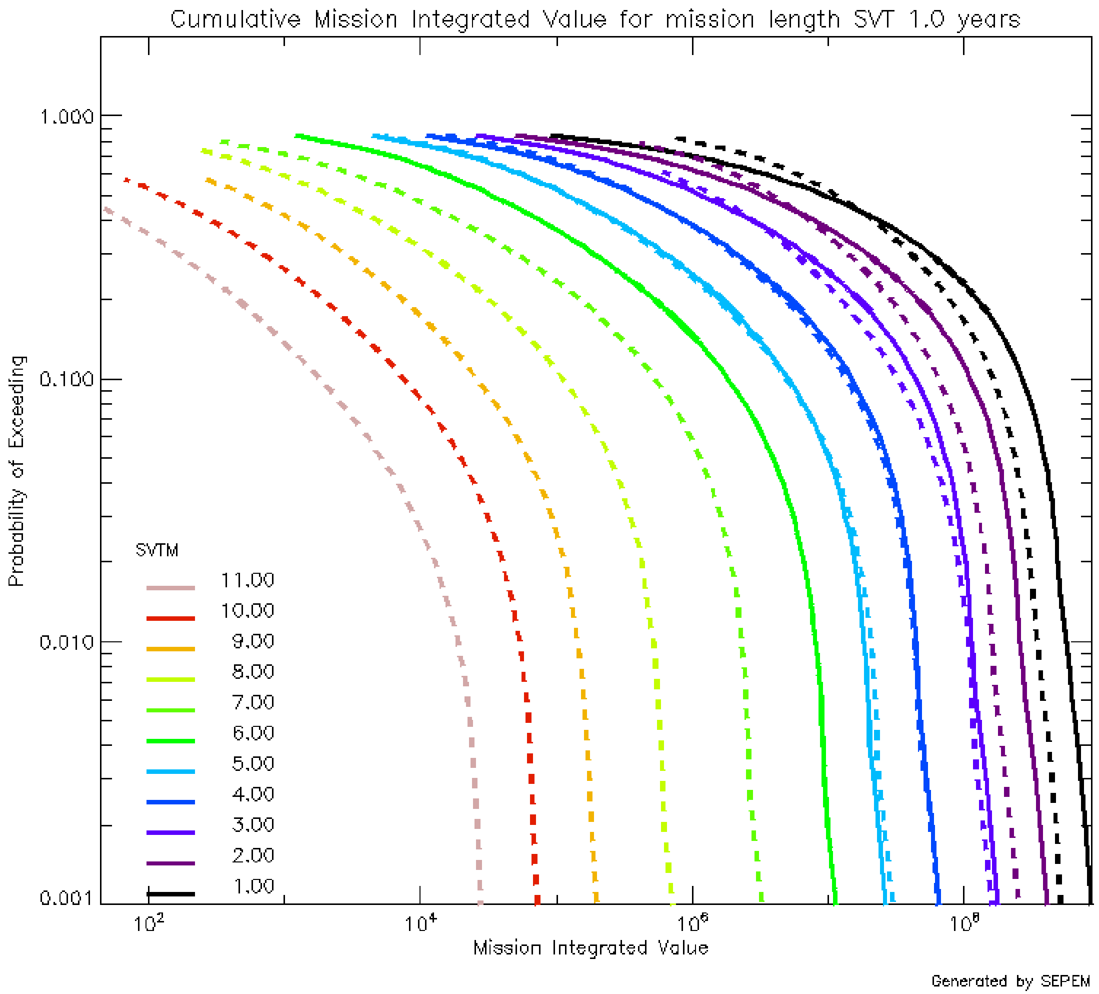
RDS 2.0: Cumulative Fluence

SVTM



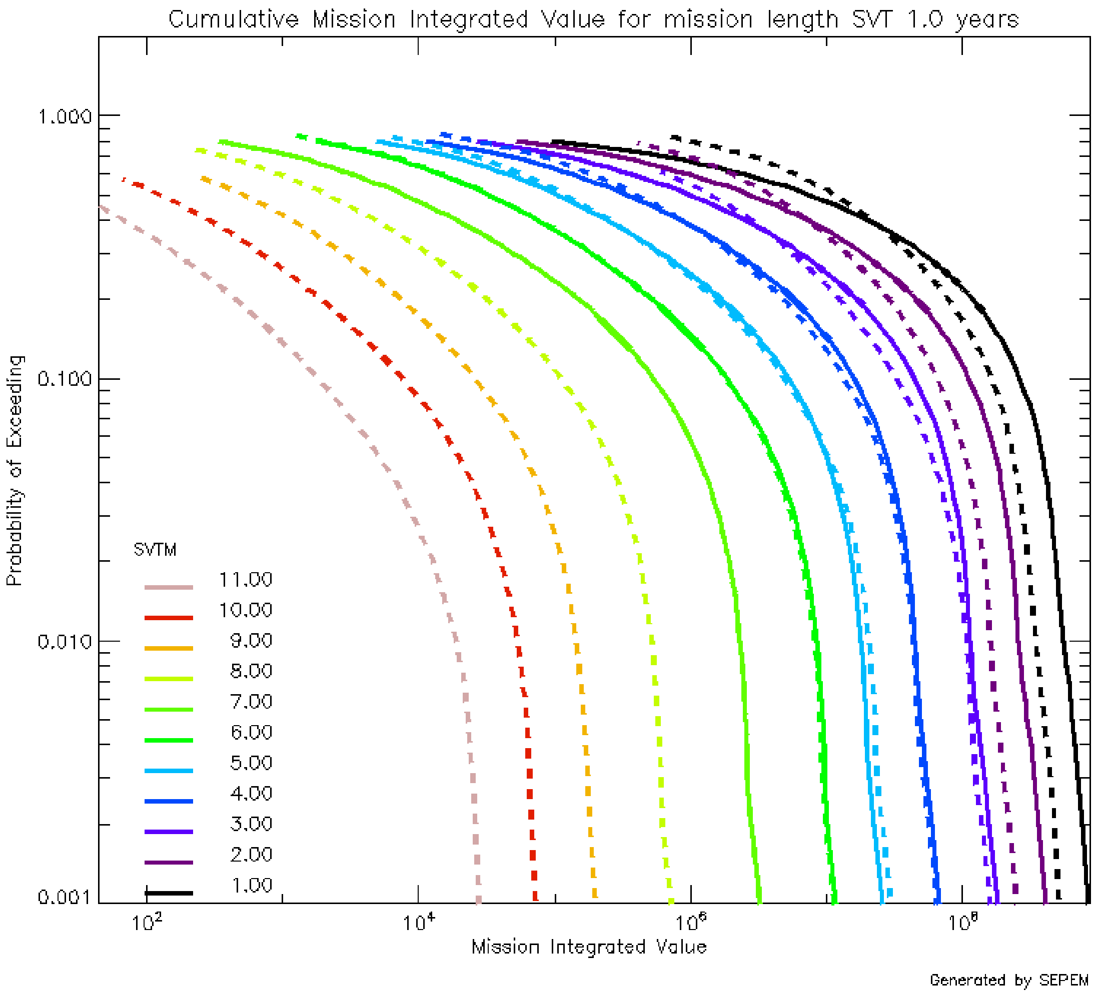
RDS 2.0: Cumulative Fluence

SVTM



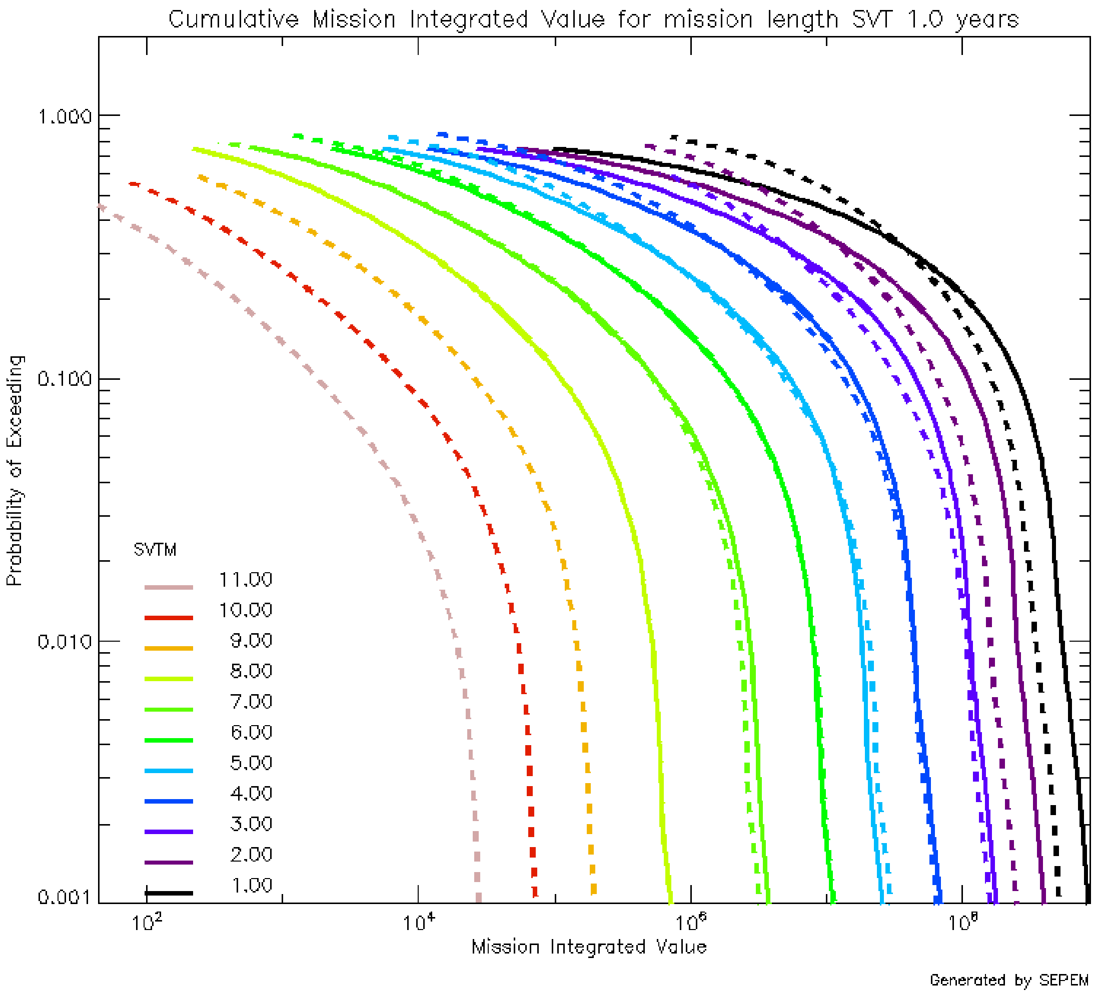
RDS 2.0: Cumulative Fluence

SVTM



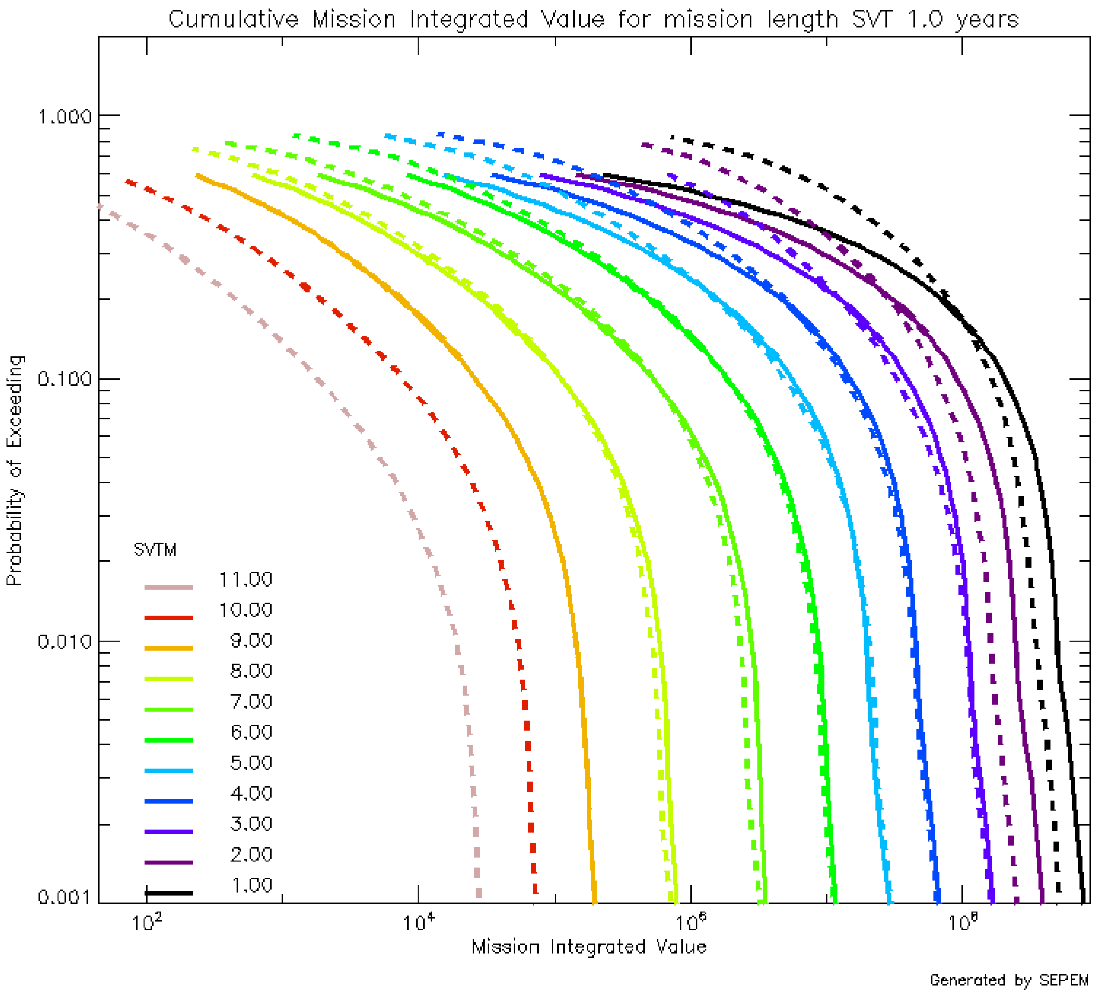
RDS 2.0: Cumulative Fluence

SVTM



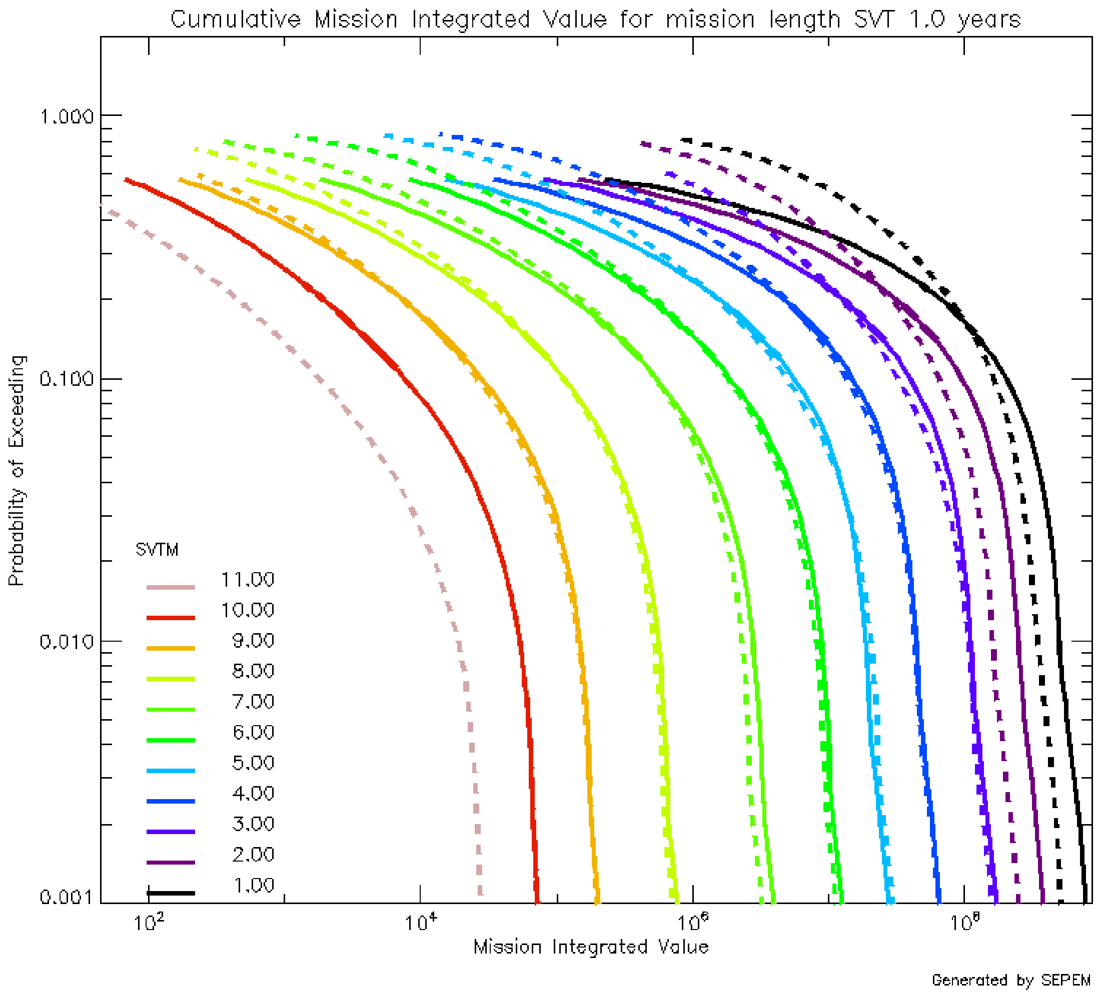
RDS 2.0: Cumulative Fluence

SVTM



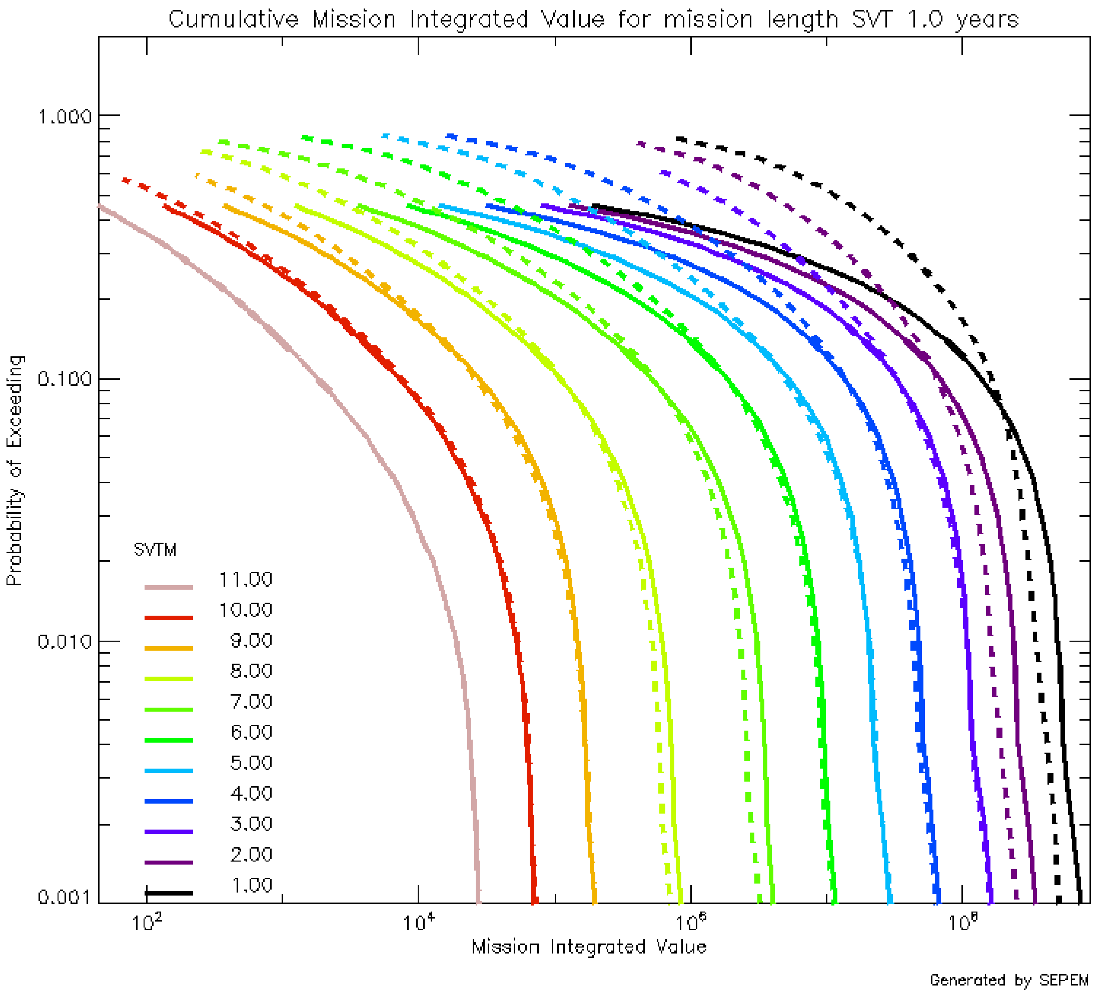
RDS 2.0: Cumulative Fluence

SVTM



RDS 2.0: Cumulative Fluence

SVTM

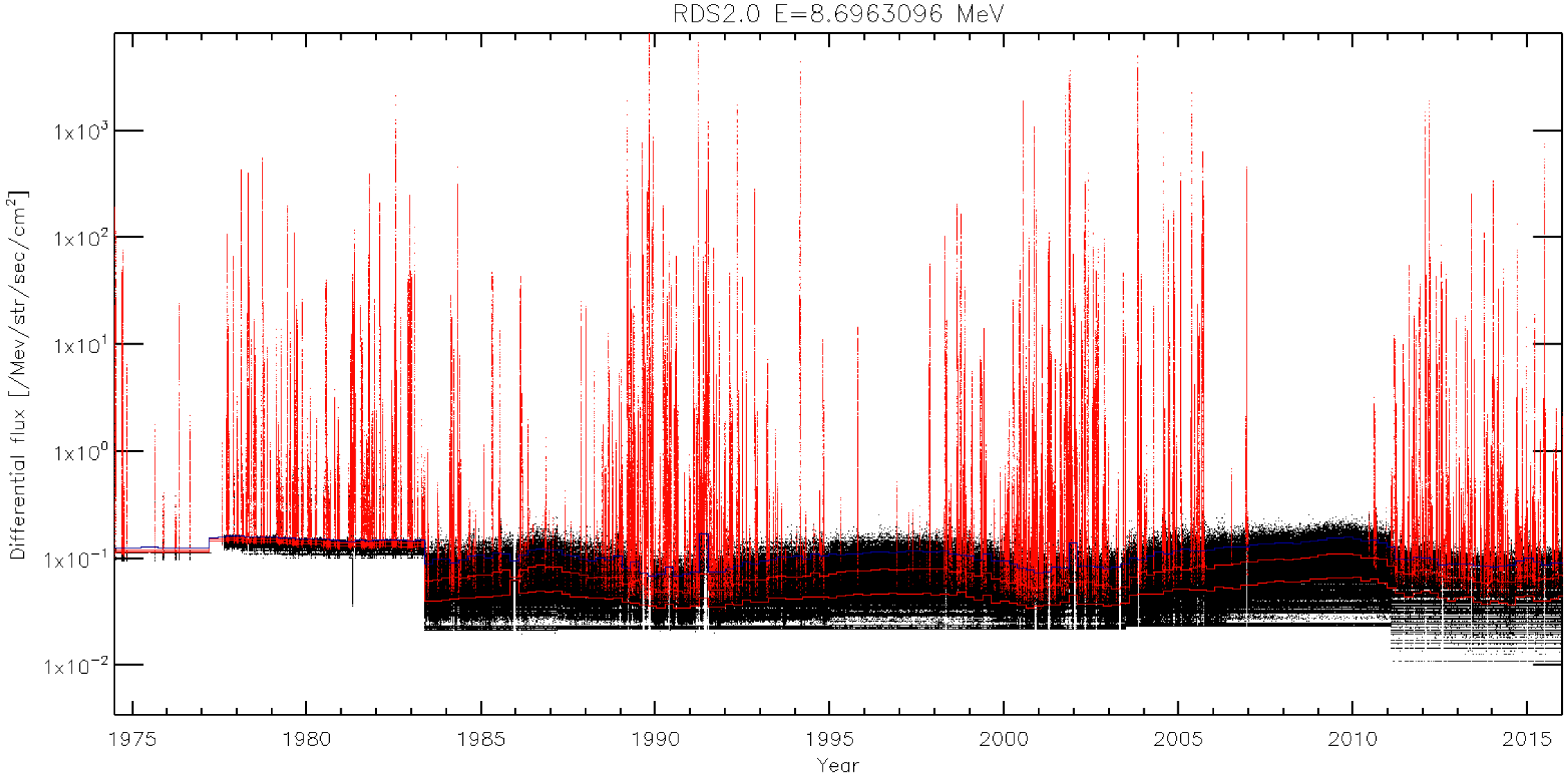


RDS 2.0: Cumulative Fluence

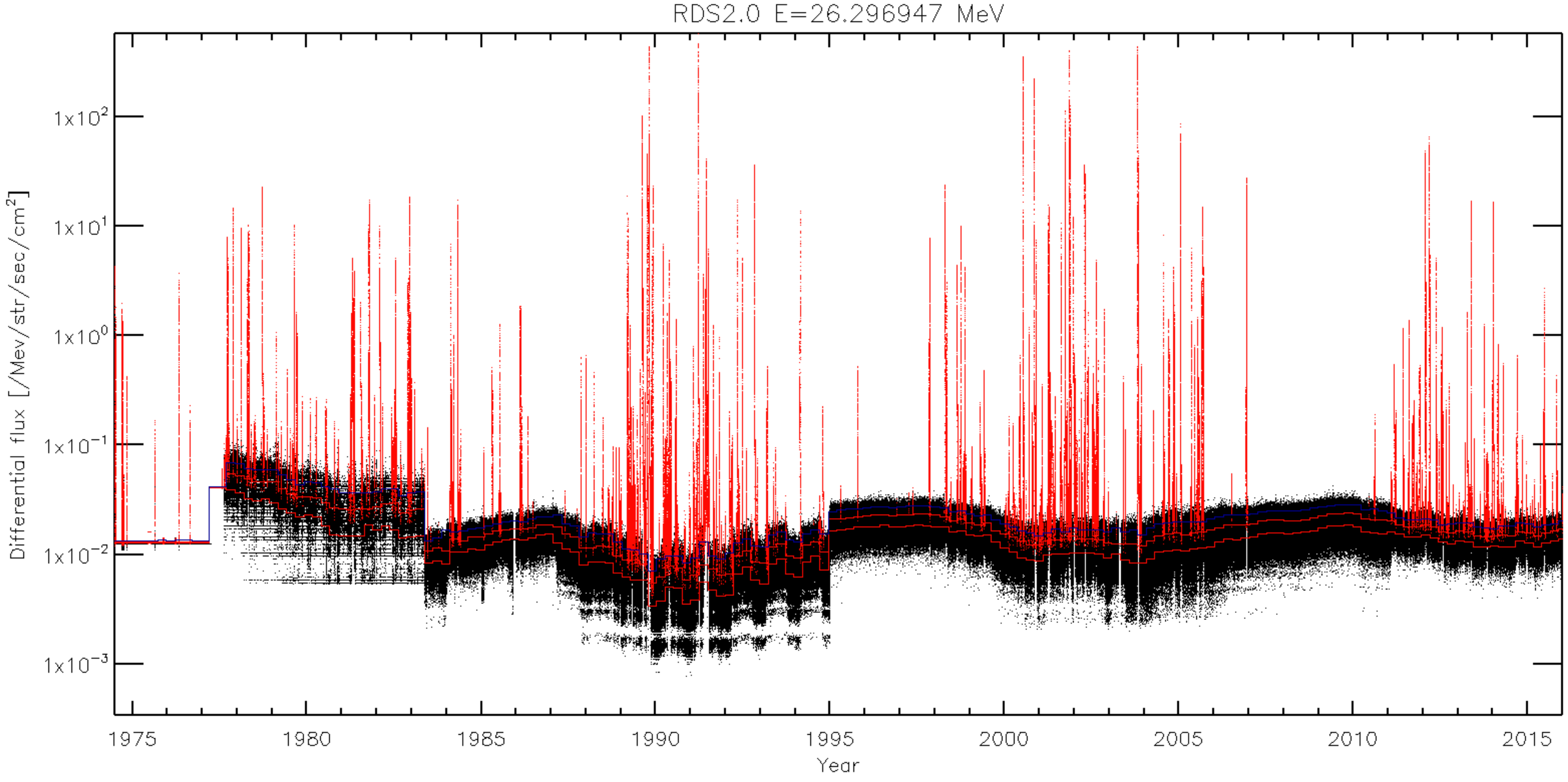
Update SPE database & event list

- Evaluate ESA SEPEM Reference Data Set 2.x
  - Test different background schemes
- Evaluate VTM outputs:
  - Use STEREO data
  - Different SPE lists
  - Different database

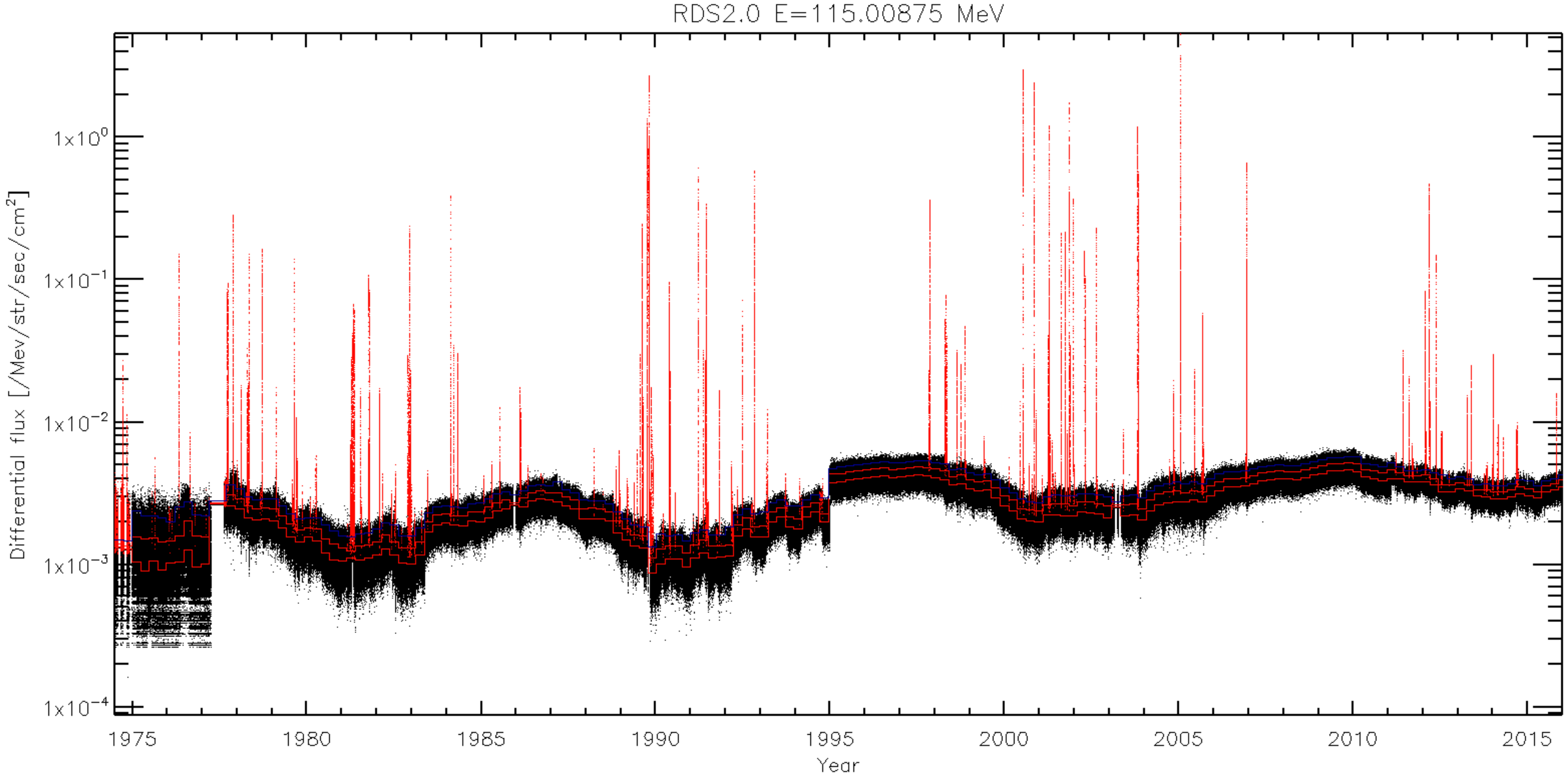
RDS2.0: signal extraction



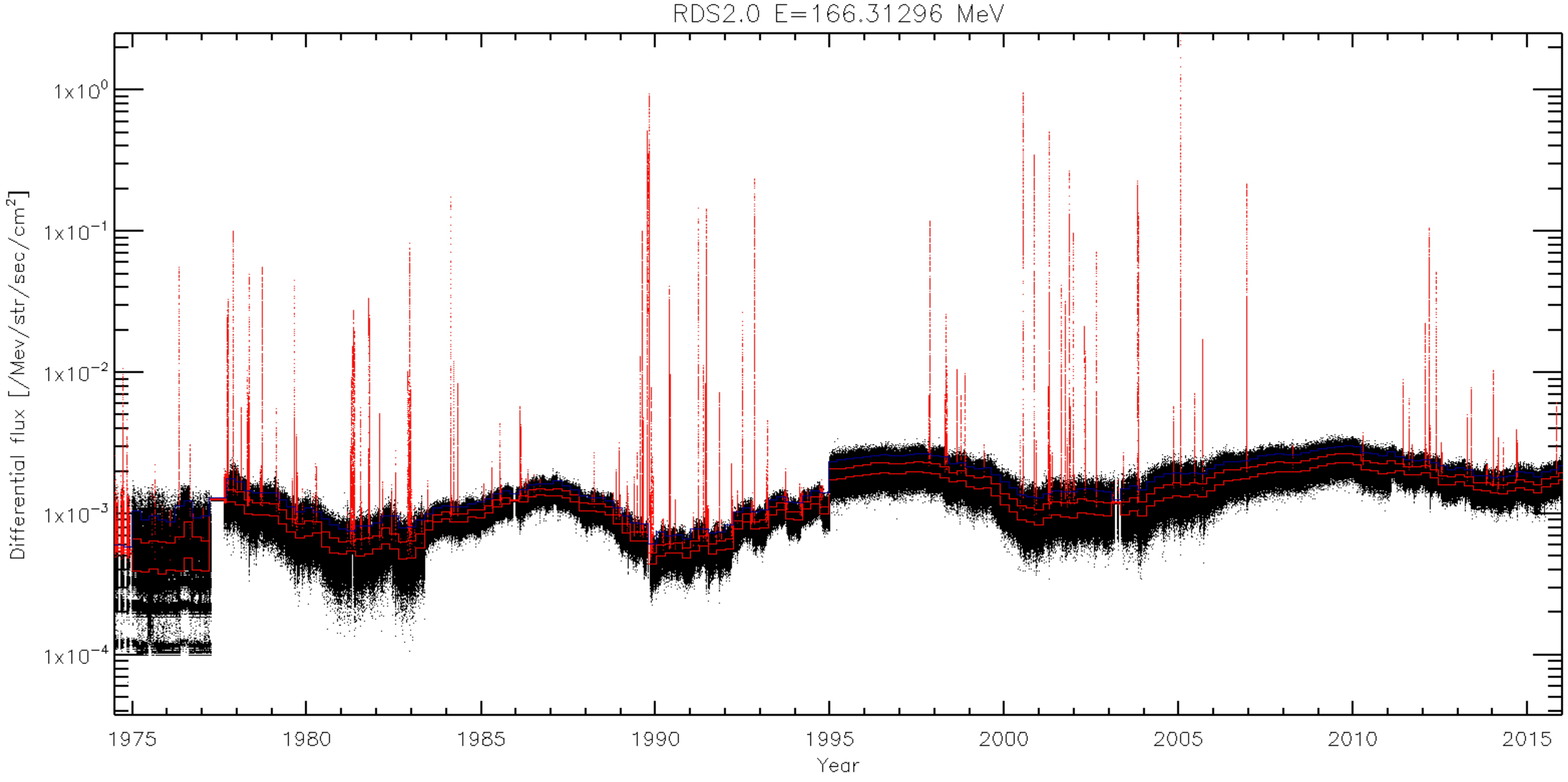
RDS2.0: signal extraction



RDS2.0: signal extraction

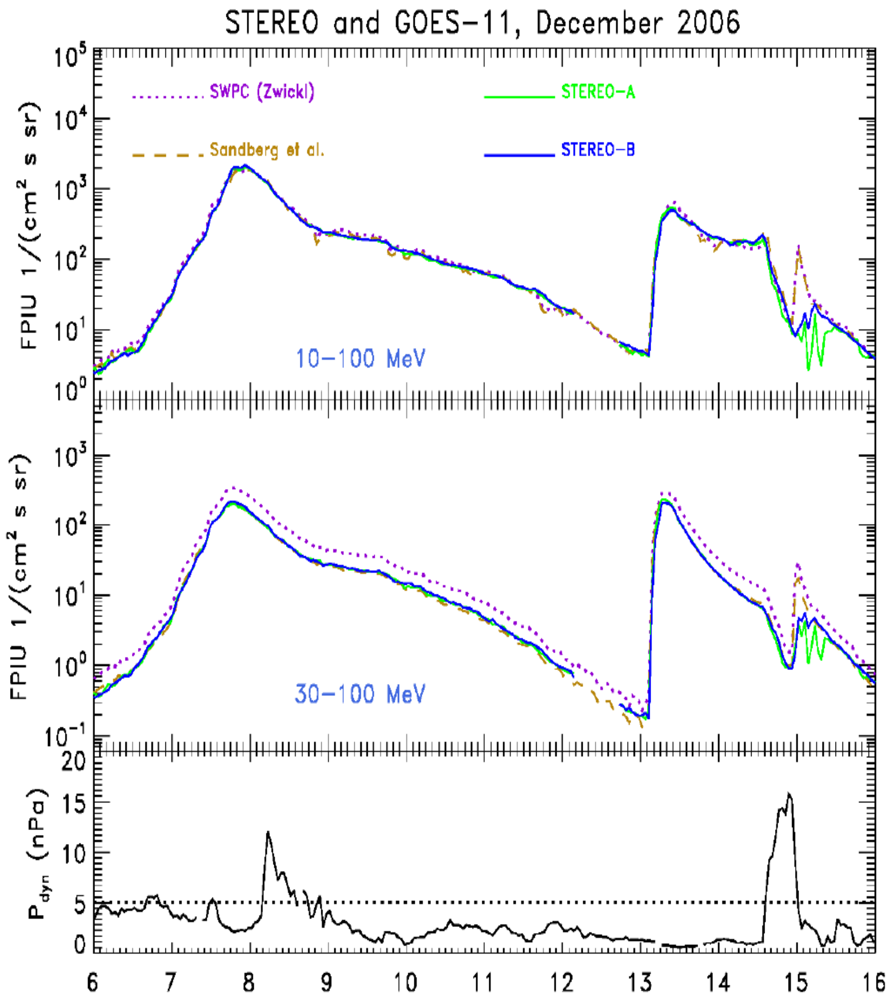


RDS2.0: signal extraction



Evaluation of ESA RDS2.0

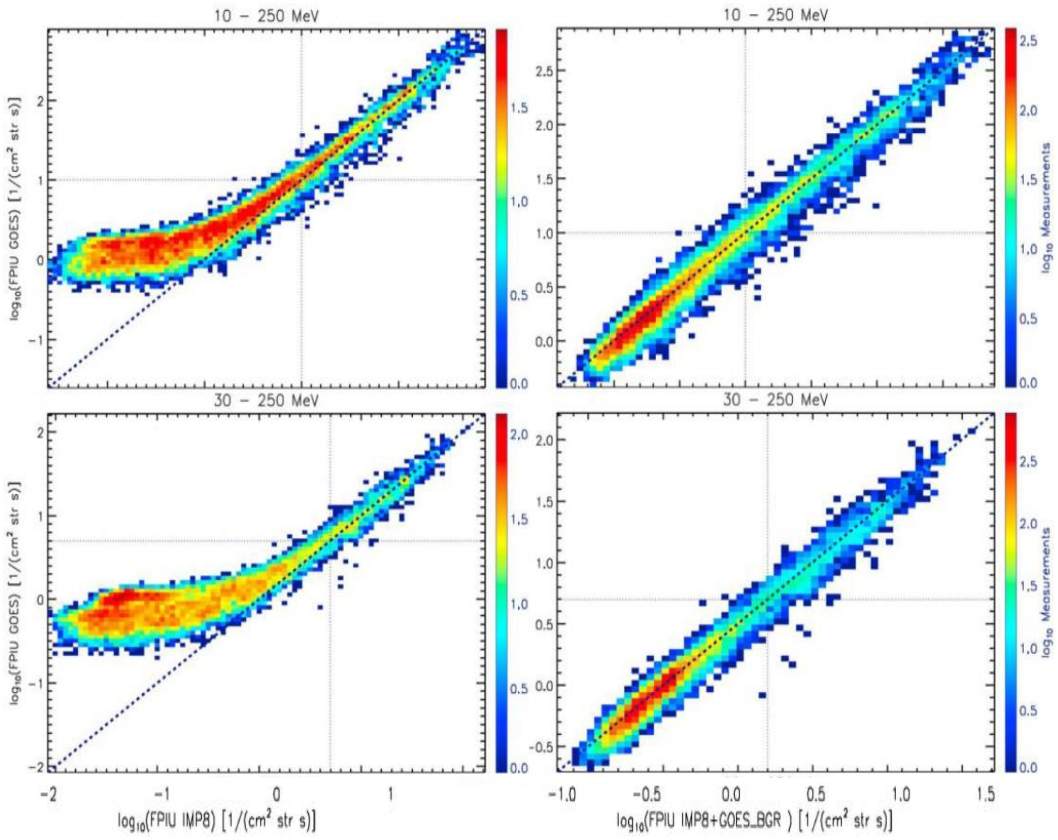
- Reconstruct RDS 2.0
- Create iRDS 2.0
- Validate iRDS 2.0



J. V. Rodriguez, I. Sandberg, et al, Space Weather, 15, (2017)

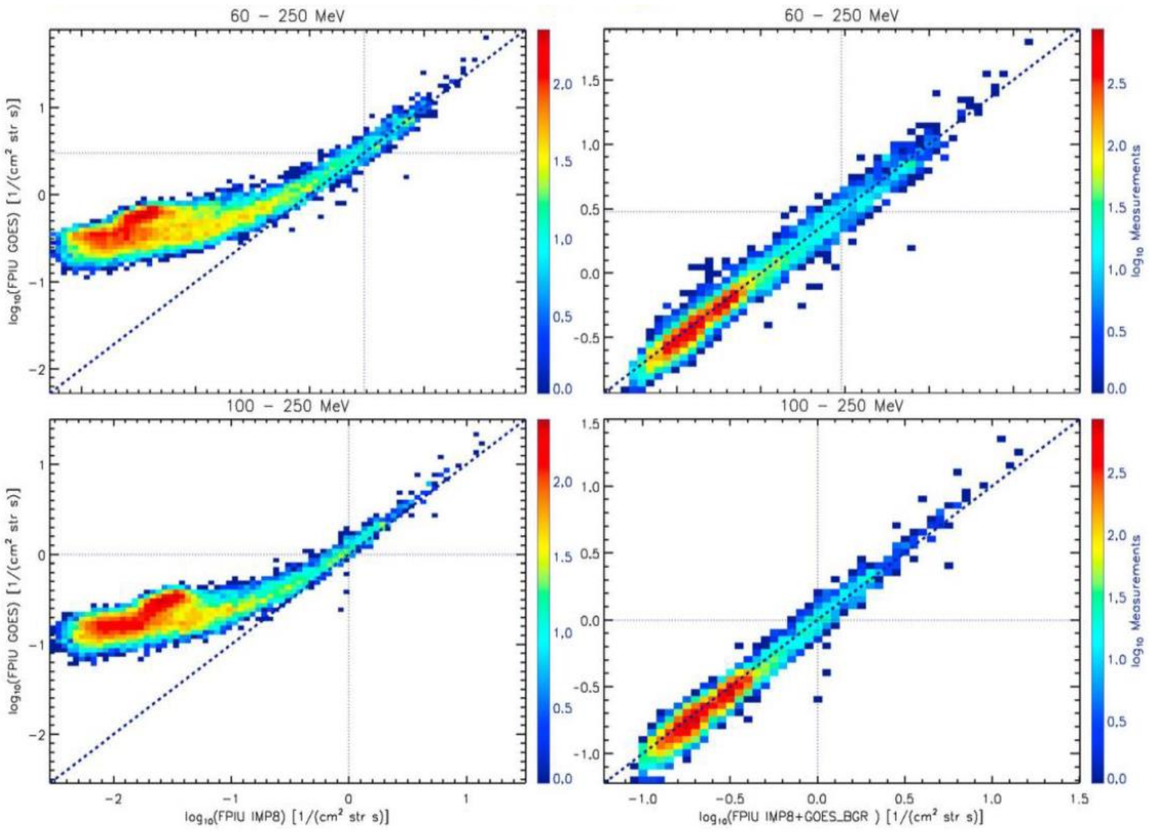
Evaluation of ESA iRDS2.0

iRDS 2.0



IMP-8 IMP-8+iRDS$_{bgr}$(t)

iRDS 2.0



IMP-8 IMP-8+iRDS$_{bgr}$(t)

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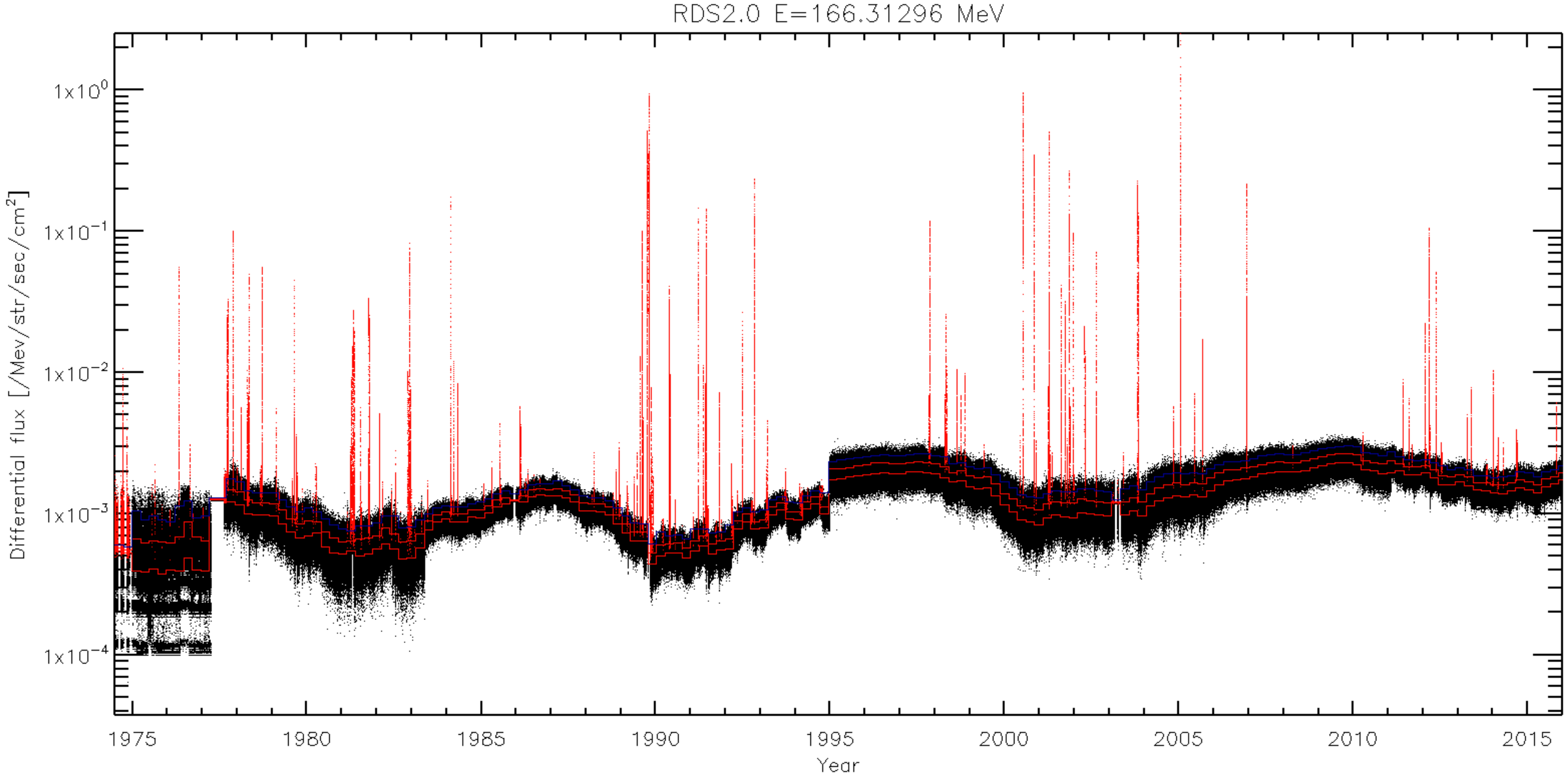
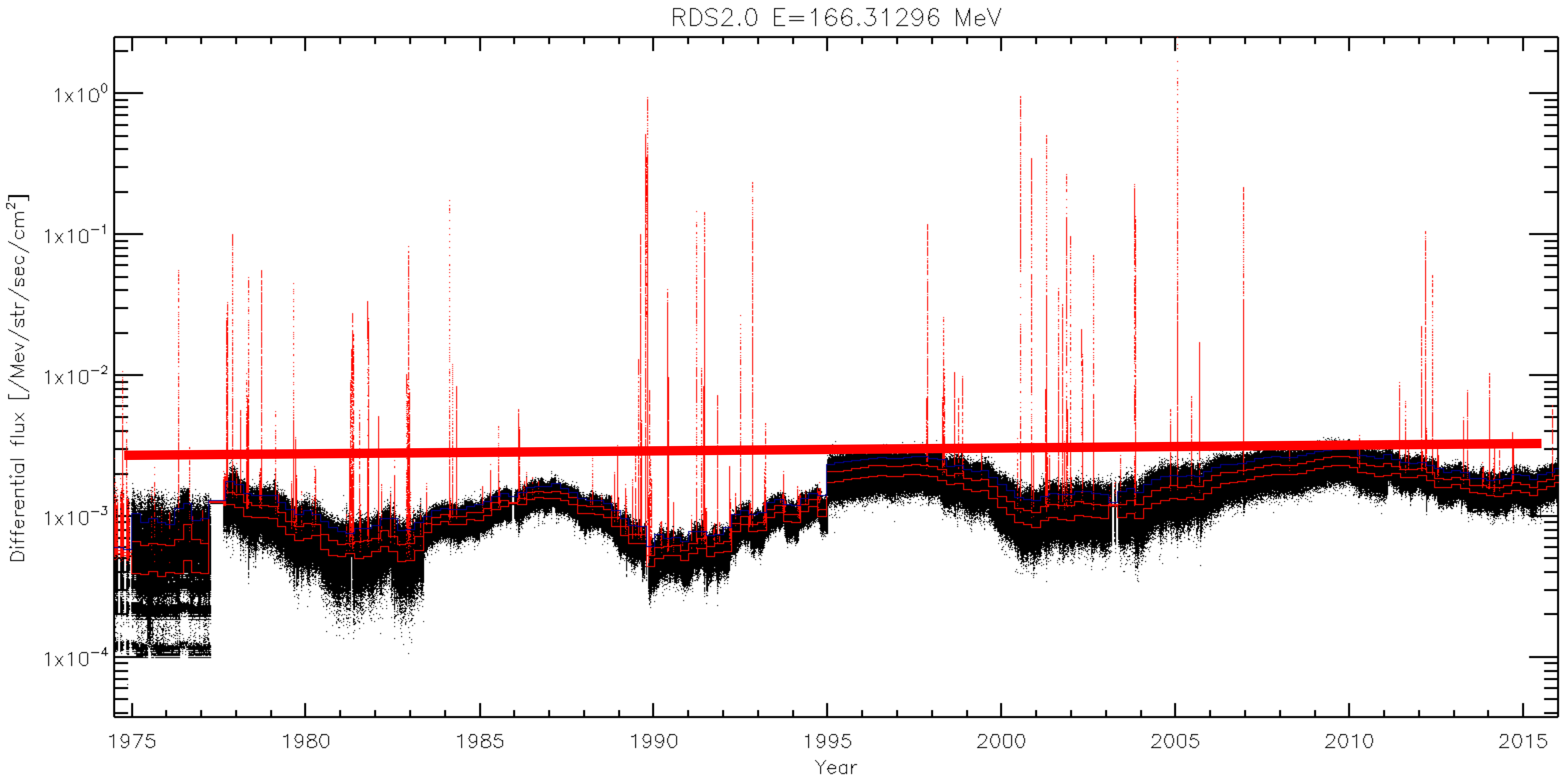
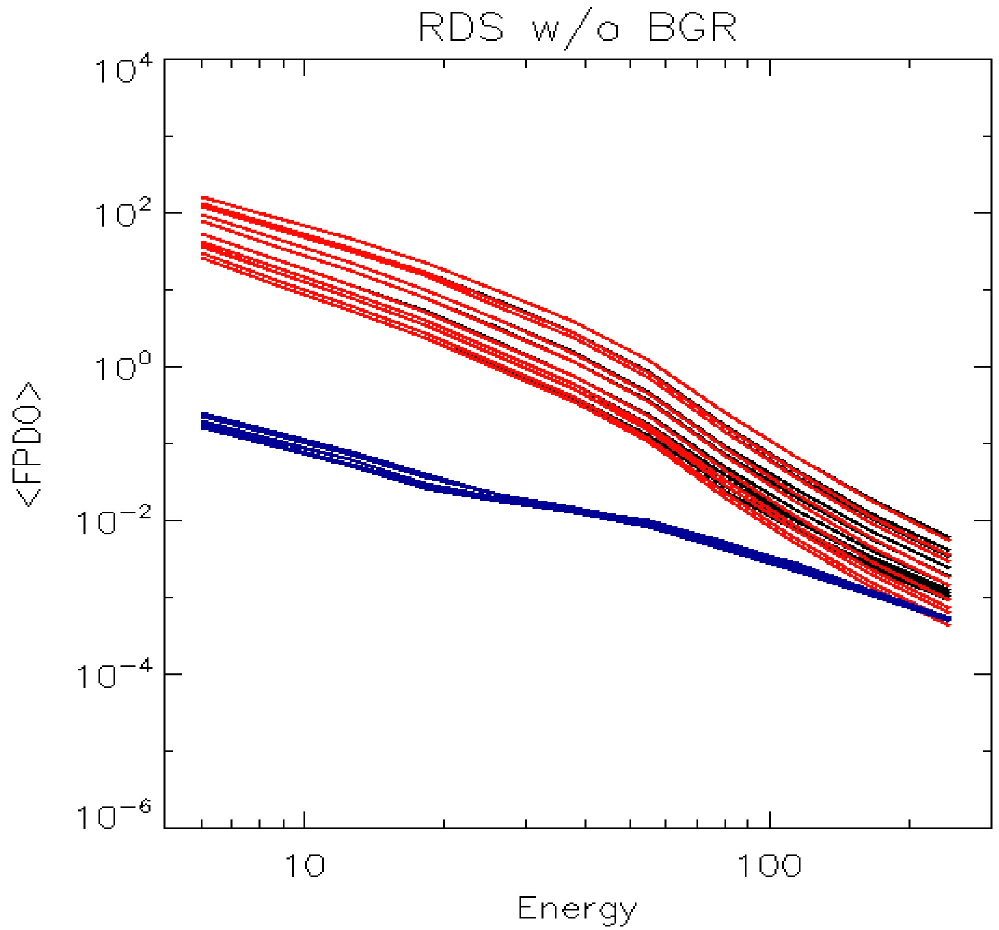
Background: RDS2.1s



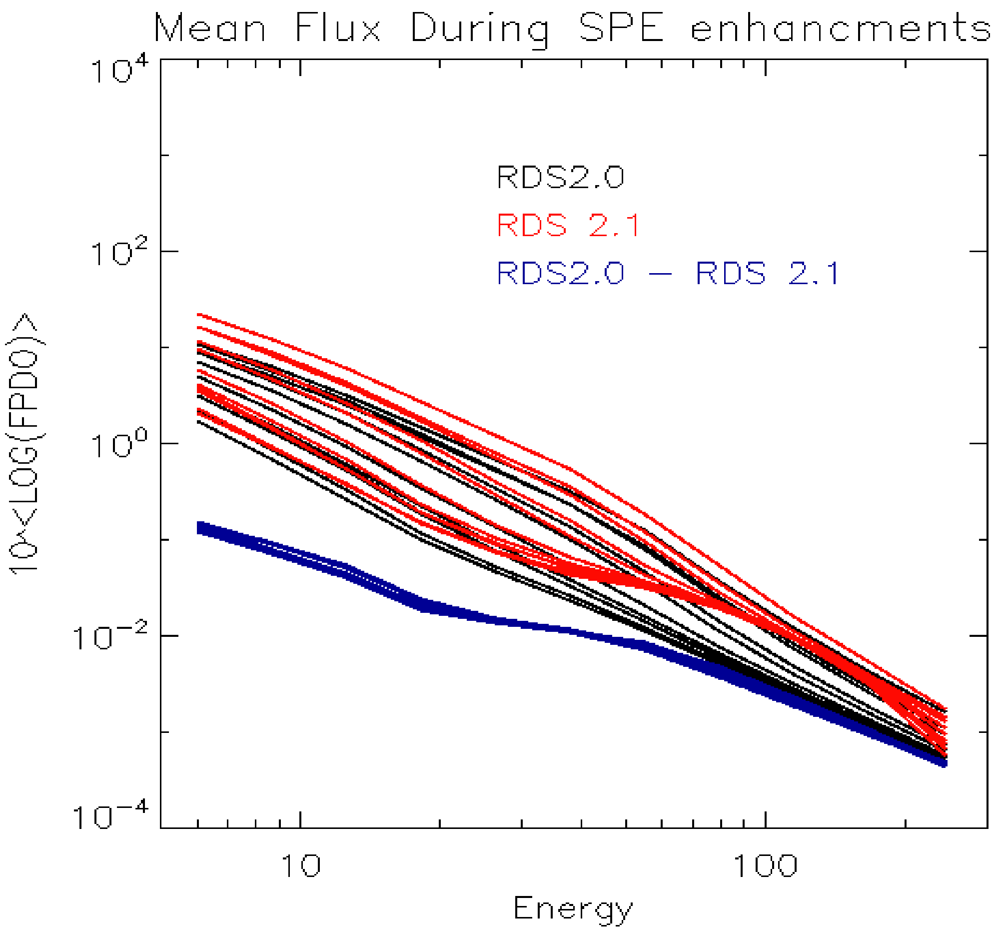
Background: RDS2.2s



RDS 2.1

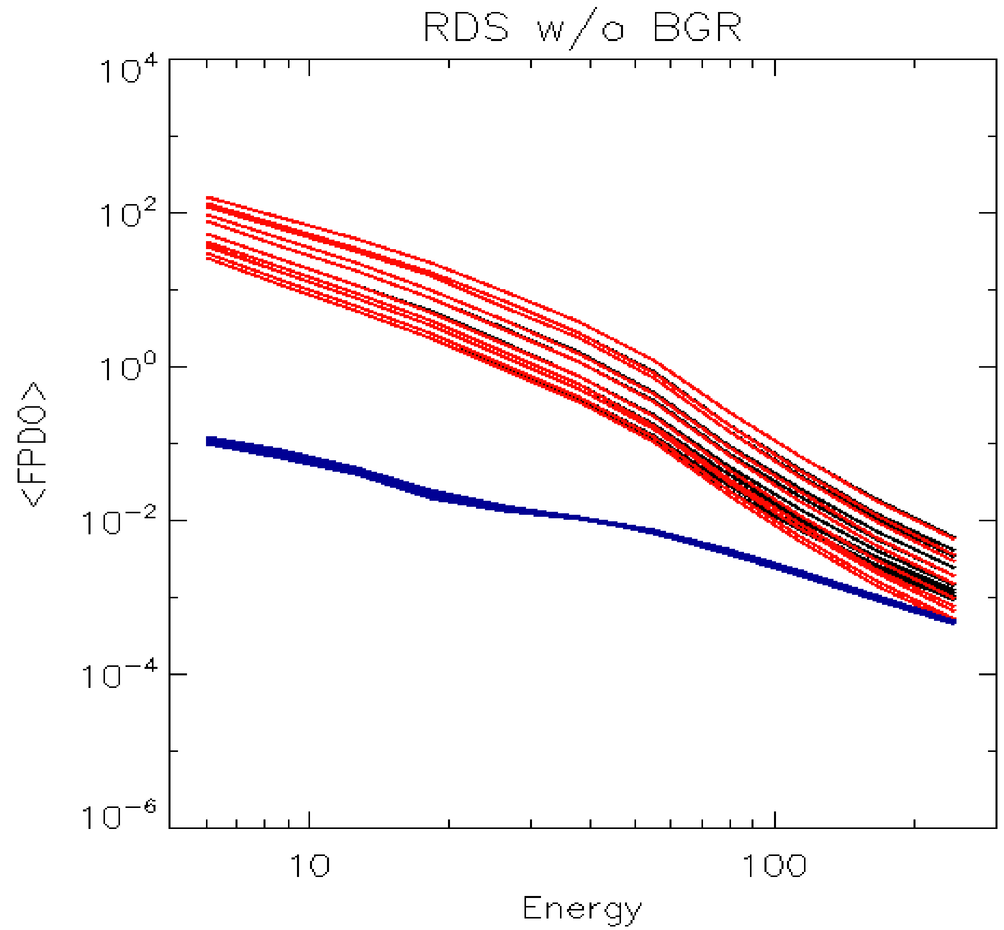


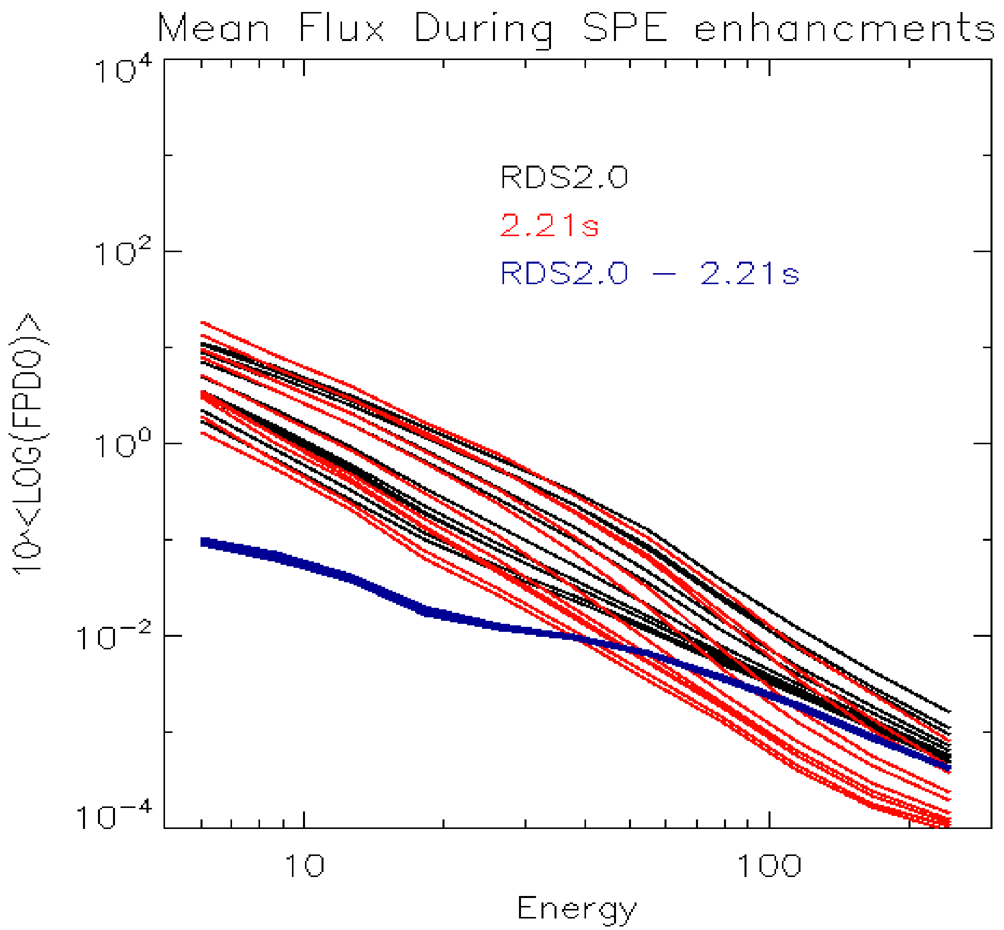
RDS w/o BGR
10^4
10^2
10^0
10^-2
10^-4
10^-6
<FPDO>
10
100
Energy



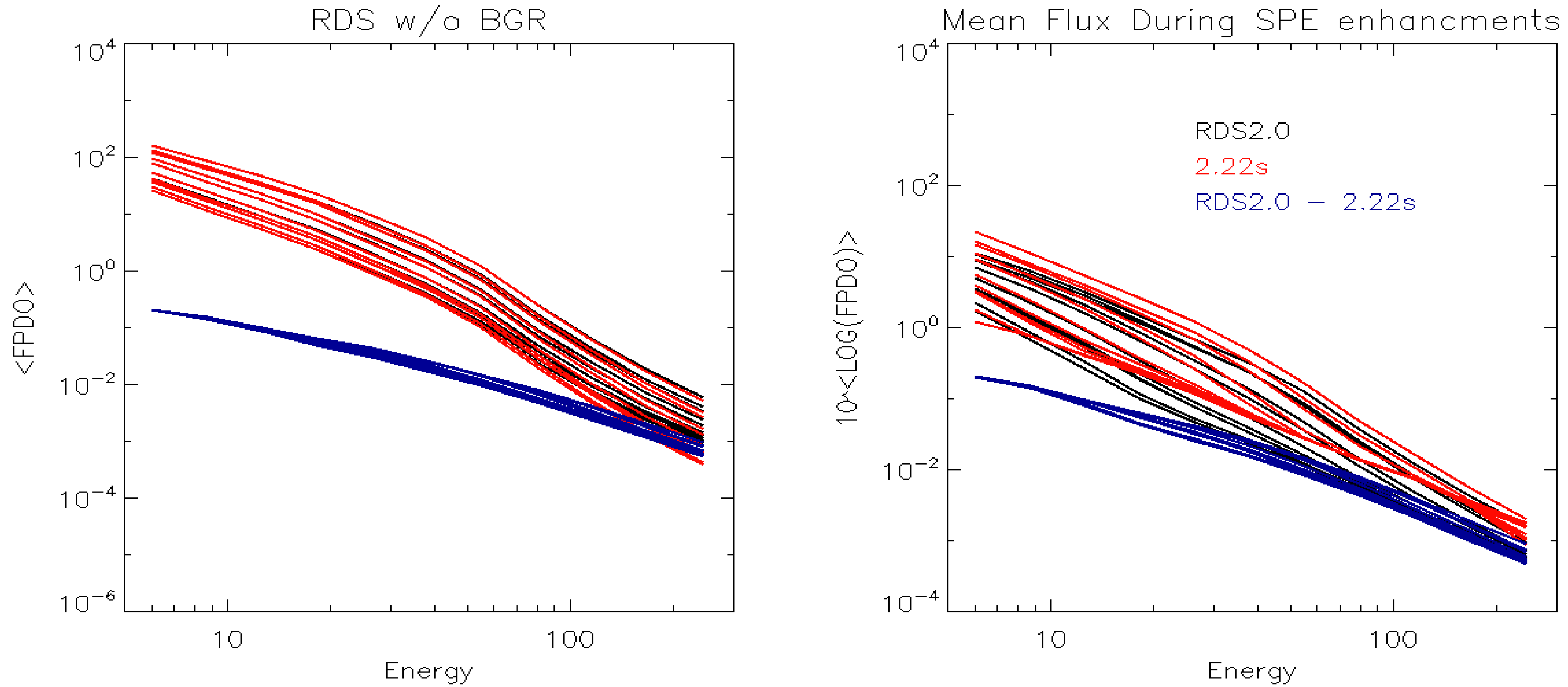
Mean Flux During SPE enhancments
RDS2.0
RDS 2.1
RDS2.0 – RDS 2.1
10^4
10^2
10^0
10^-2
10^-4
10^<LOG(FPDO)>
10
100
Energy

RDS 2.21s

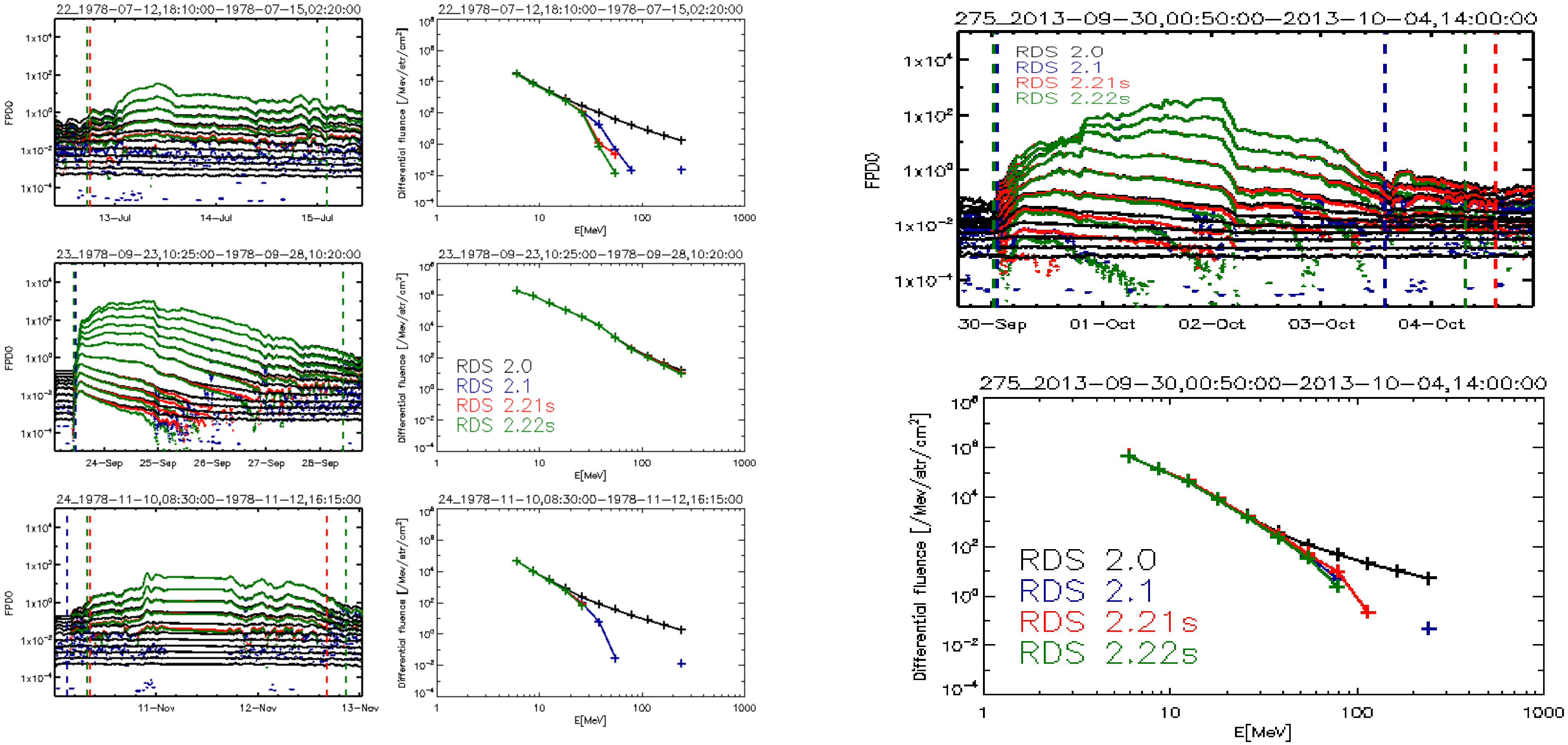

RDS w/o BGR
10^4
10^2
10^0
10^{-2}
10^{-4}
10^{-6}
<FPDO>
10
100
Energy


Mean Flux During SPE enhancments
RDS2.0
2.21s
RDS2.0 – 2.21s
10^4
10^2
10^0
10^{-2}
10^{-4}
10^<LOG(FPDO)>
10
100
Energy

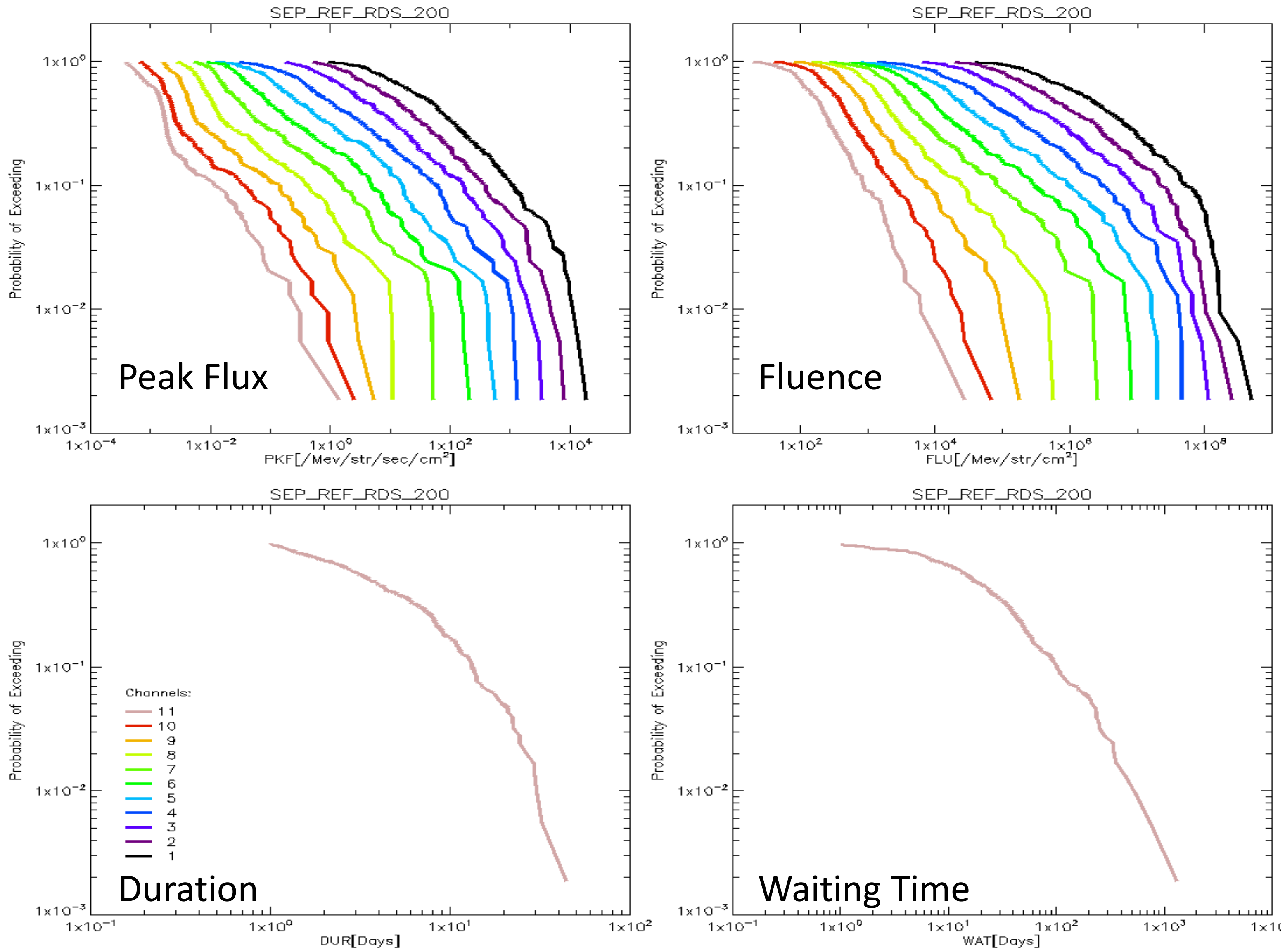
RDS 2.22s


RDS w/o BGR
<FPDO>
Energy
10
100
10^4
10^2
10^0
10^{-2}
10^{-4}
10^{-6}
Mean Flux During SPE enhancments
10^<LOG(FPDO)>
RDS2.0
2.22s
RDS2.0 – 2.22s

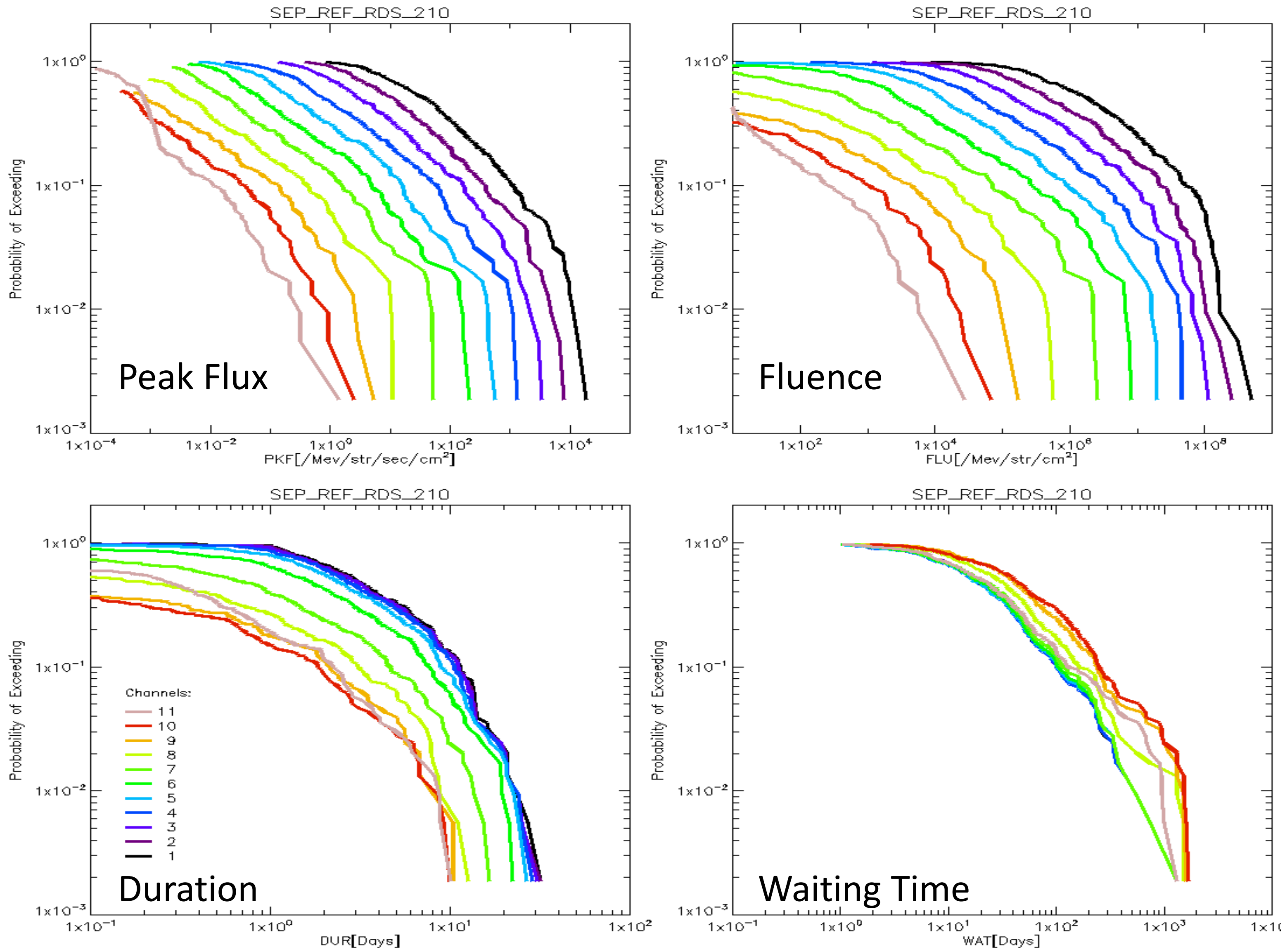
SPE spectrum w/o background



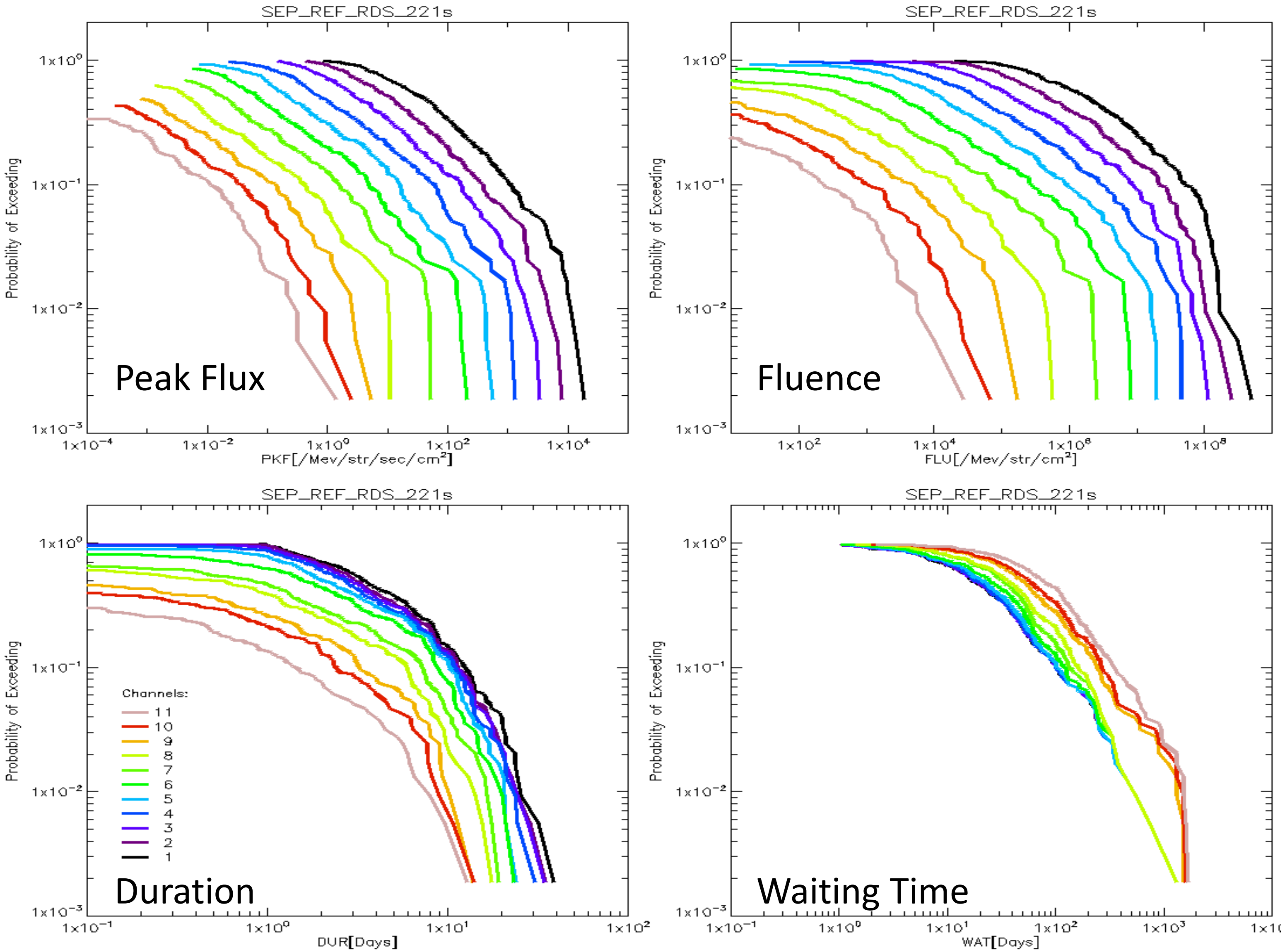
SPE characteristics: RDS 2.0



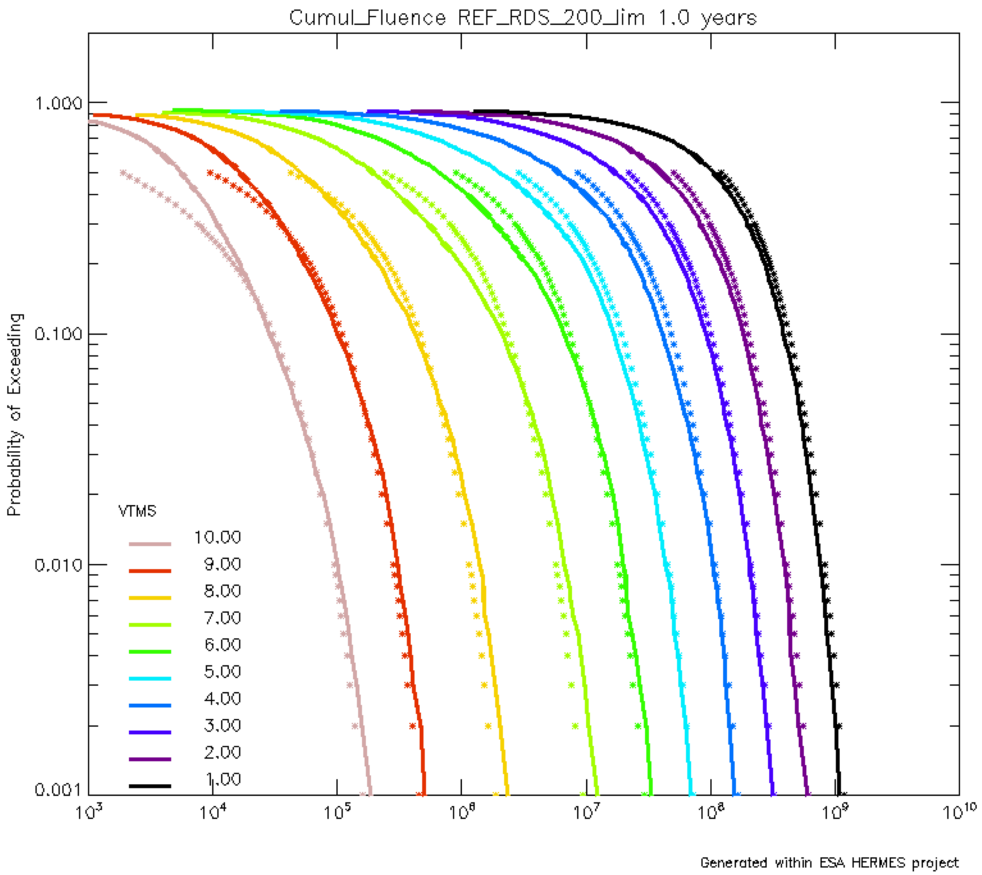
SPE characteristics: RDS 2.1



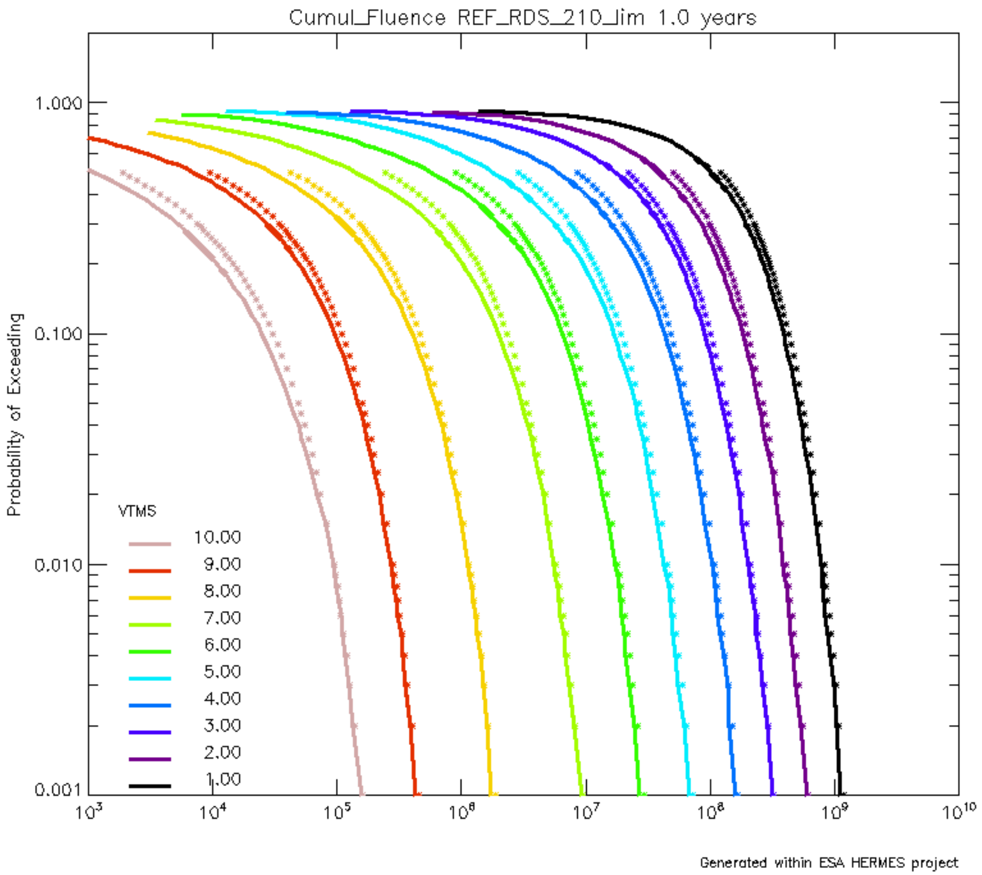
SPE characteristics: RDS 2.21s



VTM outputs: Cumulative Fluences

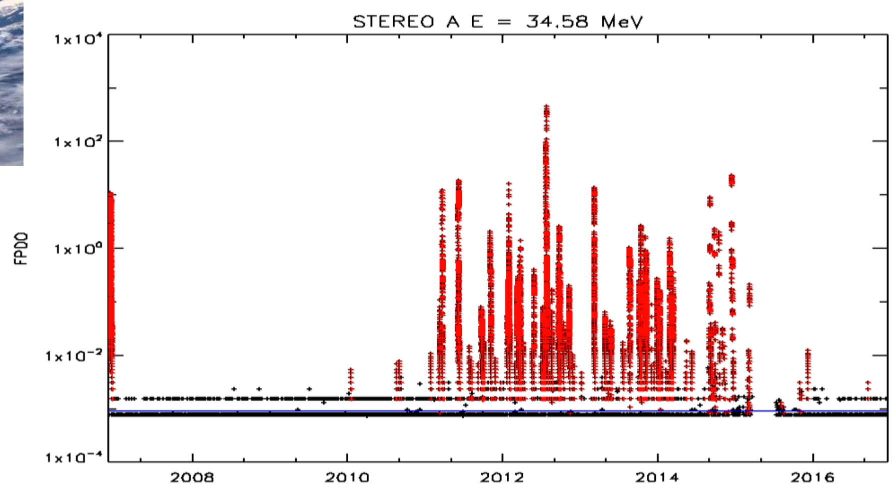


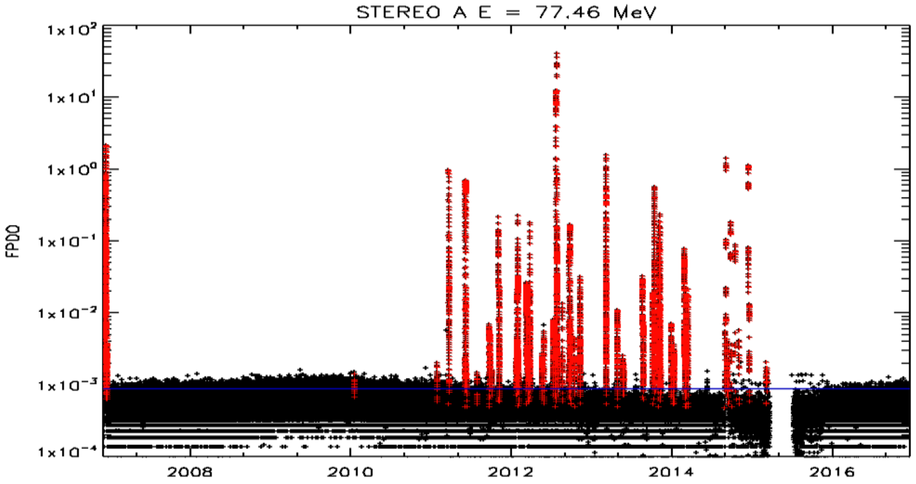
RDS 2.0: Cumulative Fluence

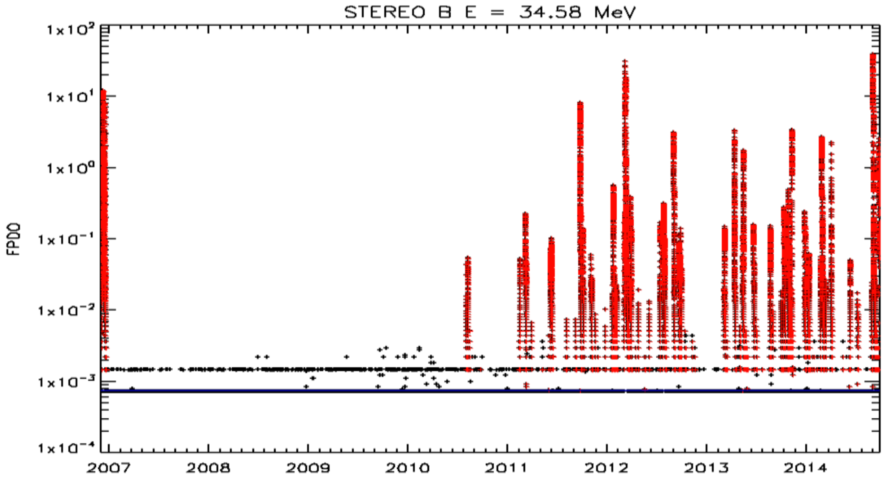


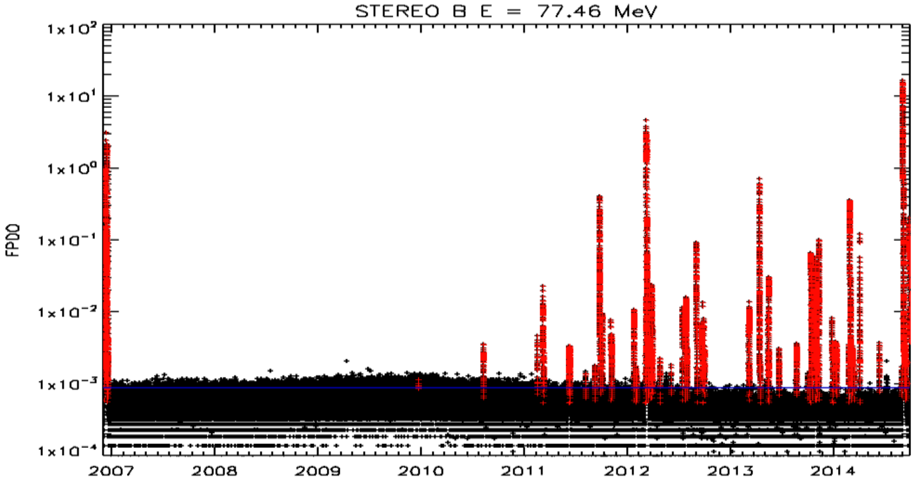
RDS 2.1 Cumulative Fluence

STEREO-A/HET data



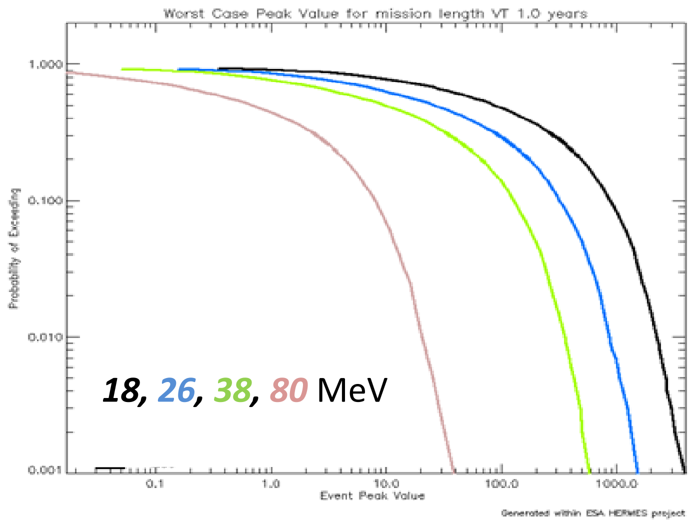


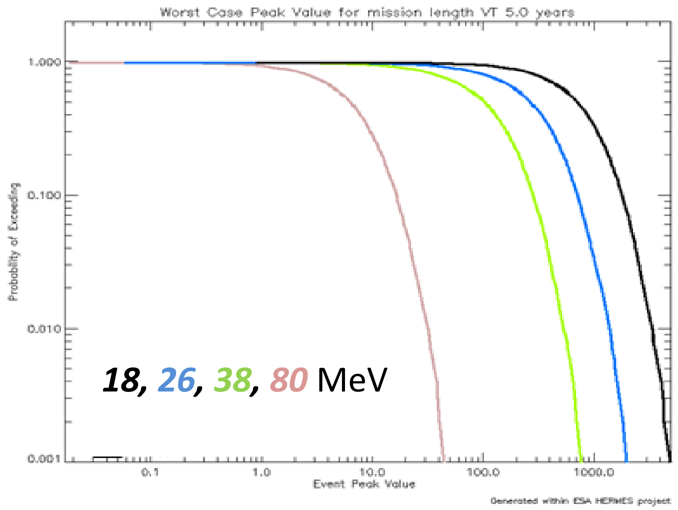




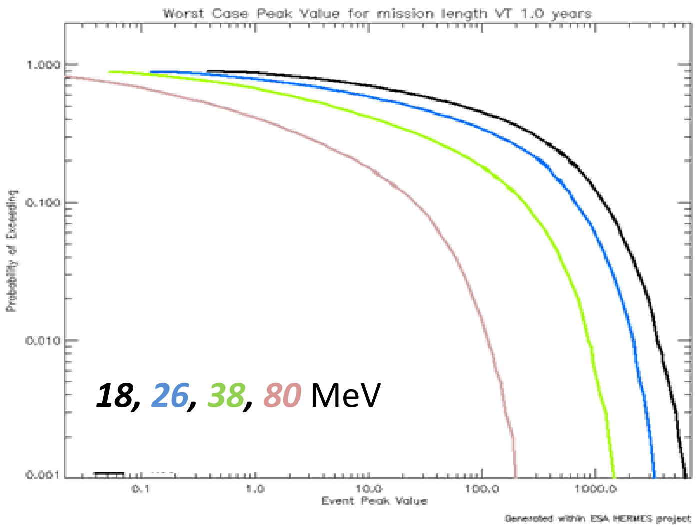
VTM outputs: STEREO vs RDS

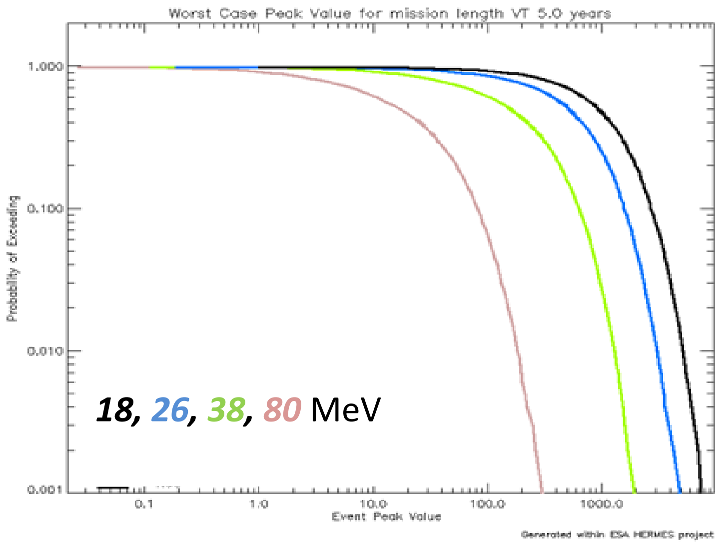
RDS2.0





STEREO-A/HET





July 2012 peak

STEREO-A:
2012-07-18 05:00:00, 2012-08-04 04:15:00
1.72e+03, 9.62e+02, 3.31e+02, 4.03e+01

RDS:
2012-07-17 15:50:00, 2012-07-26 18:00:00
5.360, **1.19**, **4.1e-01**, **3.15-02**

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VESPER model

- **Motivation**
  - Modeling and production of virtual SEP flux time-series for arbitrary mission durations
  - Combine outputs with magnetospheric shielding models and/or radiation effect tools on the time-series level
- **Approach**

  Use the VTM for the modelling of virtual SPE *durations* and *wait-times* (*Jiggens et al. 2012*)
  - Rescale "spectrally" flux time-series of existing SPEs in time and flux-intensity.
  - Creation of Virtual SPE flux series in a virtual timeline
  - Data-driven model – as few as possible assumptions and free parameters
- **Outputs can be directly used for the derivation of further products**
  - Cumulative Fluence/Peak Flux/Worst SEP Fluence distributions
  - Input in Radiation Effects tools
  - Combination with systems modelling other radiation sources (RB, CGR)

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VESPER

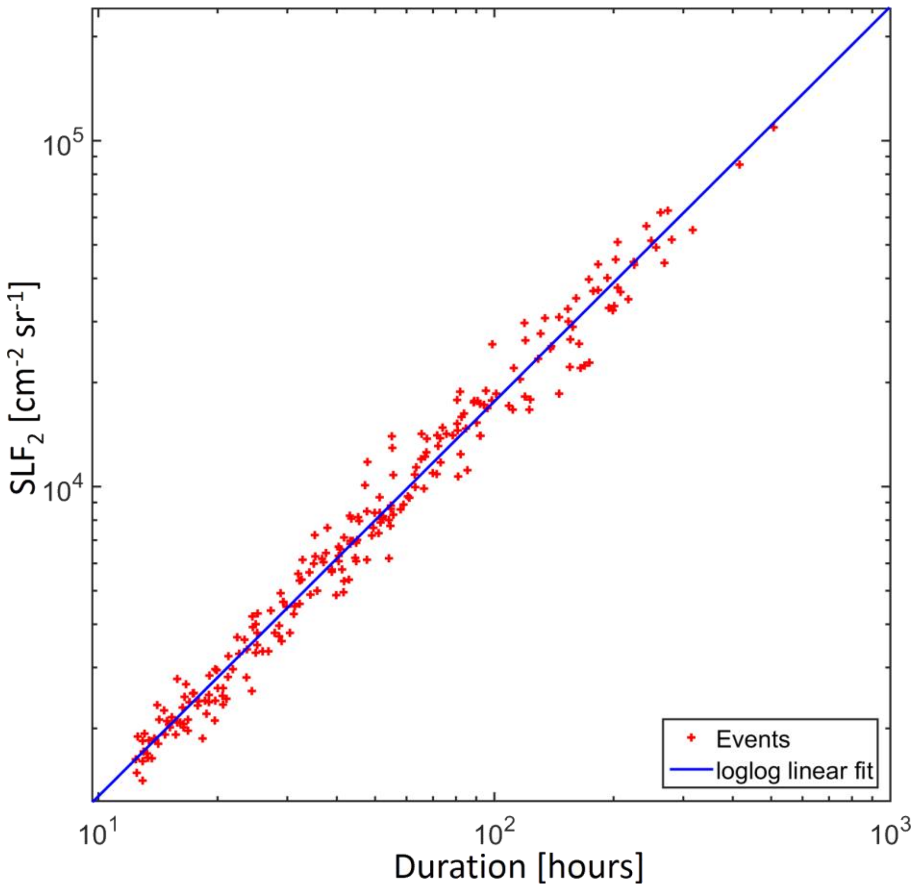
- Introduction of the LF_2 parameter - couples spectral characteristics of individual flux spectra with macroscopic characteristics of Events

$$LF_2 = \int_{ln(E_{min})}^{ln(E_{max})} ln(E^2 f(E)) dln(E)$$

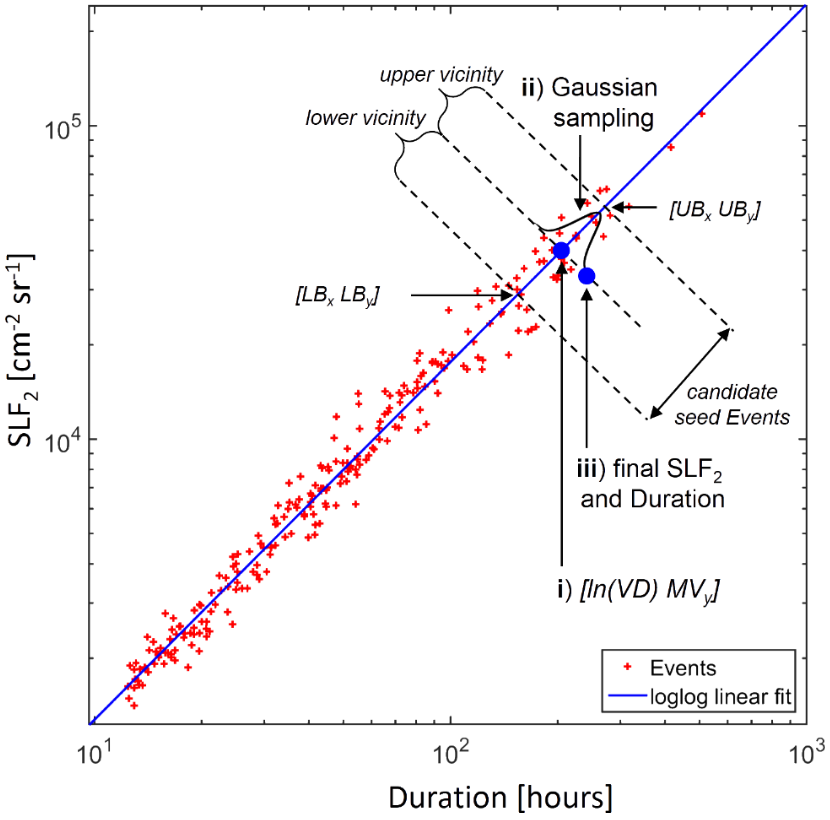
- The sum of LF_2 (SLF_2) shows a linear log-log relationship with SPE Duration

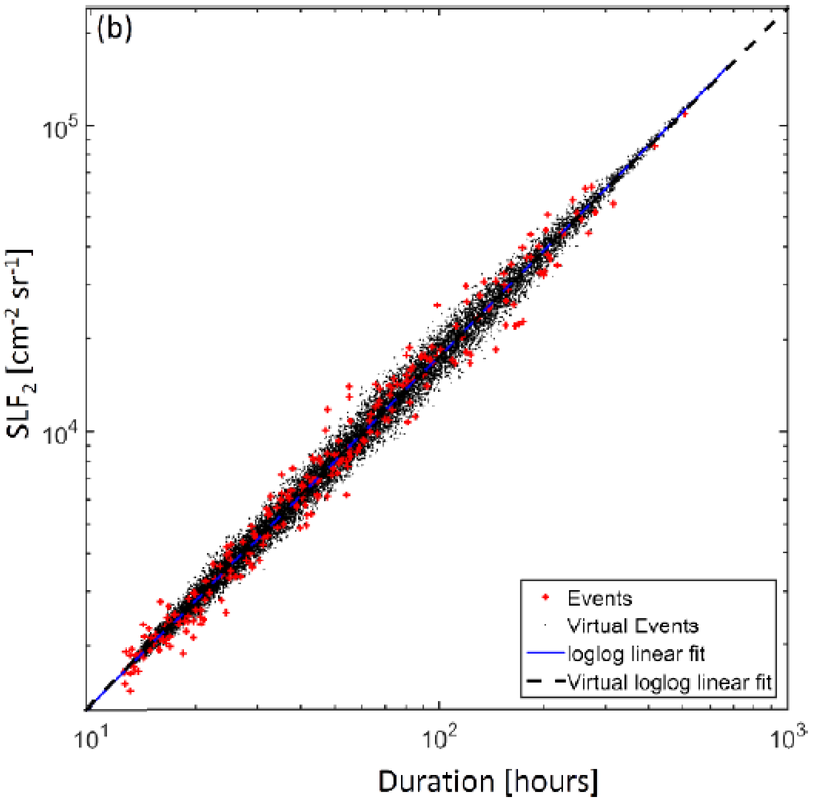
- Probabilistic filling of the event space for the creation of the macroscopic characteristics of Virtual Events

- Macroscopic SPE values (Duration-SLF_2) are translated to res-scaled flux time-series in time and intensity



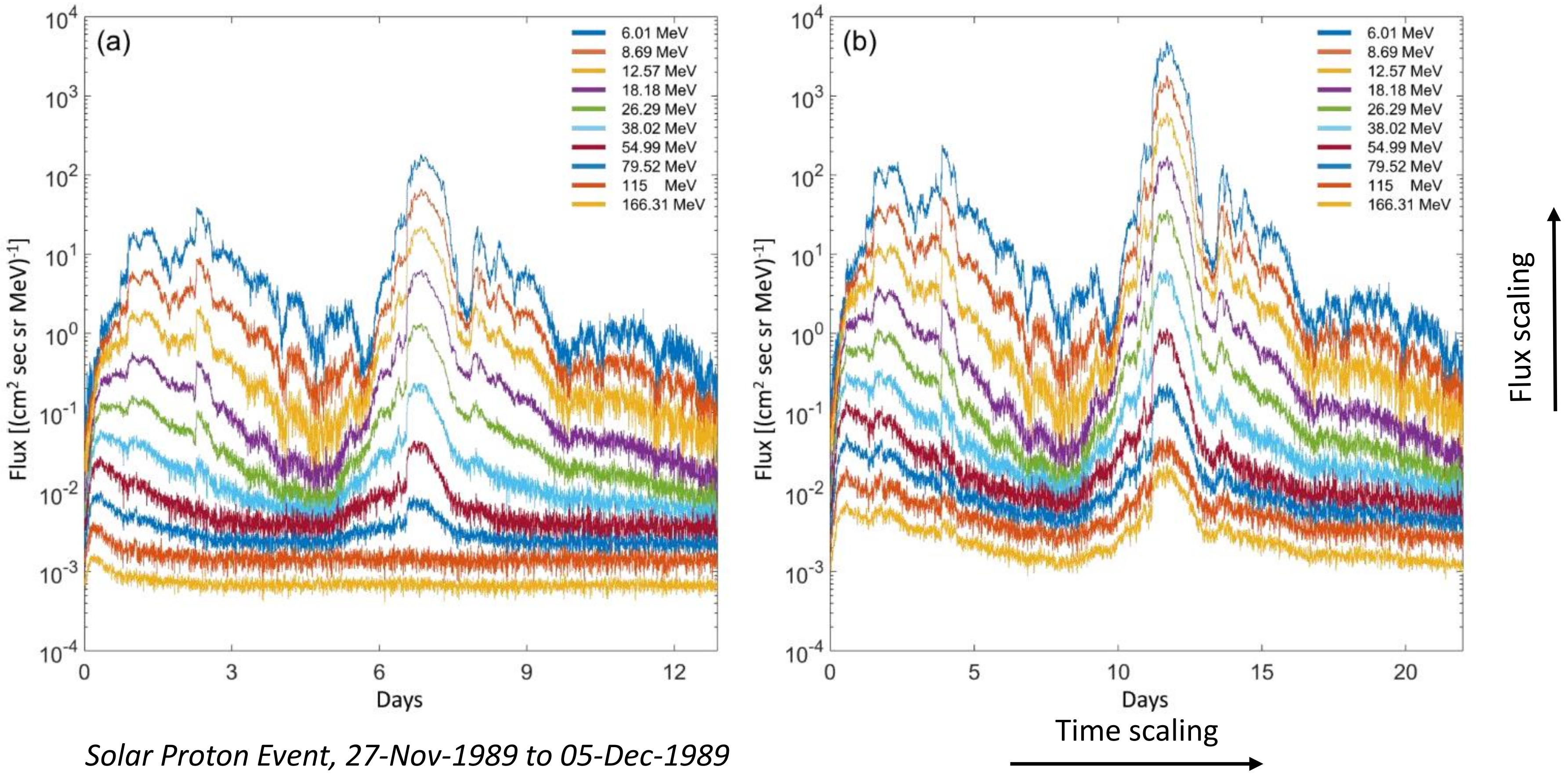
VESPER





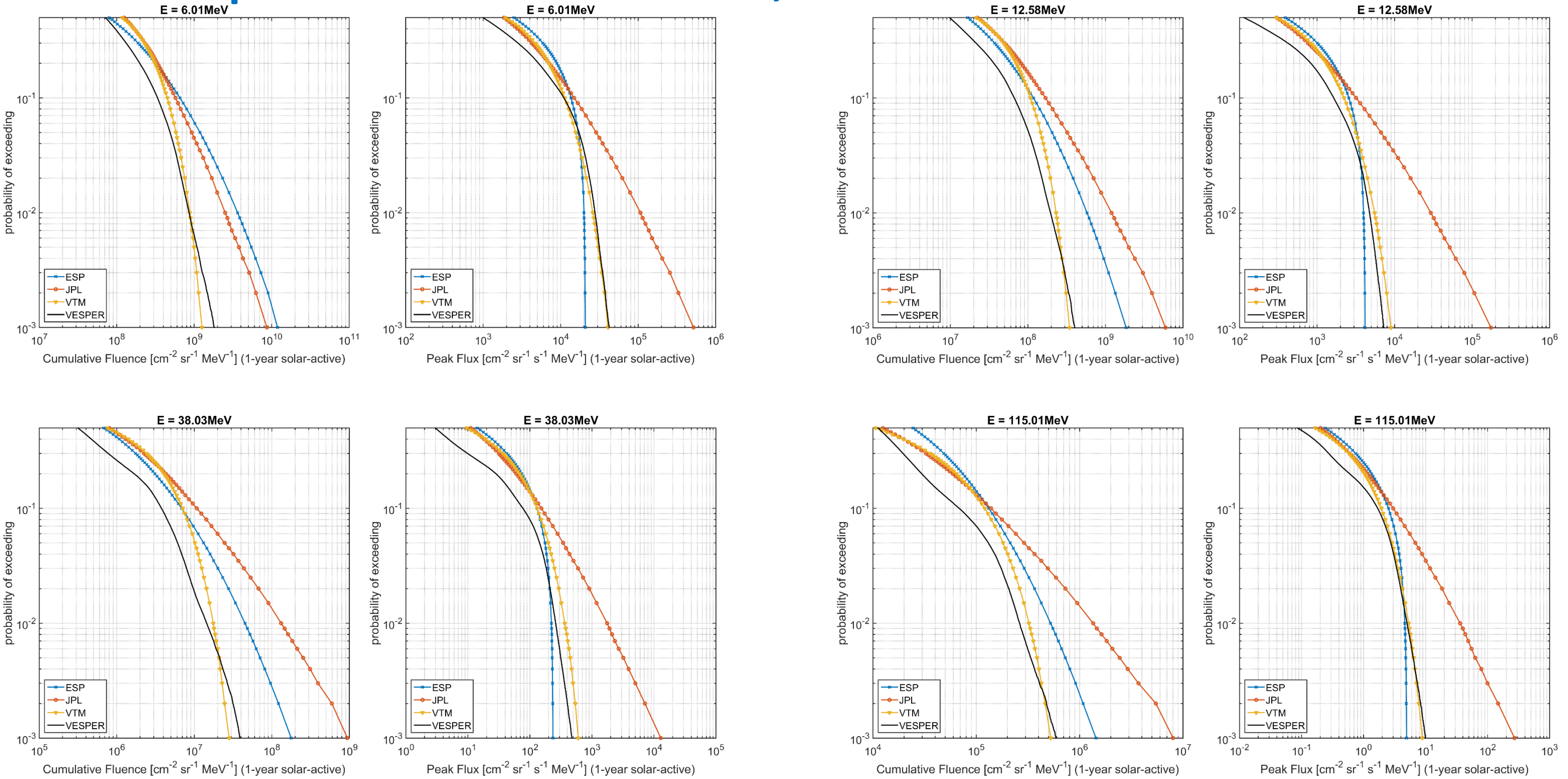
Each red point represents the flux series of a real SEP event. Each black dot represents a virtual one!

VESPER: Virtual Events



Solar Proton Event, 27-Nov-1989 to 05-Dec-1989

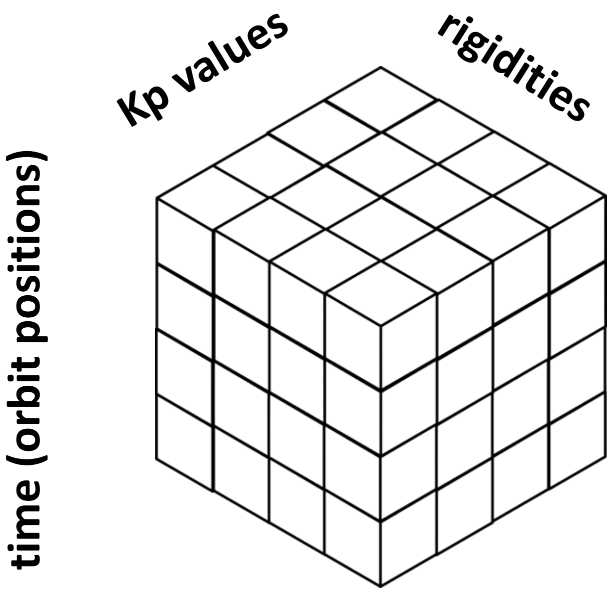
Comparison with VTM, ESP and JPL models



MSM Implementation to VESPER

- MSM (ESHIEM Project)
- msm.for code in FORTRAN
- **Input**:
  - orbit file
  - *Kp* Index value (constant)
  - Proton Rigidities
- **Output**:
  - Transmission Factor for each Rigidity value

  (this includes rigidity cut-off and the Earth's shadowing effect)

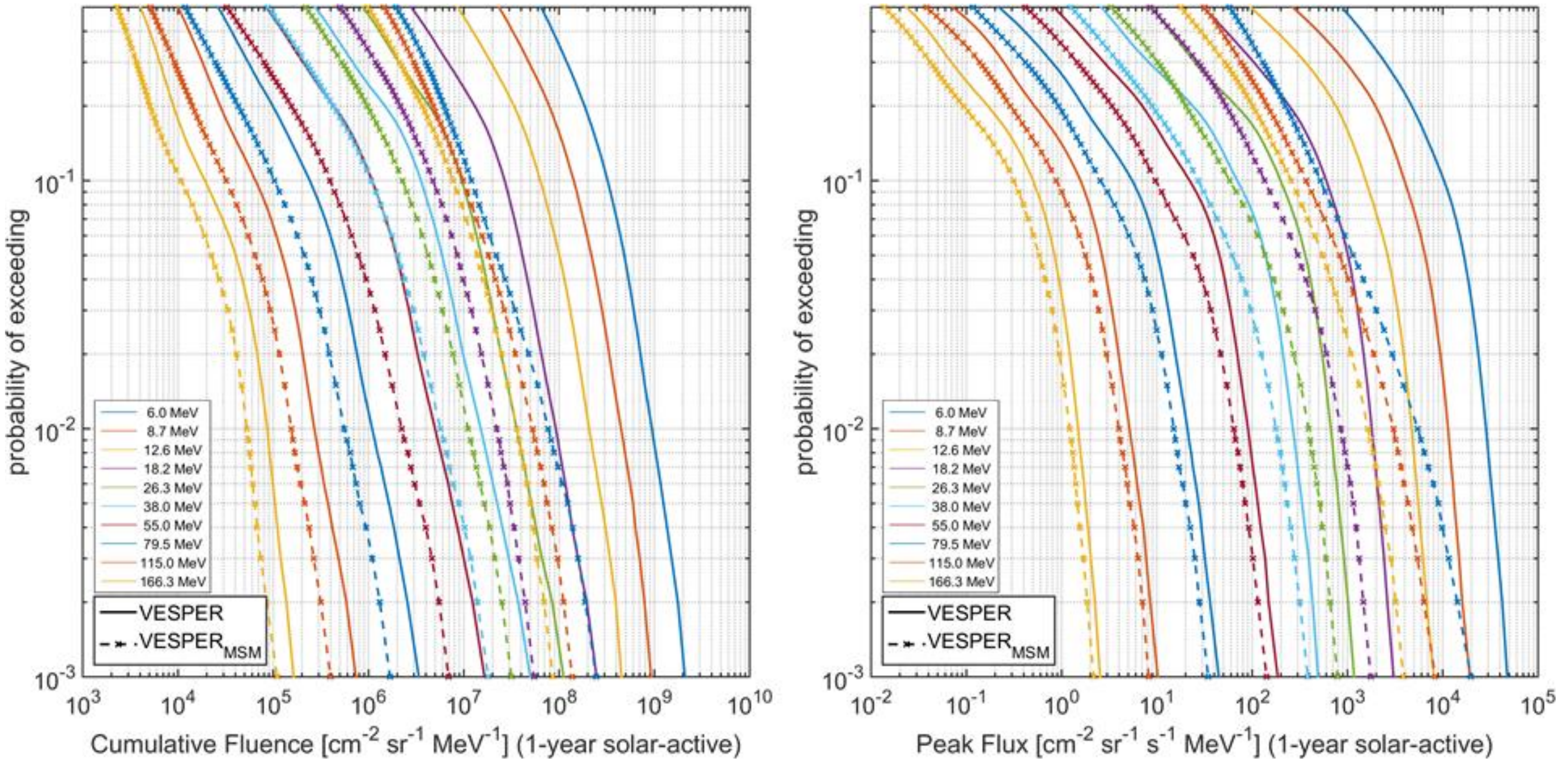


<u>"LookUp Tables" Method</u>

- For a given orbit file
  - Use custom rigidities (for energies of both VESPER & GCR)
  - Run msm for Kp values (0:9) at each orbit point
  - Produce a "cube"
- Each virtual Event is accompanied by the historical Kp time-series of its "seed" event interpolated in time to its virtual Duration
- For each time-stamp of the orbit match the Kp value
- Transmission factors for all energies are found

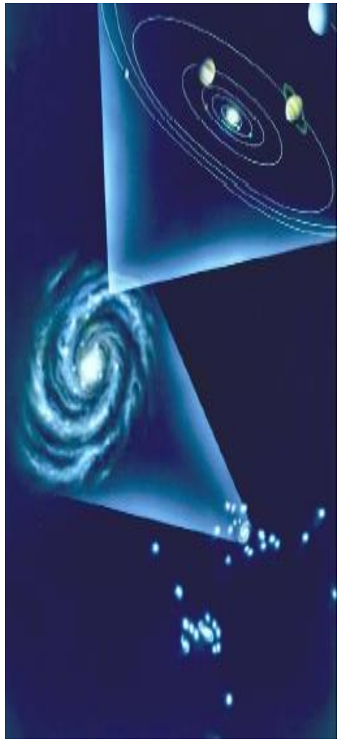
➢ **Shielding calculation on time-series level**

Application of MSM with VESPER - HEO orbit 1 year



ISO-Galactic Cosmic Ray model

- ISO model
- BON models
- DLR/Matthiä model



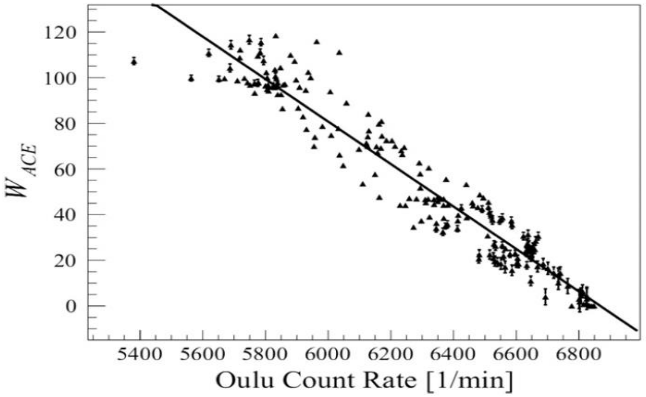
ELSEVIER

Advances in Space Research

Volume 51, Issue 3, 1 February 2013, Pages 329-338

A ready-to-use galactic cosmic ray model

Daniel Matthiä, Thomas Berger, Alankrita I. Mrigakshi, Günther Reitz



$$F_i(E,t) \equiv \frac{dN}{dA\,dt\,d\Omega\,dE}(E,t) = \Phi_i(R(E),t)\frac{A_i}{|Z_i|}\frac{1}{\beta} = \frac{C_i\beta^{\alpha_i}}{R(E)^{\gamma_i}}\left[\frac{R(E)}{R(E)+(0.37+3\cdot10^{-4}\cdot W(t)^{1.45})}\right]^{b\cdot W(t)+c}\frac{A_i}{|Z_i|}\frac{1}{\beta}$$

W(t): b & c coefficients determined: fitted the particle flux density with Cosmic Ray Isotope Spectrometer (CRIS) data on-board the Advanced Composition Explorer (ACE) spacecraft

To extend the temporal validity (and applicability) of the model the Oulu neutron monitor (NM) count rates were selected as a second source of information on the GCR flux intensity.

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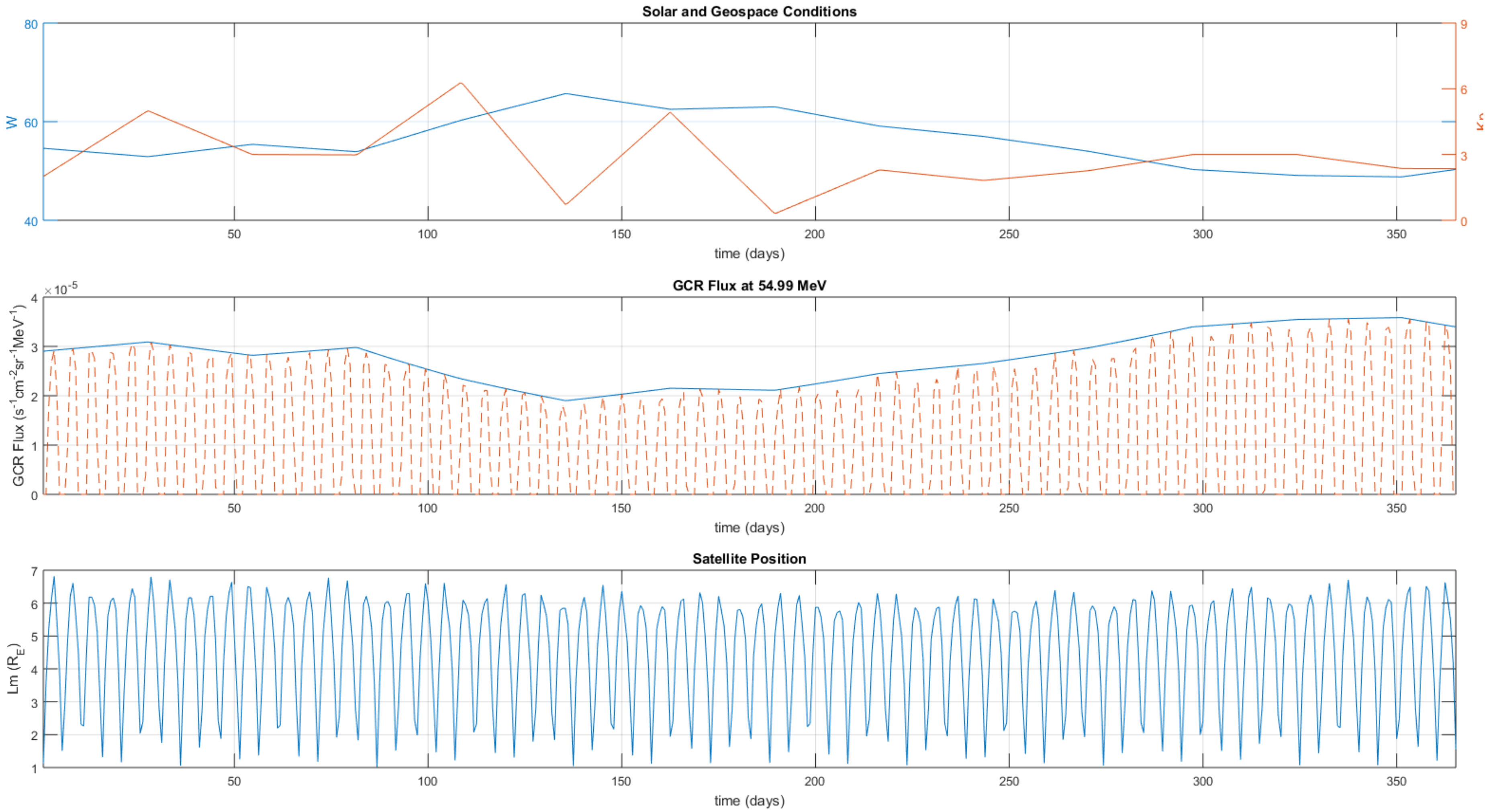
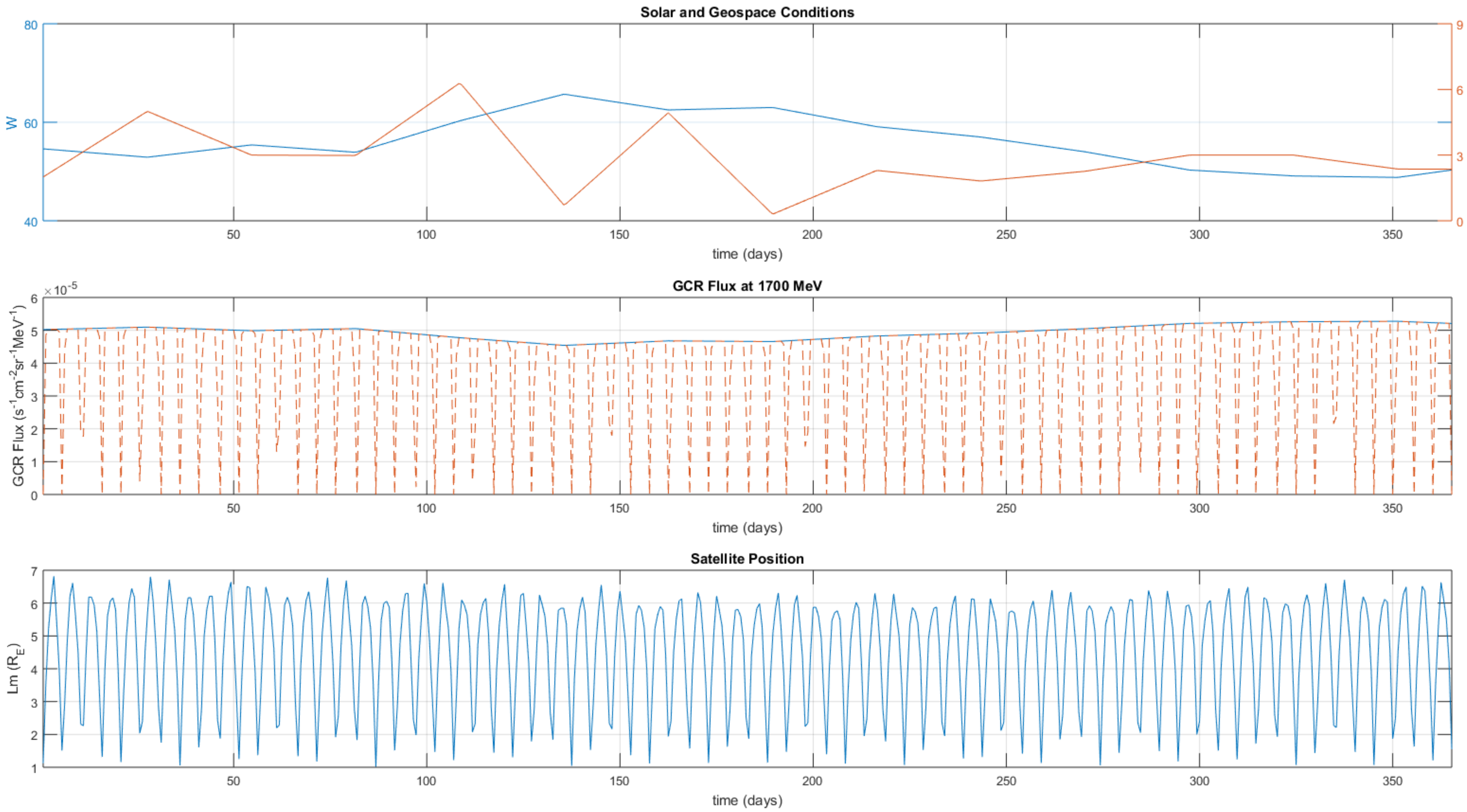
GCR with MSM


Solar and Geospace Conditions
W
Kp
time (days)
GCR Flux at 54.99 MeV
×10^-5
GCR Flux (s^-1cm^-2sr^-1MeV^-1)
time (days)
Satellite Position
Lm (R_E)
time (days)

GCR with MSM



Solar and Geospace Conditions
W
Kp
time (days)
GCR Flux at 1700 MeV
GCR Flux (s^{-1}cm^{-2}sr^{-1}MeV^{-1})
×10^{-5}
time (days)
Satellite Position
Lm (R$_E$)
time (days)

European SPace Radiation Environment Model

- **Motivation**
  - To create a modular system that combines new and standard radiation models and radiation effects tools
  - To merge the radiation effects from different sources

ESPREM system modules

- **Models:**
  - TREPEM: Trapped electron fluxes
  - VESPER: SEP proton differential fluxes
  - GCR: Galactic Cosmic Rays DLR model
  - AE9/AP9: unused but included; for verification purposes
- **Radiation effect tools:**
  - MULASSIS: TID, NID, PHS
  - IRONSSIS: TID, NID
  - MCICT: charging
  - SEU: Combination of GEMAT, LET code, IRONSSIS
- **Other tools**
  - MSM: Magnetospheric shielding
  - SPICE-based: Trajectory generator

ESPREM

TREPEM

- 0.04 MeV – 10 MeV

(less data available for E > 5 MeV)

- (E, aeq, L*) Maps

(L* calc too slow)

- **Percentile Maps**

  Model_Quantiles [(0:0.01:0.04),
  (0.05:0.05:0.95),
  (0.96:0.01:1)]

- **Average Maps**
- **St.Dev Maps**
- **Outputs**
  - Mean
  - Percentiles (any)
  - Histogram
  - Diff & Int Fluxes

RB DATASETS

RBSP-A/MagEIS
RBSP-B/MagEIS
RBSP-A/REPT
RBSP-B/REPT
GIOVE-B/SREM
INTEGRAL/IREM
PROBA1/SREM
CRRES/MEA
CRRES/HEEF
POLAR/CEPPAD
XMM/ERMD

SPE DATASETS

ESA SEPEM RDS
(x-calibrated GOES)

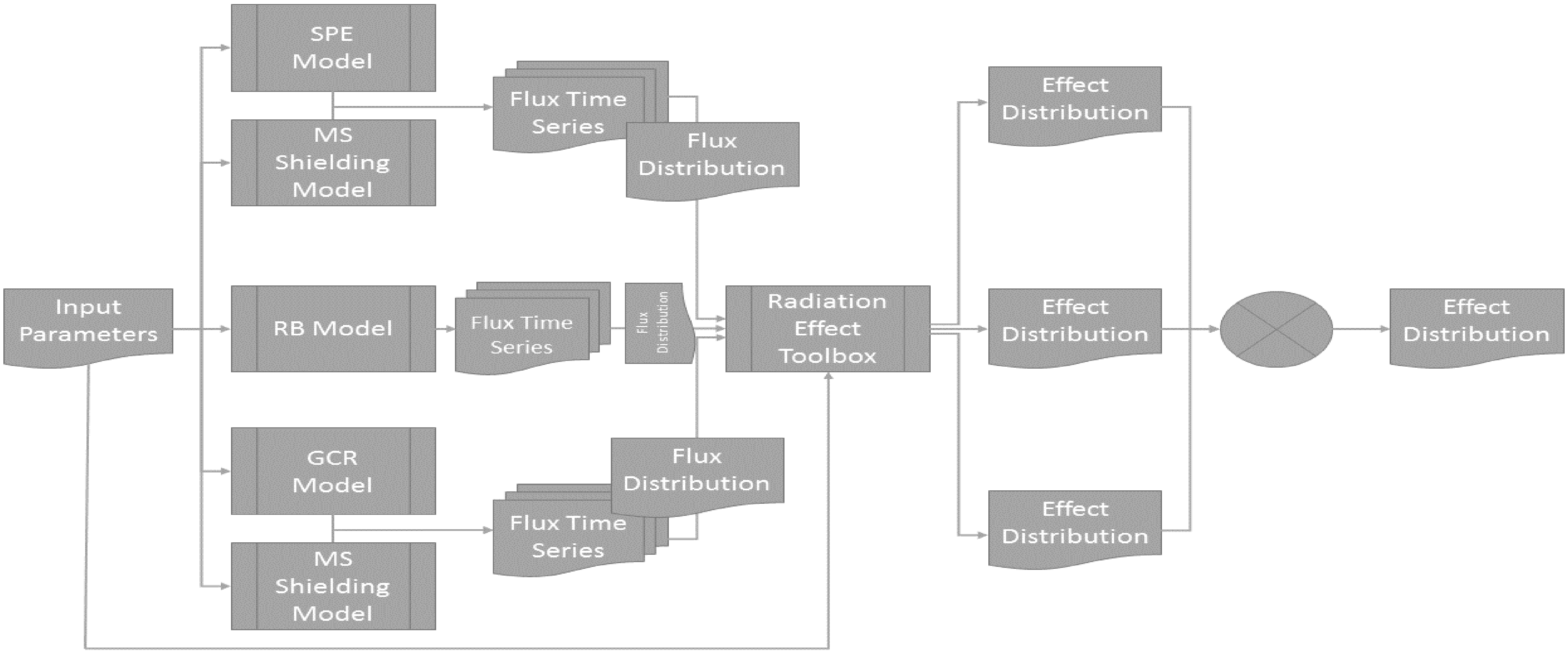
VESPER & MSM

- 5 MeV – 200 MeV
- Event DB driven
- Kp driven (for MSM)
- Solar Active/Quiet/Mixed Conditions
- Multiple-Scenario Runs
- Outputs
  - Percentiles of Average Scenario Diff. Flux

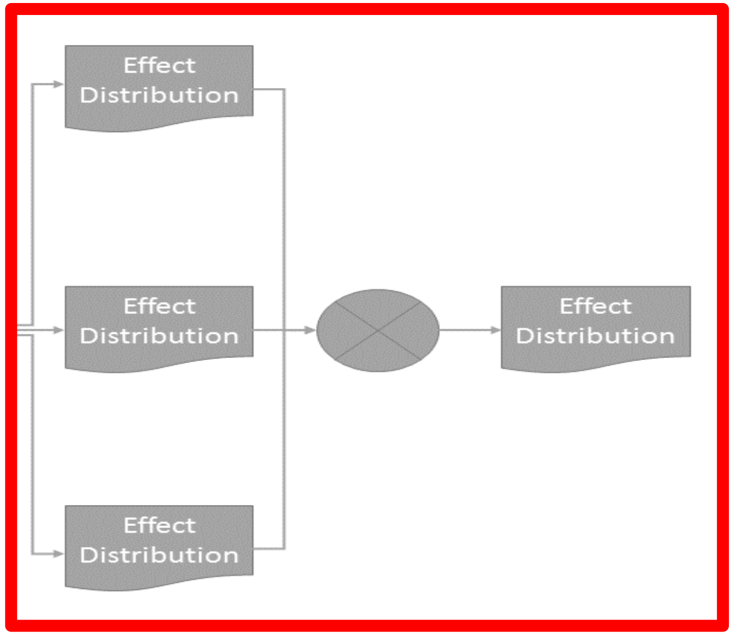
GCR & MSM

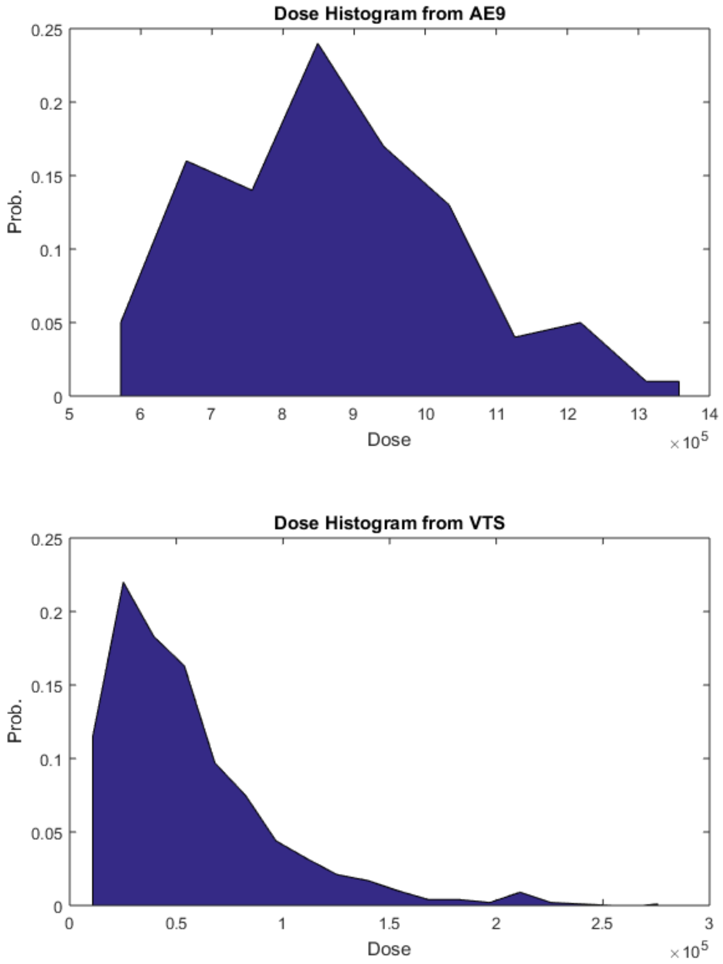
- 12.58 MeV – 100 GeV
- W driven
- Kp driven (for MSM)
- Multiple-Scenario Runs
- Outputs
  - Percentiles of Average Scenario Diff. Flux

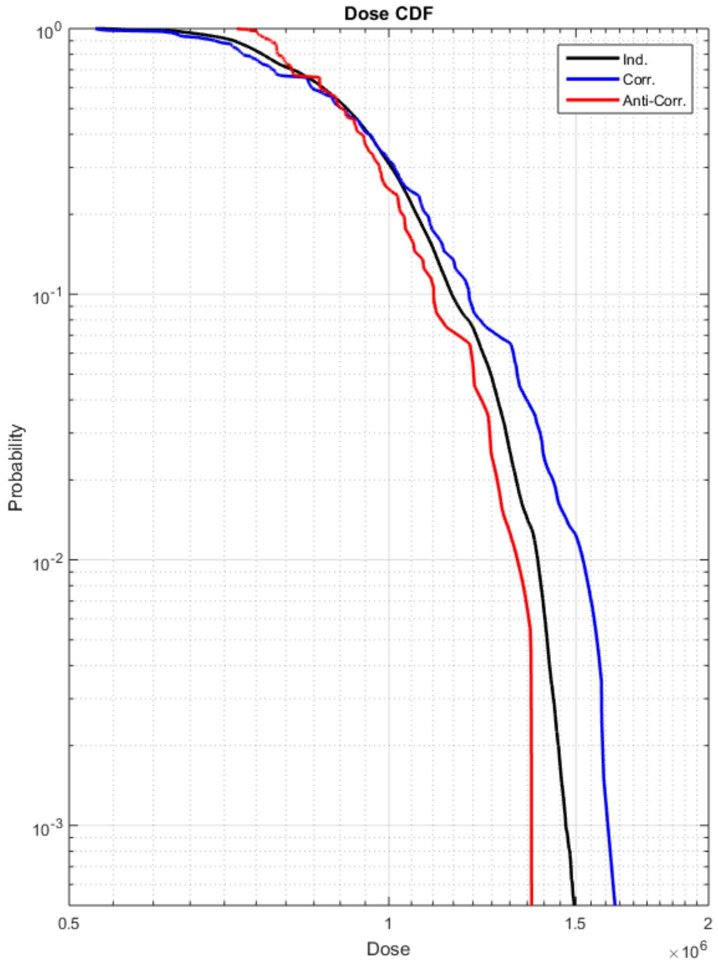
ESPREM: model description



Example: combination of Dose @GEO from AE9 & VTM







ESPREM system overview

- A suite of models and (radiation effects & more) tools
- Tools are encapsulated in wrappers to homogenize interfaces
- Client server model
  - System runs on the cloud (or locally in a VM)
  - Clients can perform queries over **RPC with JSON data**
- Client library (python3) provides plotting, parsing utilities
- Depending on the user query the system:
  - Runs the requested module and returns all results serialized in JSON
  - Runs a series of modules in a pipeline transforming intermediate data as required and returns all intermediate data

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***Main Contributor**: A. Tsigkanos*

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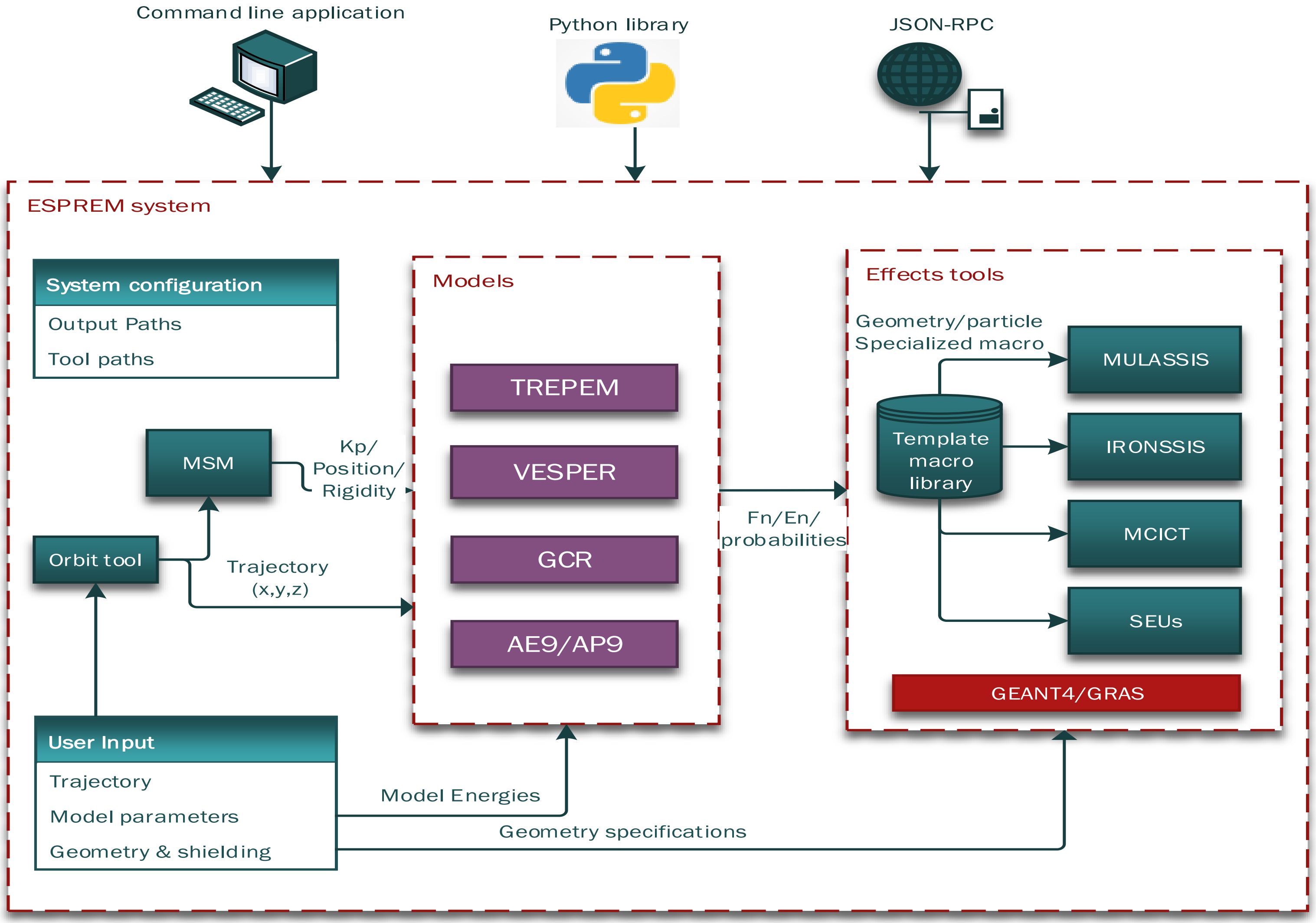
ESPREM system architecture



ESPREM system use cases

- Suite of models and tools with convenient and consistent APIs (Application Program Interfaces)
- Designed as a backend to the ESPREM model combining the models/effects
  - ESPREM model is the frontend, using the ESPREM system as backend
  - The combination model is a special client which uses probability outputs
  - Can trigger multiple runs of effects tools for flux quantiles
- Modular & loosely coupled: modules can be queried individually, new modules can be easily added
  - Can be used **standalone** as python libraries
  - **Easy to extend** with new modules: guide is included in docs.
  - Easy to test/document new modules with existing test/docs framework.

ESPREM system: small conveniences

- Automated unit/e2e tests and reporting with Pytest/Sphinx
  - Reference test cases checked with known-good tools (e.g. SPENVIS) where possible
- **Auto-generated documentation** with Sphinx from **source code**, examples and tutorials
- Automated construction of Virtual Machine with fully installed software with Vagrant
- User step-by-step tutorials in Ipython notebooks
- Docs on extending the system
- Full transparency with intermediate data to accommodate validation

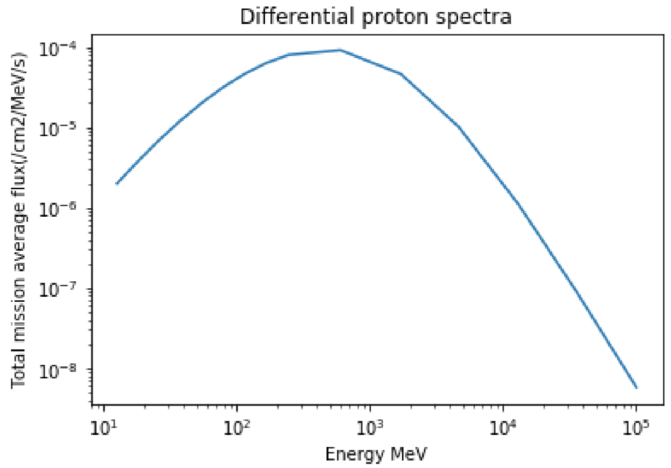
Query example from Ipython cont.

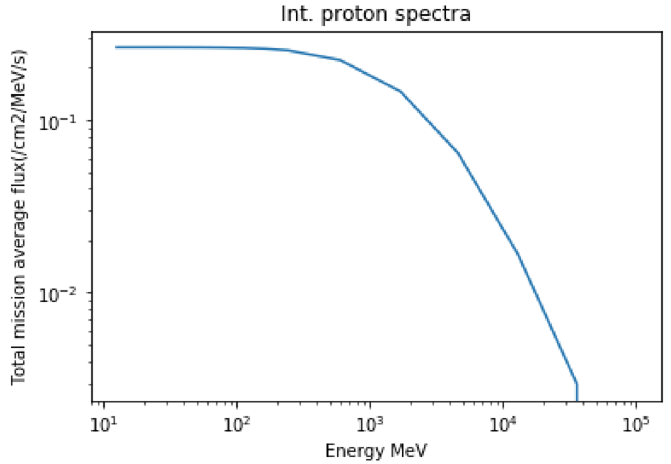
In [11]:

```
# convert 50pct fluxes response string from ESREPM query into pandas DF
flux_df = pd.read_csv(StringIO(
    rsp9["gcr/q50"]), names= ['Energy','intflux', "diffflux"], comment='#', sep="\s+")
flux_df["diffflux"]

# sample plots of the fluxes with matplotlib:
plt.loglog(flux_df["Energy"].as_matrix(),
             flux_df["diffflux"].as_matrix())
plt.title('Differential proton spectra')
plt.xlabel('Energy MeV')
plt.ylabel('Total mission average flux(/cm2/MeV/s)')
plt.show()

plt.loglog(flux_df["Energy"].as_matrix(),
             flux_df["intflux"].as_matrix())
plt.title('Int. proton spectra')
plt.xlabel('Energy MeV')
plt.ylabel('Total mission average flux(/cm2/MeV/s)')
plt.show()
```





Example run of the ESPREM System

Shielding Geometry Definition

```
geometry_slab = ["/geometry/layer/delete  0",
            "/geometry/material/addNIST G4_Al",
            "/geometry/layer/shape slab",
            "/geometry/layer/add  0 G4_Al   1    1.000E+00 mm",
            "/geometry/layer/add  1 Vacuum   1    1.000E+00 mm",
           ]
```

Trajectory definition

Model Parameters

Effects Toolboxes

```
name = "LEOdd_1dy_allmodels"
pipeline_full = { "trajectory": {
                              "orbit_title": name,
                              "mission_title": "none",
                              "INITIALFRAME": 1, #body fixed, non-inertial frame
                              "NAIFCODE": 399,
                              "ORBITSPECIFICATION": 202,
                              "STARTDATE": "2015-06-21 12:00:00", # vernal equinox
                              "DURATION": 1,
                              "TIMESTEP": 60.0,
                              "INCLINATION": 90,
                              "RAAN": 0.0,
                              "ARGPER": 0.0,
                              "TRANO": 0.0,
                              "HPER": 800,
                              "HAPO": 810,
                              "mission_duration_days" : 1
                         },
                "trepem_model": {
                            "energies": [
                                1.0000E-01, 1.5000E-01, 2.0000E-01, 3.0000E-01, 4.0000E-01, 5.0000E-01,
                                6.0000E-01, 7.0000E-01, 1.0000E+00, 1.5000E+00, 2.0000E+00, 3.0000E+00,
                                4.0000E+00]
                            },
                "msm": {
                            "kps" : 19,
                            "timestep" : 60},
                "vesper_model": {
                            "model_type": 'VESPER',
                            "mult_limit": '1.5',
                            "tolerance": '0.1',
                            "misdur": '1',
                            "iters": '1000',
                            "solarphase": 'mixed',
                            "msm_enable_int": 1,
                            "mission_name": 'test'
                            },
                "gcr_model" : {
                            "msm_enable": "true",
                            "numsims": "1000",
                            "energies": "12.58, 18.18, 26.3, 38.03,54.99, 79.53, 115.00, 166.3,"
                            "244.2, 600, 1700, 4600, 13000, 36000, 100000",
                            "quantiles": "5, 10, 15, 20, 25, 30, 35, 40, 45, 50, 55, 60, 65, 70,"
                            "75, 80, 85, 90, 95"
                            },
                 "mulassis" : {
                            "geometry" : geometry_slab,
                            "events" : 1000
                             },
                "ironssis" : {
                            "geometry" : geometry_slab,
                            "events" : 1000
                            }

                }
res_full  = esprem_rpc(server, port, "esprem_pipeline_rpc", pipeline_full)
esprem_deserial('/home/sparc/Desktop/ESPREM_res/' + name + '_slab', res_full)
```

Output Files

MULASSIS DOSE ANALYSIS for TREPEM outputs
'geant4-09-06-patch-02 (17-May-2013)'
'Layer', , 1,'Layer number''Thickness', 'cm', 1,'Thickness of layer''Density', 'g/cm3', 1,'Density of layer''Dose','rad', 1,'Dose/energy deposition''Error','rad', 1,'Error dose/energy deposition'
1, 1.0000e-01, 2.6990e+00, 7.2124e+02, 1.5845e+01
2, 1.0000e-01, 1.0000e-25, 1.5728e+01, 9.1249e+00

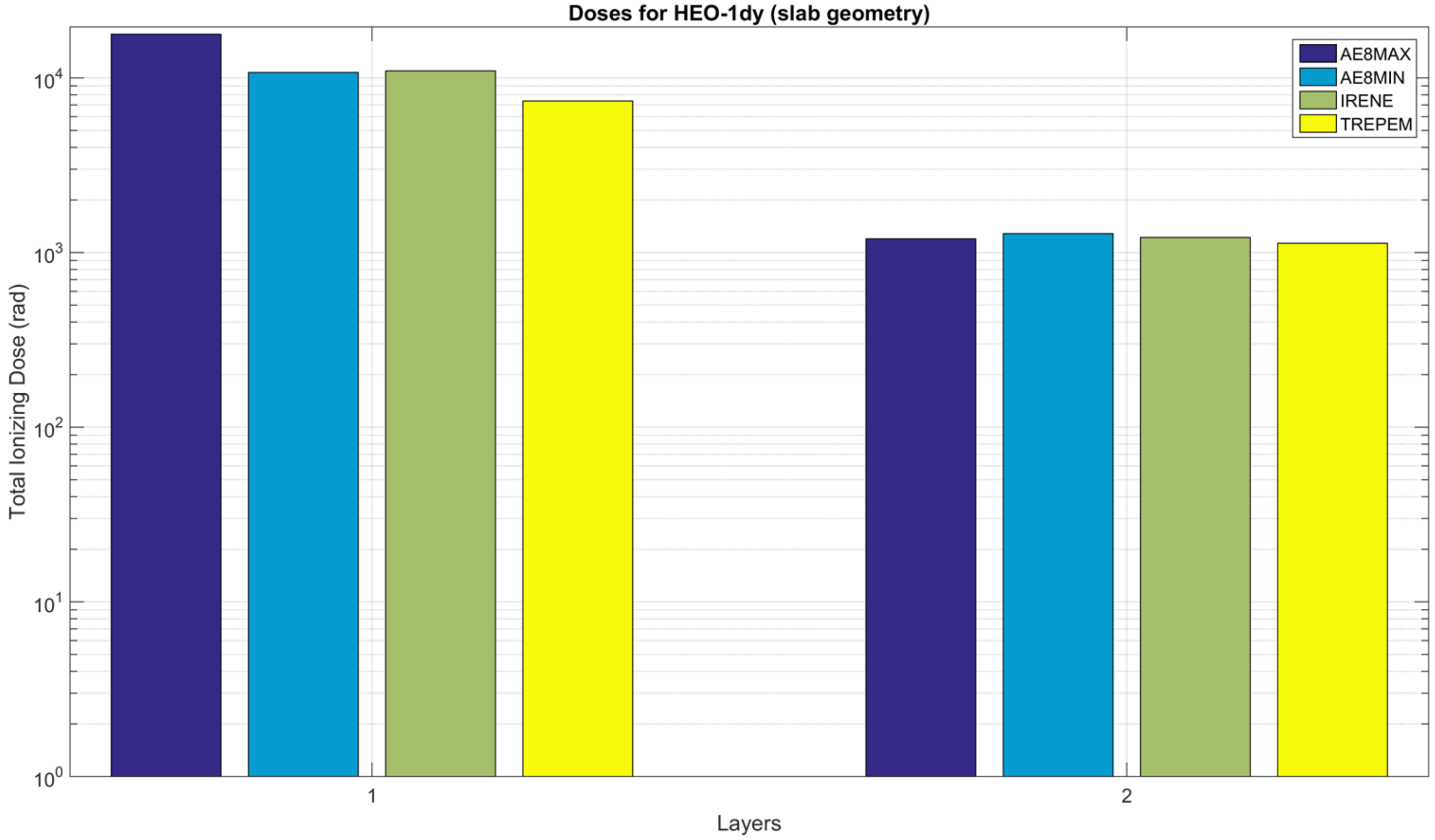
Validation Against SPENVIS

RBSP-type Orbit

```
pipeline_config = { "trajectory": {
                                    "orbit_title": "HEO_1dy",
                                    "mission_title": "none",
                                    "INITIALFRAME": 1, #body fixed, non-inertial frame
                                    "NAIFCODE": 399,
                                    "ORBITSPECIFICATION": 202,
                                    "STARTDATE": "2015-03-20 12:00:00", # vernal eq.
                                    "DURATION": 1,
                                    "TIMESTEP": 120.0,
                                    "INCLINATION": 9.783,
                                    "RAAN": 210.6049,
                                    "ARGPER": 118.3203,
                                    "TRANO": 0.0,
                                    "HPER": 618.0,
                                    "HAPO": 30414.0,
                                    "mission_duration_days" : 1
                                  }
                                }
rsp_heo  = esprem_rpc(server, port, "esprem_pipeline_rpc", pipeline_config)
```

2-Layer Slab Geometry

/geometry/layer/delete 0
/geometry/material/addNIST G4_Al
/geometry/layer/shape slab
/geometry/layer/add 0 G4_Al 1 1.000E+00 mm
/geometry/layer/add 1 Vacuum 1 1.000E+00 mm



Acknowledgments

- Daniel Heynderickx (DH Consultancy)
  - Technical consultancy on ODI
  - Integration of radiation effect tools into ESPREM system
  - Independent validation of ESPREM system
  - Support on SPICE orbit tool
- Fan Lee (RADMOD, UK)
  - MSM tool (ESHIEM project)
- D. Matthiae, T. Berger, R. Günther (DLR)
  - DLR ISO GCR model s/w
- P. O'Brien (Aerospace, US)
  - Support on AE9/AP9 model & effect tools
- Patrícia Gonçalves (LIP)
  - Alphasat/MFS data & response functions
- N. Messios et al (BIRA, SPENVIS team)

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HERMES: conferences & papers

Presentations in Conferences

Results of ESA HERMES project have been presented in a series of European and US workshops and conferences.

- The European Space Radiation Environment Model,C. Papadimitriou, I. Sandberg, S. Aminalragia-Giamini, A. Tsigkanos, O. Giannakis, C. Katsavrias, P. Jiggens and I.A. Daglis, COSPAR 2018,(Oral)
- New approaches in SEP description and modelling, I. Sandberg, S.A. Giamini, C. Papadimitriou, I.A. Daglis and P. Jiggens, 13th European Space Weather Week, Oostende, Belgium, November 2016. (Oral)
- The first Iteration of the Trapped Energetic Particle Environment Model, C. Papadimitriou, I. Sandberg, Ch. Katsavrias, A. Tsigkanos, O. Giannakis, I.A. Daglis and P. Jiggens;, Radiation Modelling and Data Analysis Workshop, October 5–7, 2016, Sykia, Greece. (Oral)
- Pre-processing methods for energetic particle measurements, C. Papadimitriou et al 12th European Space Weather Week, Oostende, Belgium, 2015. (Poster)
- Data Unfolding using Neural Networks, C. Papadimitriou et al, 12th European Space Weather Week, Oostende, Belgium, 2015. (Poster)
- The Virtual Time-Series Solar Proton Event Model, Aminalragia-Giamini, I. Sandberg, C. Papadimitriou et al, Space Weather Workshop, Broomfield, USA, 2017. (Poster)

Peer Reviewed

The following publications have been resulted entirely or partially from the work performed within ESA HERMES project.

- Validation of the effect of cross-calibrated GOES solar proton effective energies on derived integral fluxes by comparison with STEREO observations, J. V. Rodriguez, I. Sandberg, et al, Space Weather, 15, doi:10.1002/2016SW001533 (2017).
- SEP Protons in GEO measured with the ESA MultiFunctional Spectrometer, L. Arruda, P. Gonçalves, I. Sandberg, S. Aminalragia-Giamini, I.A. Daglis et al. DOI 10.1109/TNS.2017.2714461, IEEE TNS (2017).
- The virtual enhancements solar proton event radiation (VESPER) model, S. Aminalragia-Giamini, I. Sandberg, C. Papadimitriou, I.A. Daglis, P. Jiggens, J. Space Weather Space Clim. 2018, 8, A06, https://doi.org/10.1051/swsc/2017040

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HERMES Workshop

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SPACE RADIATION MODELLING AND DATA ANALYSIS WORKSHOP 2016

SYKIA, PELOPONNESE, GREECE

5-7 OCTOBER 2016

SCIENTIFIC PROGRAMME

SCIENTIFIC ORGANIZING COMMITTEE
PIERS JIGGENS, EUROPEAN SPACE AGENCY, THE NETHERLANDS
IOANNIS A. DAGLIS, UNIVERSITY OF ATHENS, GREECE
PAUL O'BRIEN, AEROSPACE CORPORATION, USA
INGMAR SANDBERG, IASA, GREECE

LOCAL ORGANIZING COMMITTEE
THE LOCAL ORGANISATION IS BEING UNDERTAKEN BY THE INSTITUTE FOR ACCELERATING SYSTEMS & APPLICATIONS (IASA), GREECE

INGMAR SANDBERG, IOANNIS A. DAGLIS, SIGIAVA A. GIAMINI, CHRISTOS KATSAVRIAS, CONSTANTINOS PAPADIMITRIOU

- 22 participants
- EU & US participants

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Thank you!

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DEADLINE
DEADLINE
Everything is okay.
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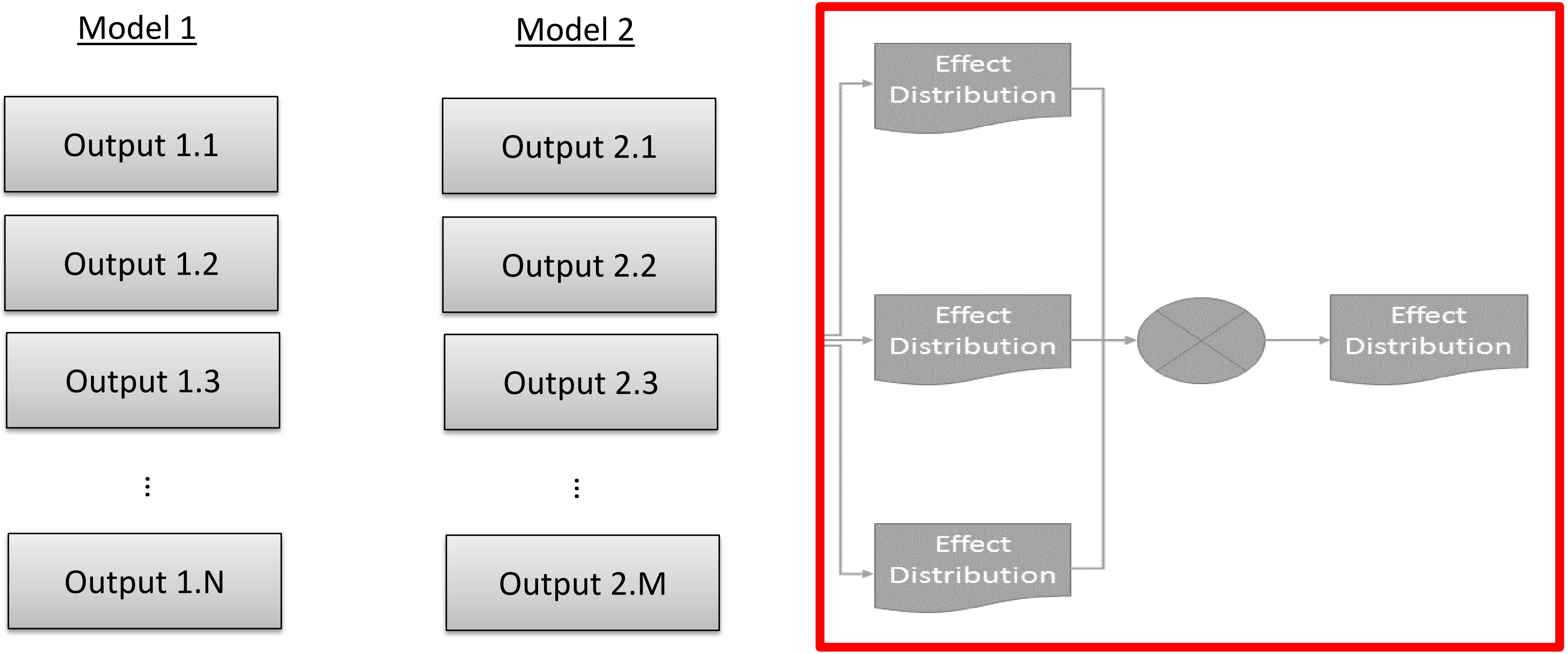
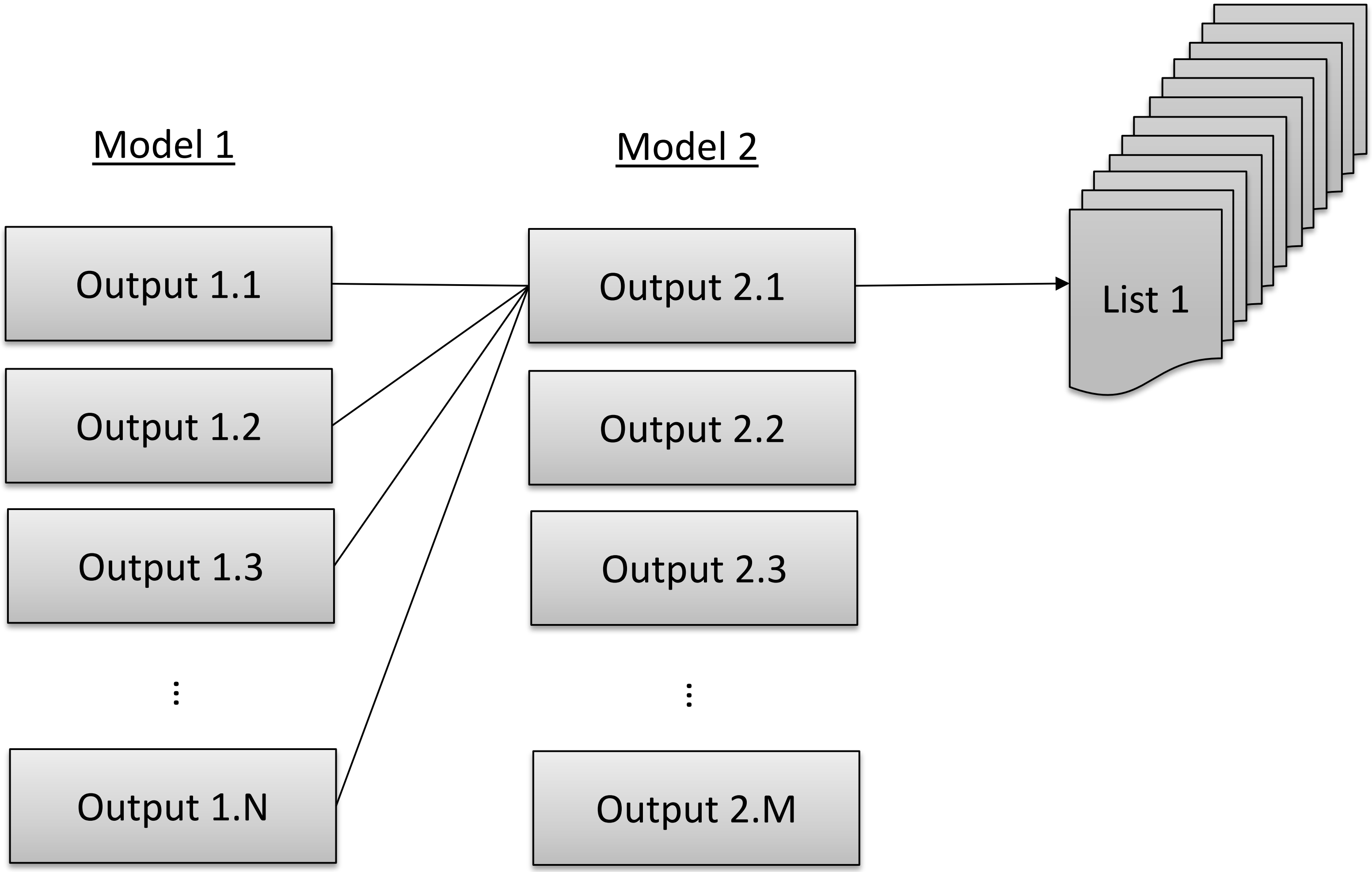
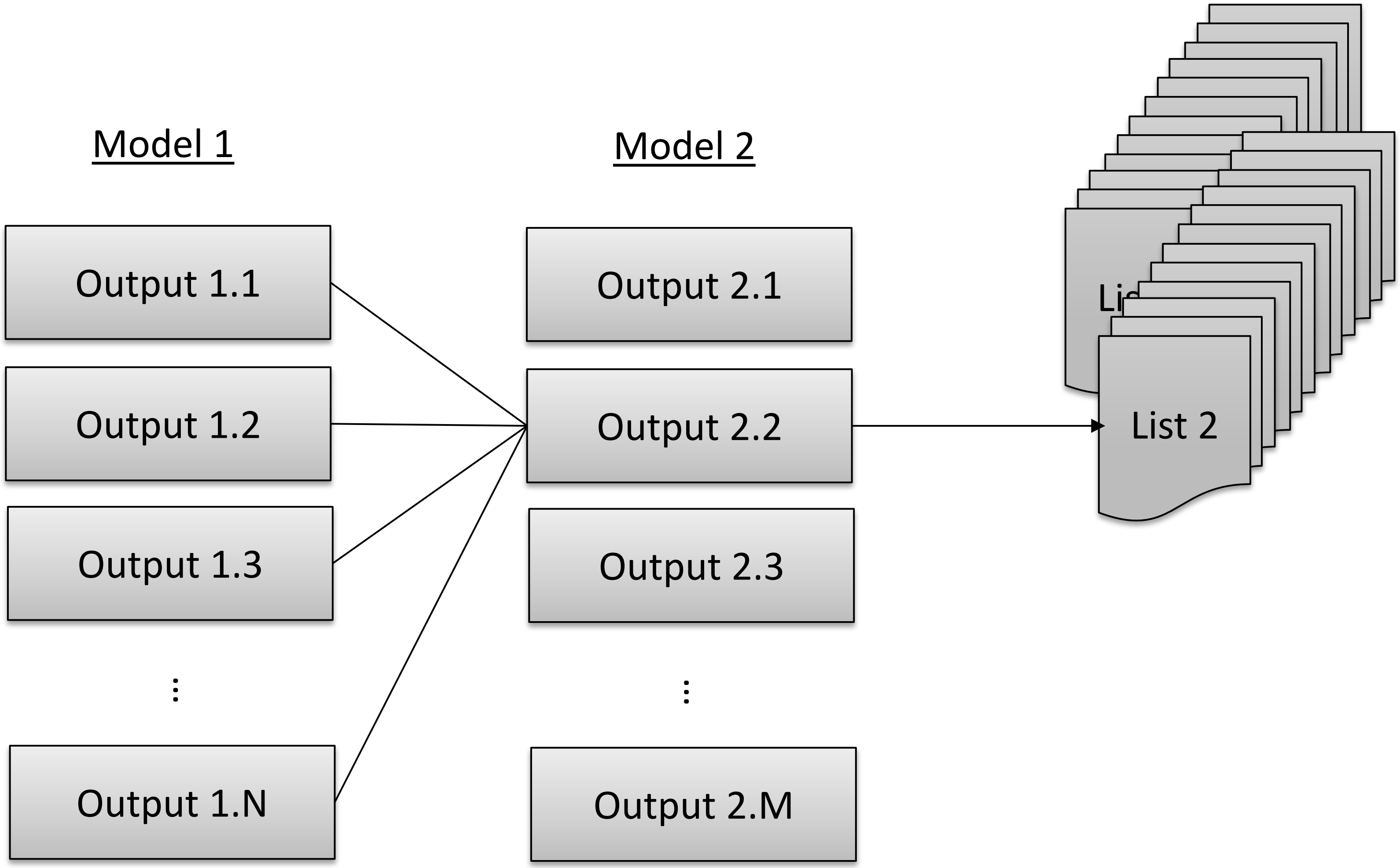
Effect Combination: All Pairwise Combinations



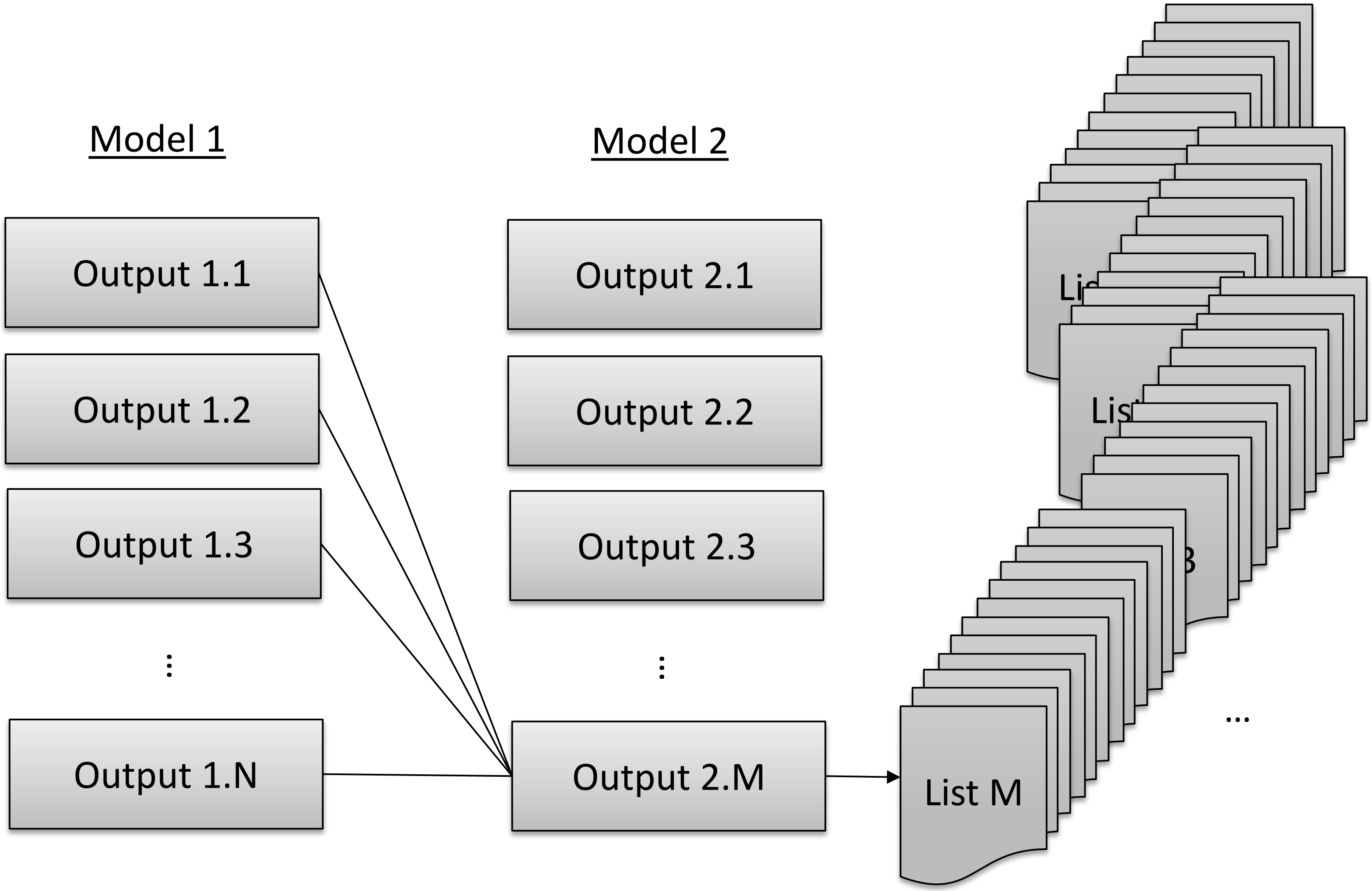
Effect Combination: All Pairwise Combinations



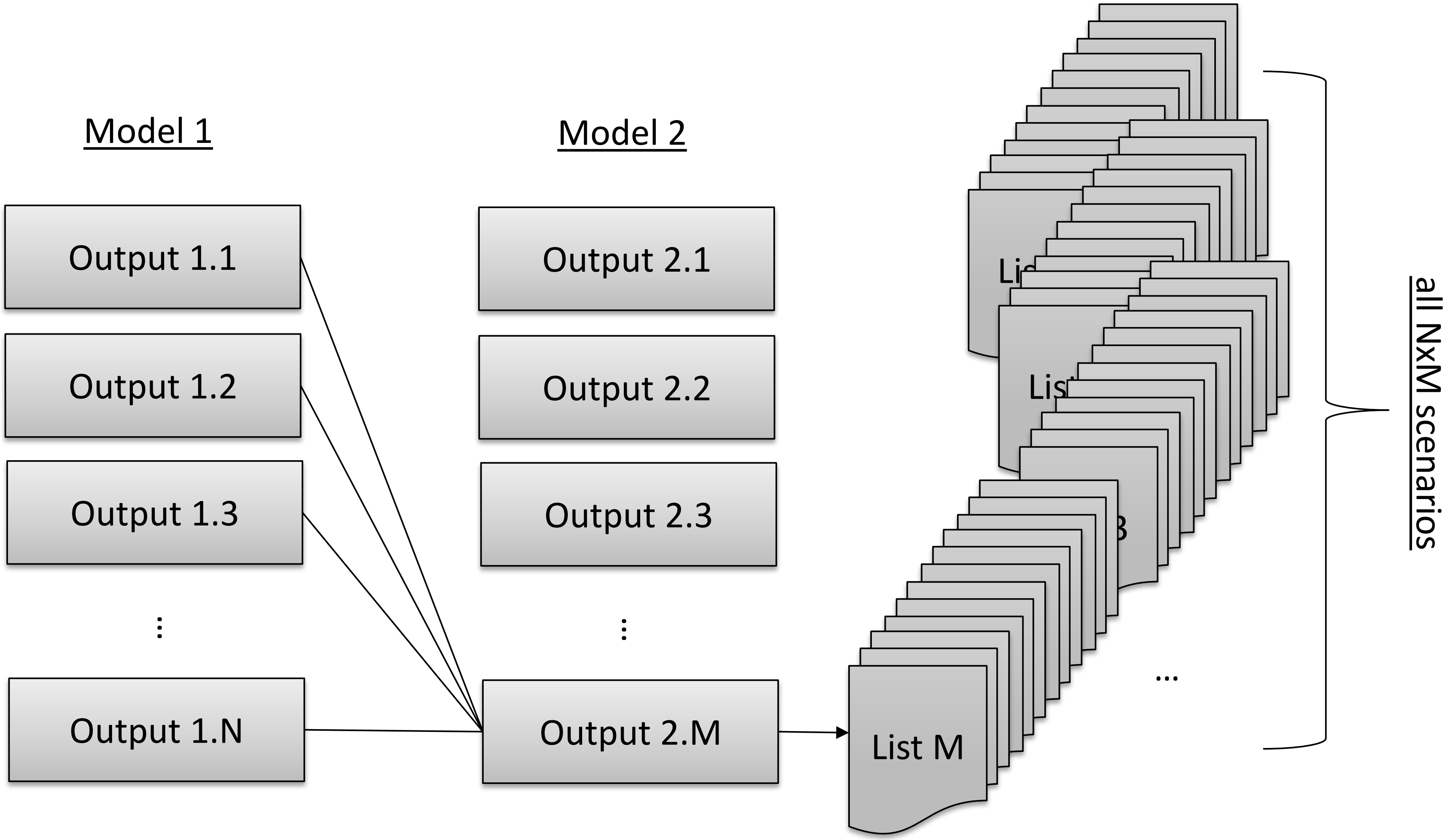
Effect Combination: All Pairwise Combinations



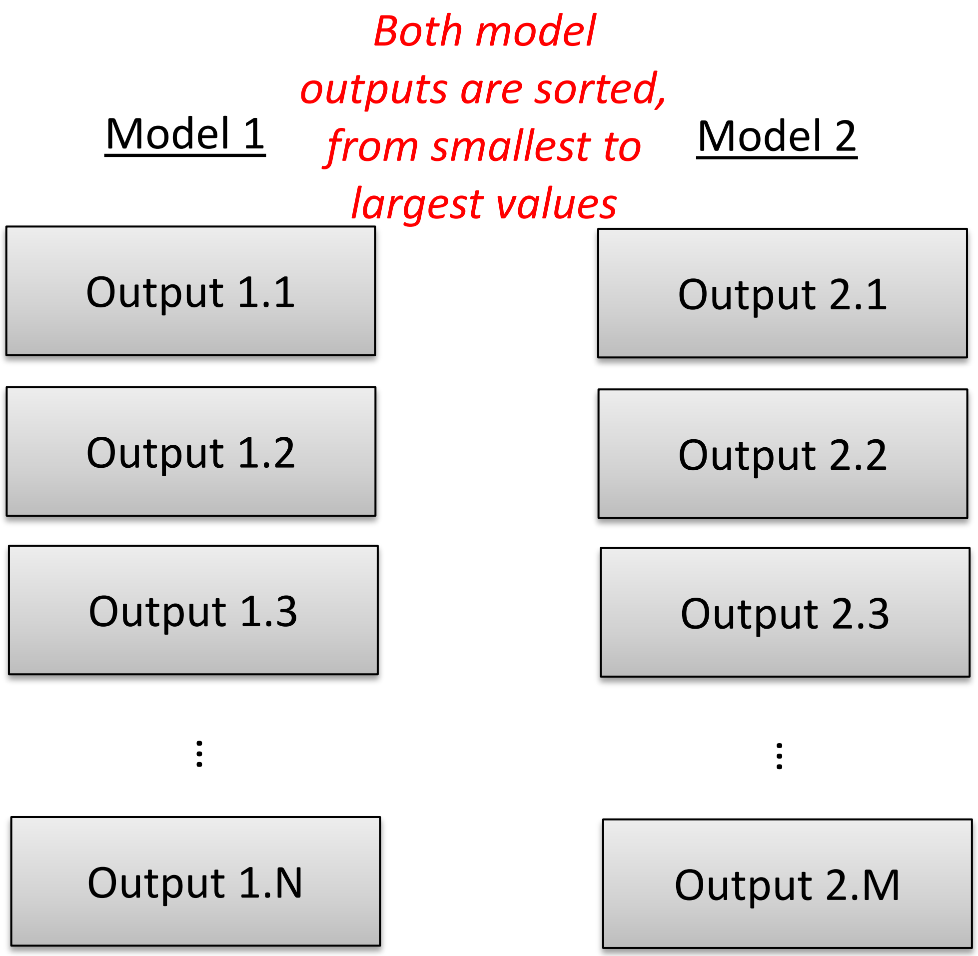
Effect Combination: All Pairwise Combinations



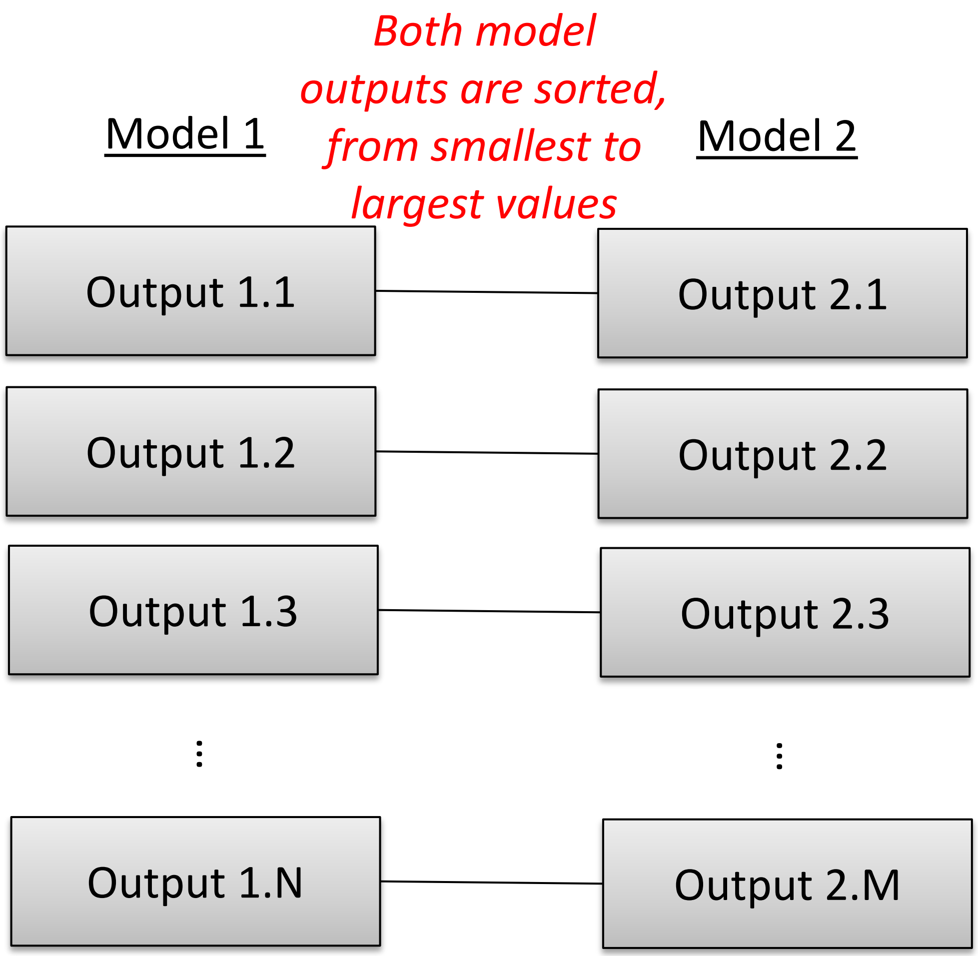
Effect Combination: All Pairwise Combinations



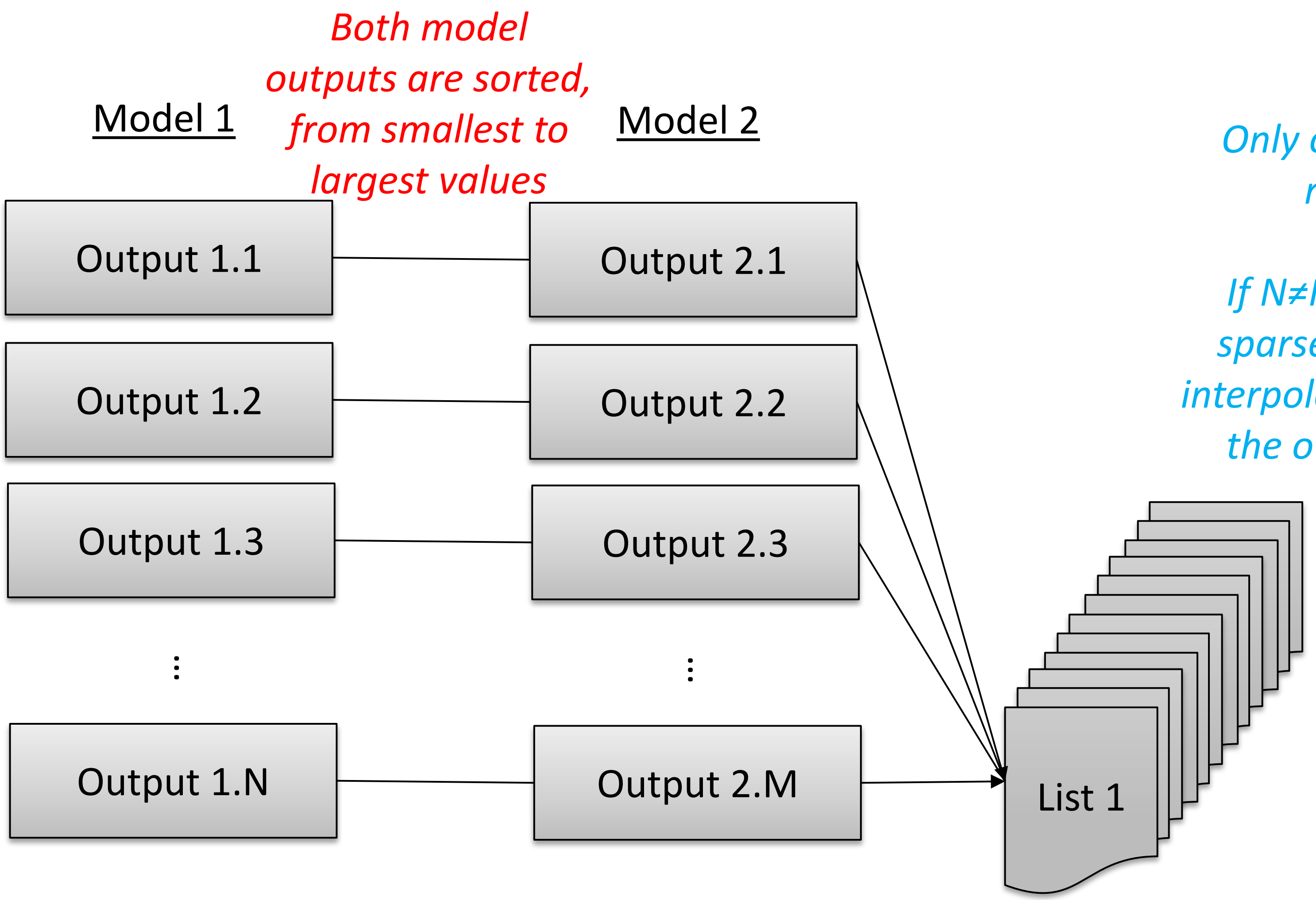
Effect Combination: Ranked Pairwise Combinations



Effect Combination: Ranked Pairwise Combinations



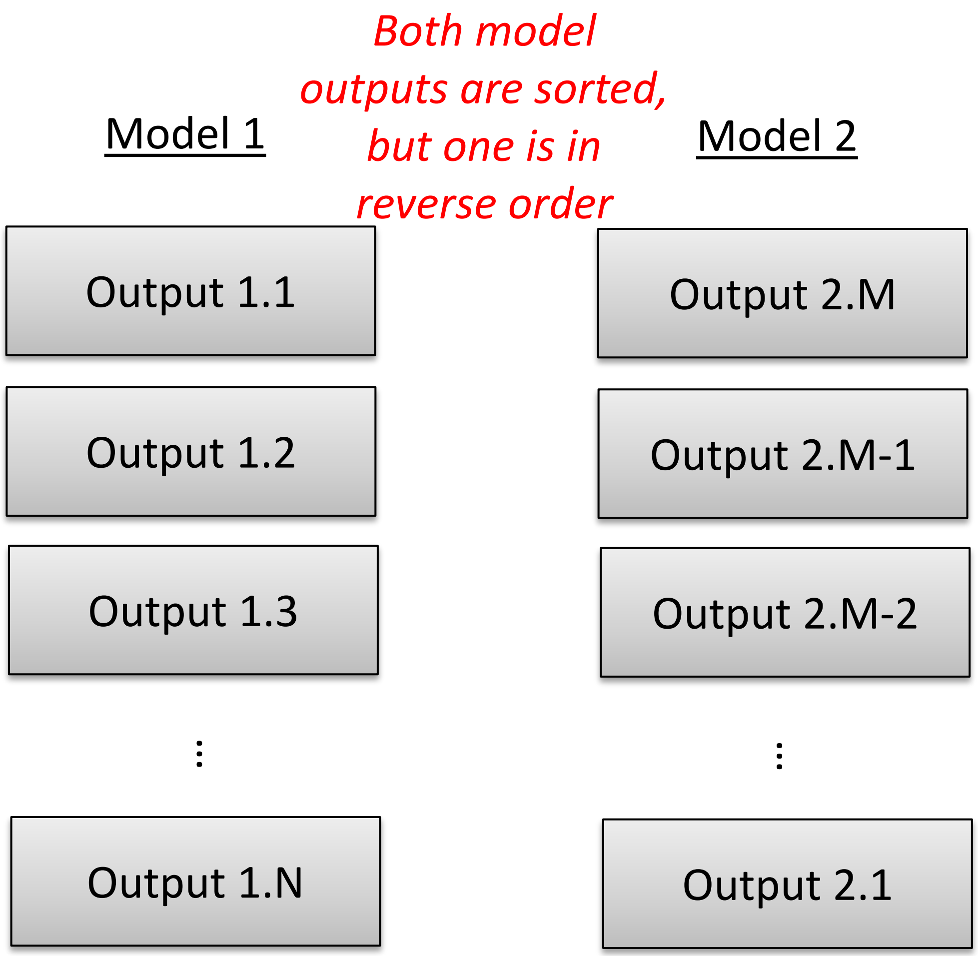
Effect Combination: Ranked Pairwise Combinations



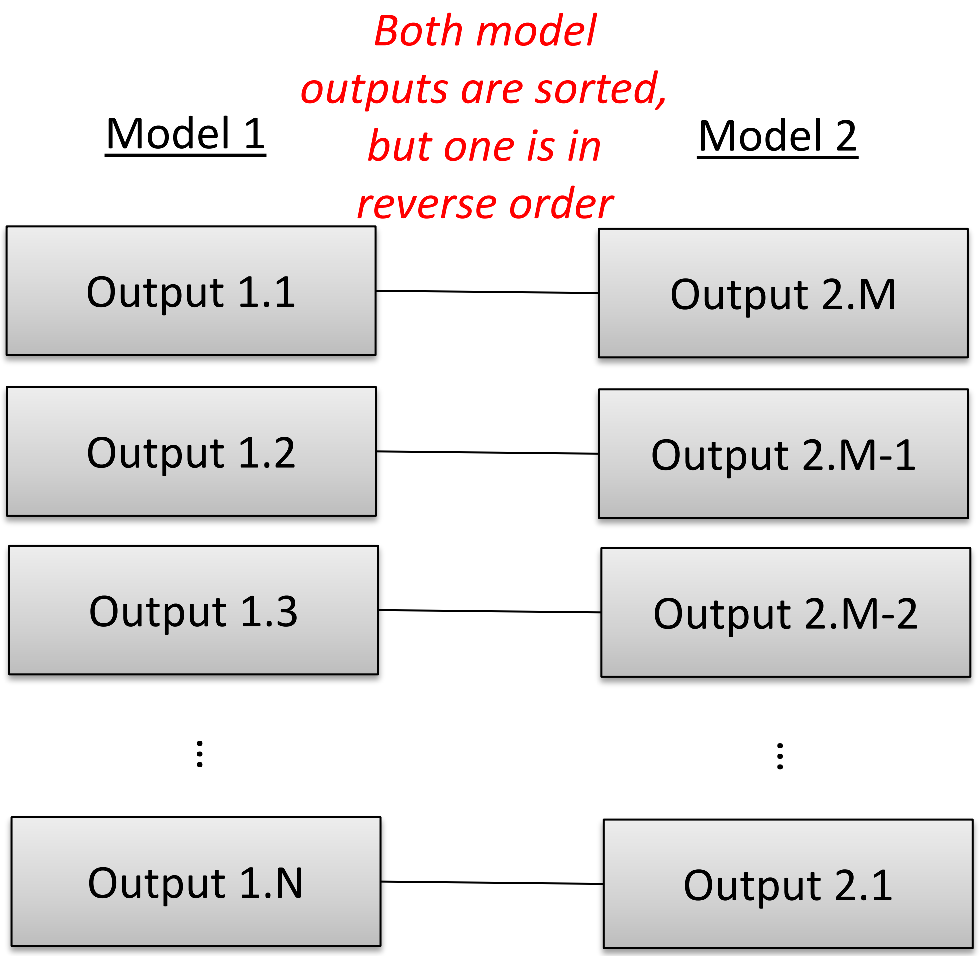
Only one list of N results!

If N≠M, then the sparser dataset is interpolated to match the other in size.

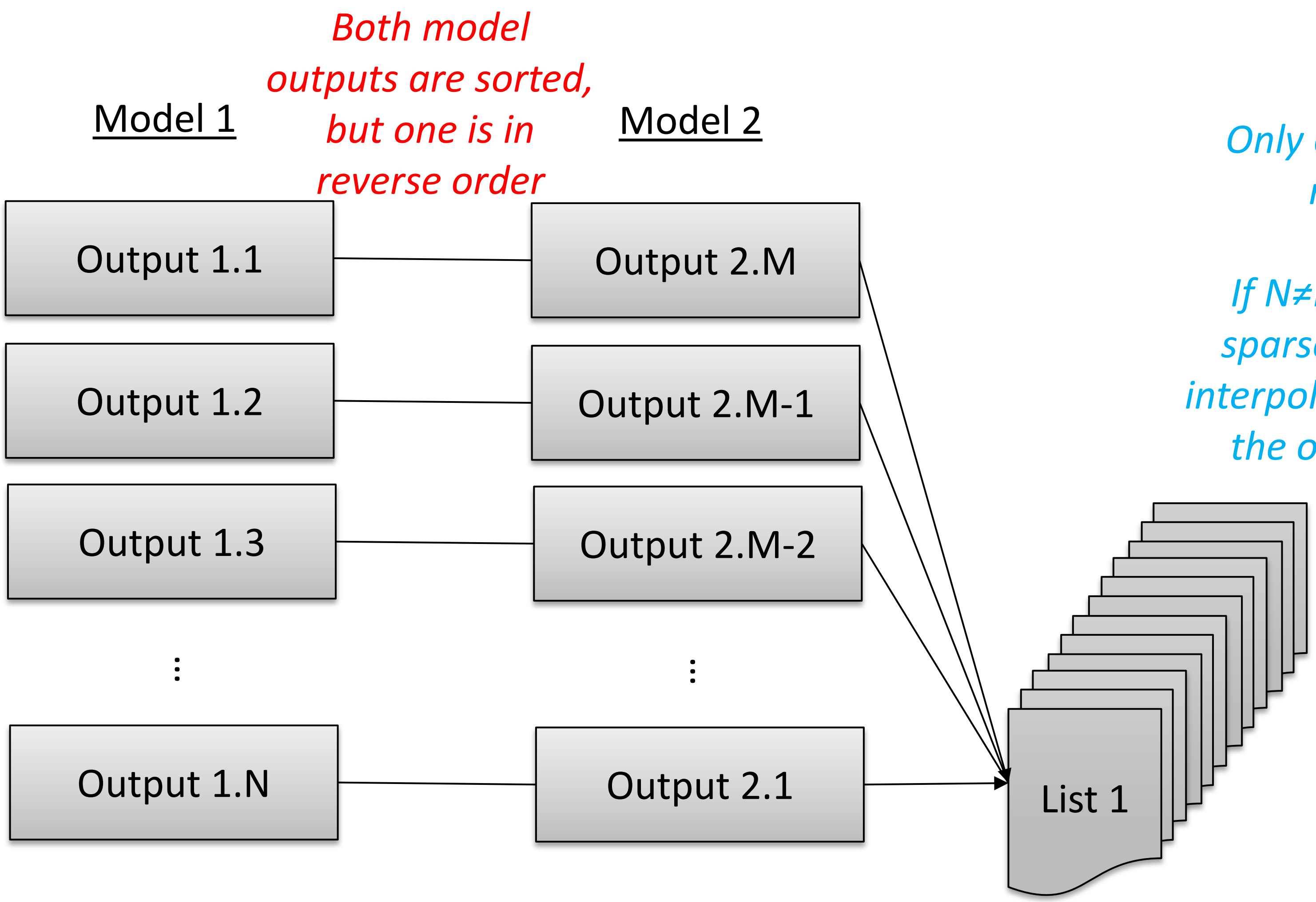
Effect Combination: Inverse-Rank Pairwise Combinations



Effect Combination: Inverse-Rank Pairwise Combinations



Effect Combination: Inverse-Rank Pairwise Combinations



Only one list of N results!

If N≠M, then the sparser dataset is interpolated to match the other in size.