Solar particle analyses: needs, data and analysis tools

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The Solar Accumulated and Peak Proton and Heavy Ion Radiation Environment (SAPPHIRE) Model

- The SAPPHIRE SEP model is intended to provide outputs applicable for:
  - TID, TNID effects (including solar arrays and thin coatings)
  - SEEs: Upsets, Latch-up and Burnout
  - Sensor interference
  - Effects on astronauts
- To achieve this we have models for:
  - Severe environments (either peak flux or worst week equivalent)
  - Cumulative mission fluence environments
  - Extrapolations to low (0.1 MeV/nuc) and high (1 GeV/nuc) energies
- All models are probabilistic in nature with a basis of protons and helium and extensions to Heavy Ions (HIs)

The SAPPHIRE Model Outputs - Overview

SEP species [protons (H); alphas (He)]

Solar Maximum

21 outputs

Prediction periods (0.5 – 35 years)

[5 cycles with 7 active years per cycle]

Particle Energies

Core Model: 5-300 MeV (11 logarithmically-spaced channels)

Extrapolation/Interpolation: 0.1 MeV – 1 GeV (81 Energies)

Confidence Levels

53 outputs from 0.5 – 99.9%

Ch.	Energy (MeV/nuc)		
	Lower	Upper	Mean
1	5.00	7.23	6.01
2	7.23	10.46	8.70
3	10.46	15.12	12.58
4	15.12	21.87	18.18
5	21.87	31.62	26.30
6	31.62	45.73	38.02
7	45.73	66.13	54.99
8	66.13	95.64	79.53
9	95.64	138.3	115.0
10	138.3	200.0	166.3
11	200.0	289.2	240.5

Solar Minimum

25 outputs

Prediction periods (0.5 – 55 years)

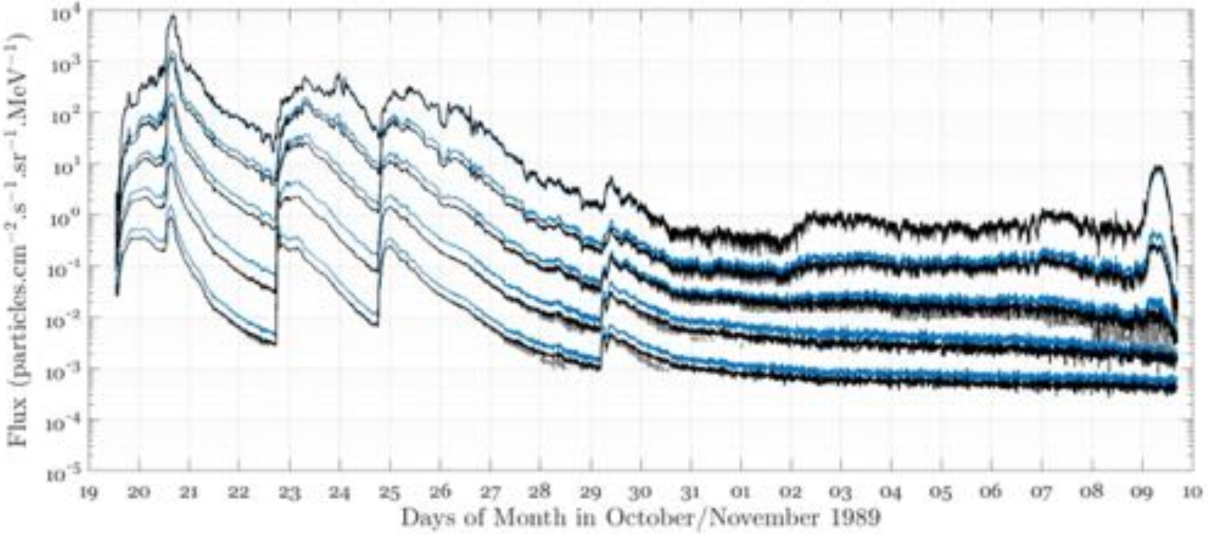
[5 full cycles for statistically sensible implementation]

Model Outputs

Cumulative Mission Fluence;
Worst-case SPE Fluence; SEP Peak Flux

Model Data and Processing

- Newly processed data including solar protons and solar helium (1974-2015)
- GOES(SMS)/SEM/EPS/MEPAD data corrected in energy using IMP8/GME
- Difference of processed data w.r.t. (geo.) mean of bin upper/lower energies

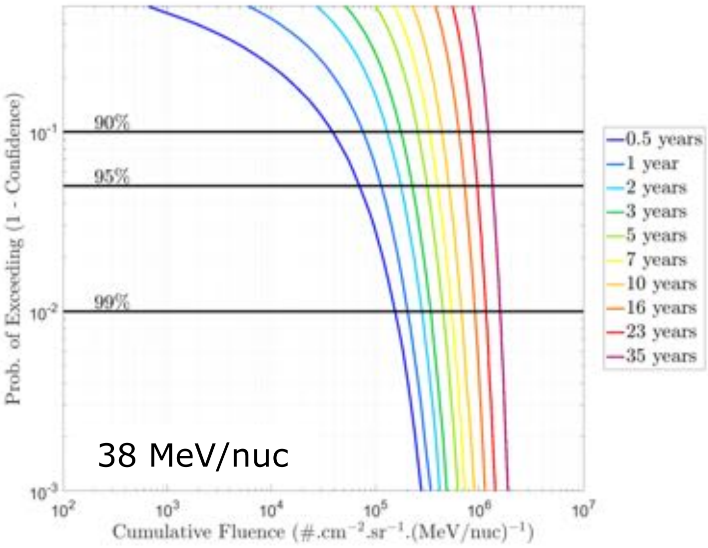


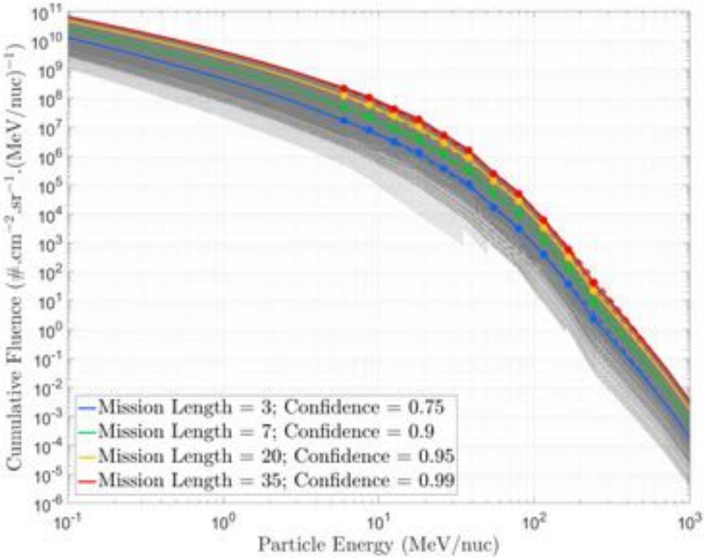
Ch.	Energy (MeV/ nuc)
2	8.70
4	18.18
6	38.02
8	79.53
10	166.3

Underlying Data, resulting from major clean-up, is available at:
http://test.sepem.eu/help/SEPEM_RDS_v2-01.zip

Model for Solar Energetic Helium

- Exponential cut-off power law probability distribution fit to SPEs at 11 energies
- Outputs of cumulative fluence/peak flux/worst-case SPE fluence vs confidence
- Extrapolations based on Band Fit and 4 benchmark cases

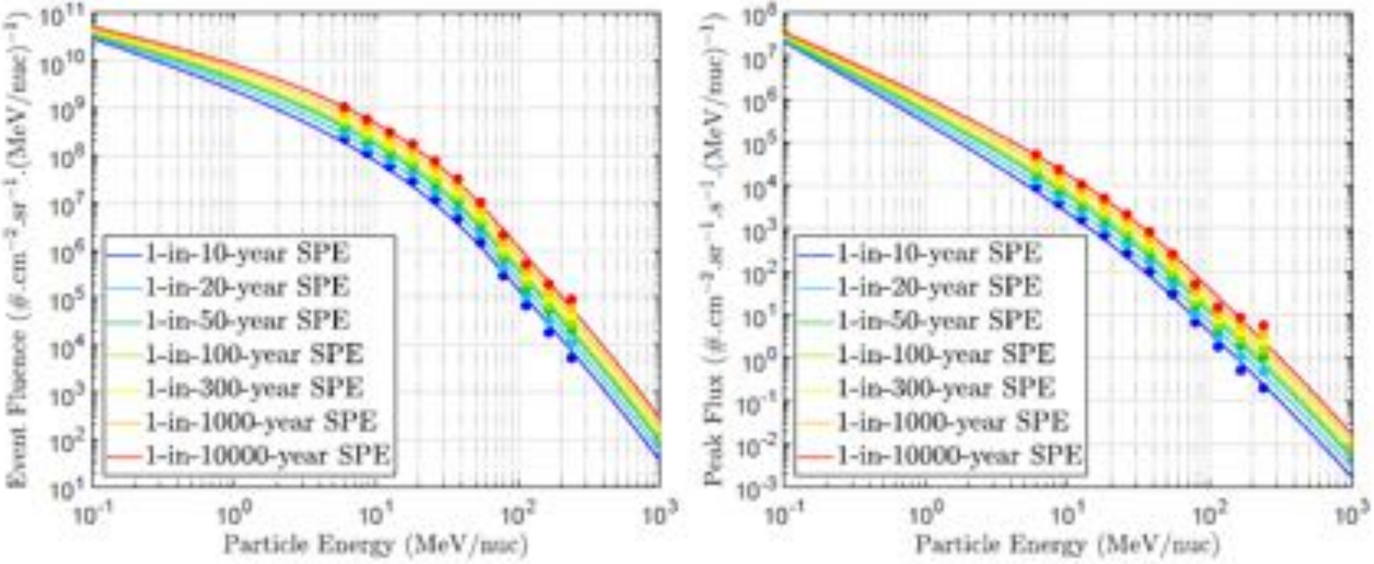




1-in-x-year Solar Particle Events

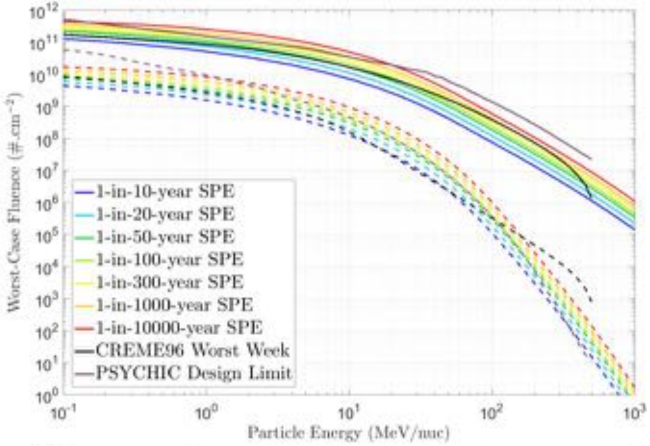
$$\Pr_D(N=0) = \Pr(N=0)^{\frac{D}{x}\times\frac{11}{7}} = 0.3679^{\frac{D}{x}\times\frac{11}{7}} = 1-p$$

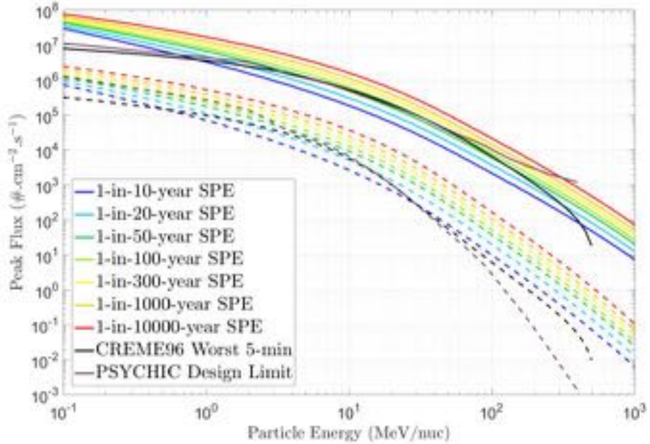
SPE Freq.	model Period (D)	Prediction Prob. (p)	Ideal $p(D)$
10	2	0.2700	0.2697
20	3	0.2100	0.2100
50	3	0.0900	0.0900
100	6	0.0900	0.0900
300	18	0.0900	0.0900
1000	26	0.0400	0.0400
10000	32	0.0050	0.0050



Rare SPEs and Comparisons with CREME96/ESP

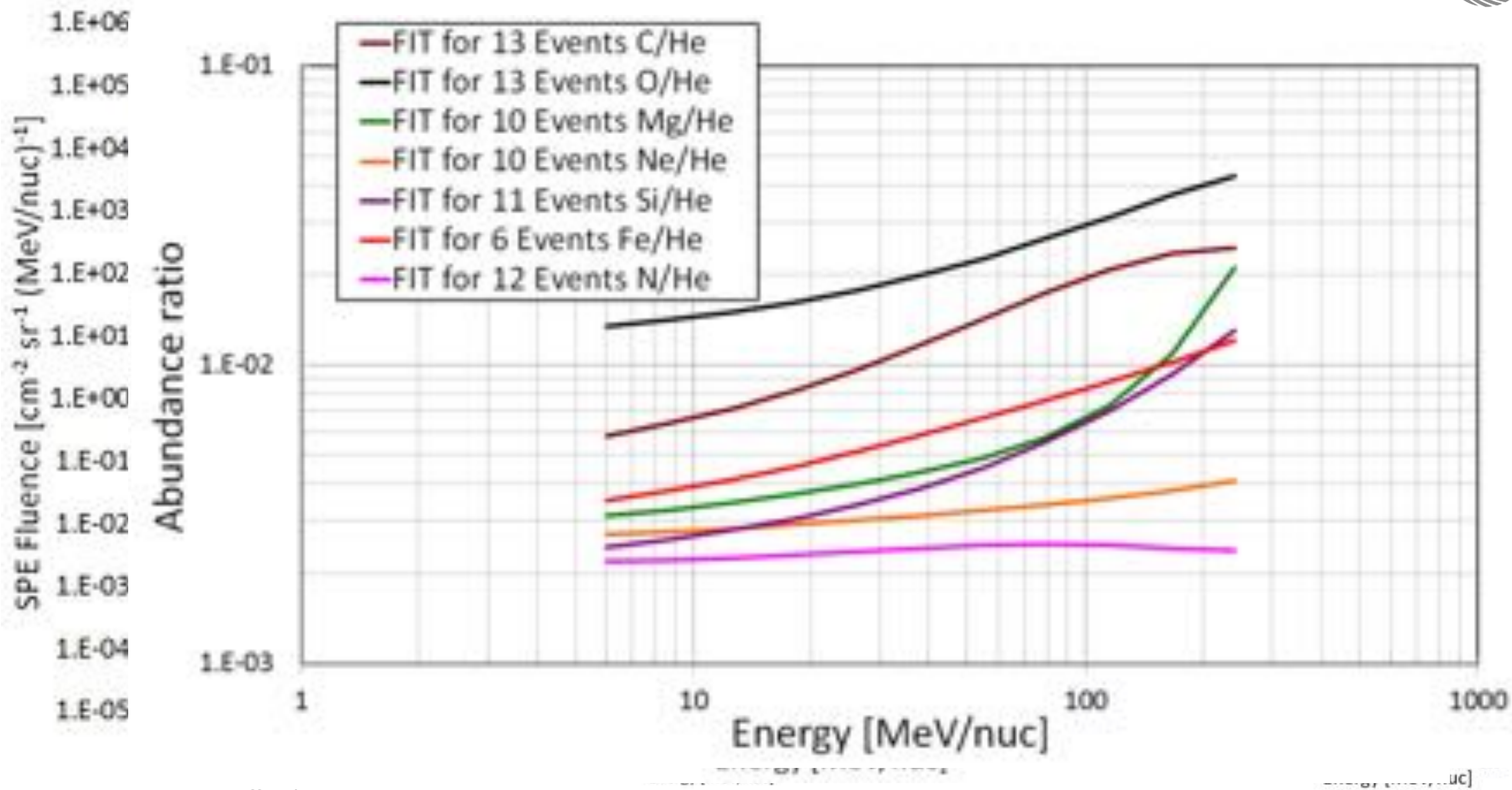
- Method to transform results from confidence-duration into SPEs that occur once in every *x* years
- Protons (solid lines) and alphas (dashed)





- SAPPHIRE, CREME96 and ESP-PSYCHIC show different spectral shapes
- CREME96 Worst week more severe than Worst 5 minutes

Heavy Ion Abundances



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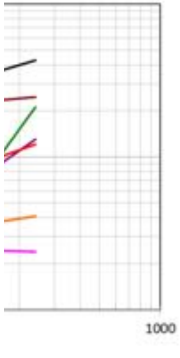
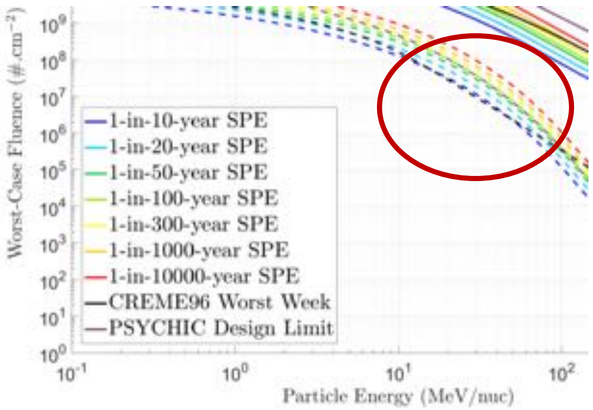
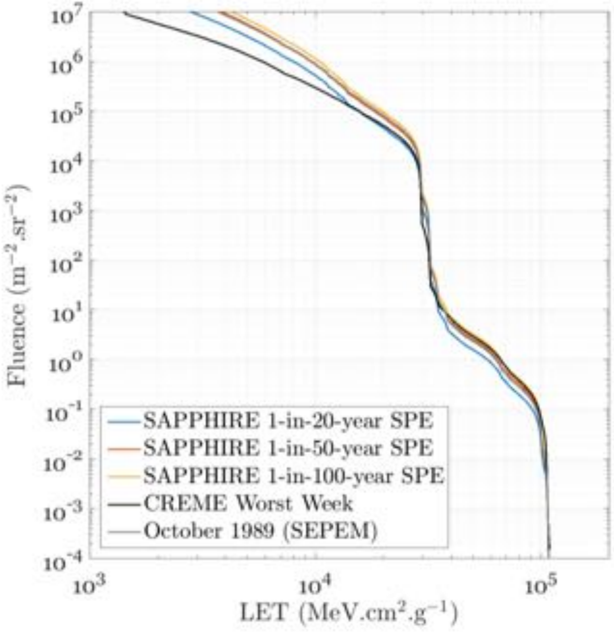


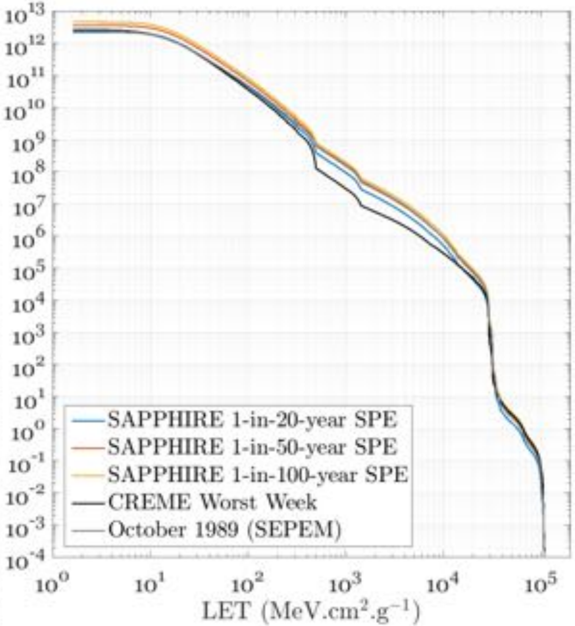
Single Event Effects Quantities (LET Spectra)

- Abundances to helium outputs allows derivation of flux/fluence spectra as a function of particle Linear Energy Transfer (LET)

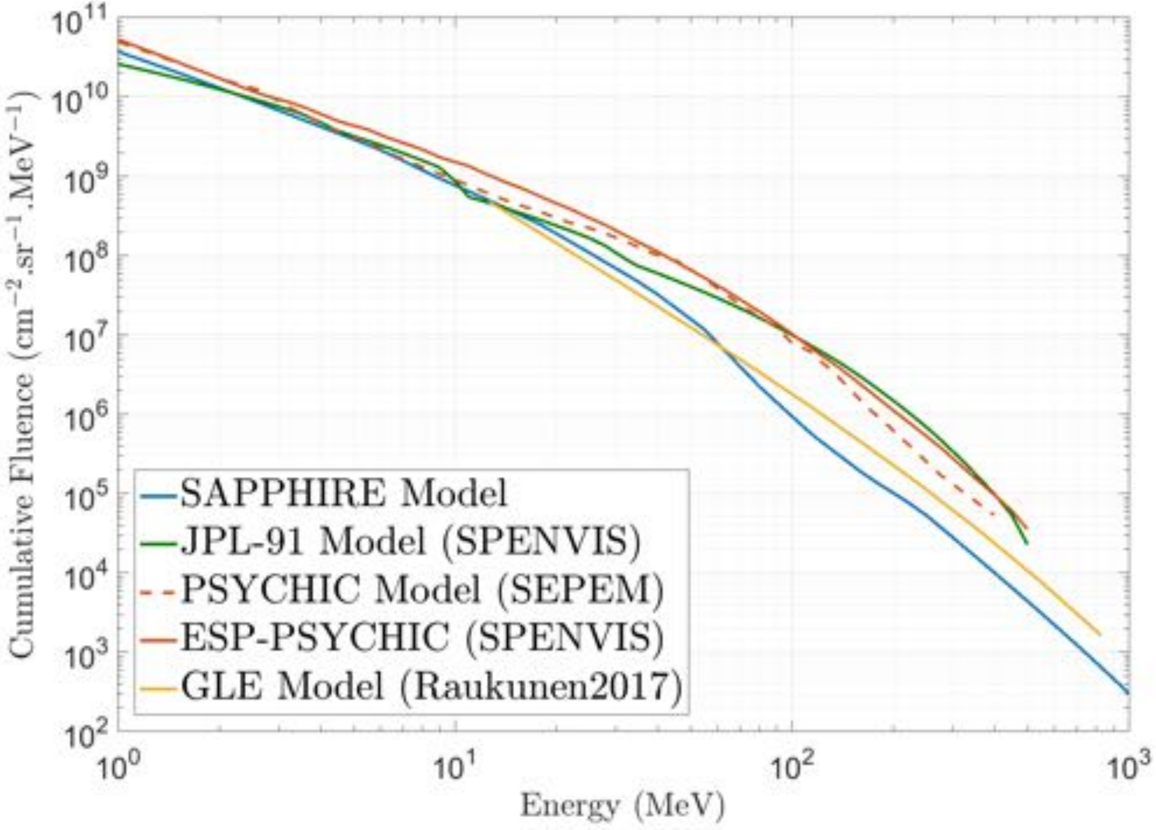
- 1 g.cm^{-2}: spectral differences to CREME96





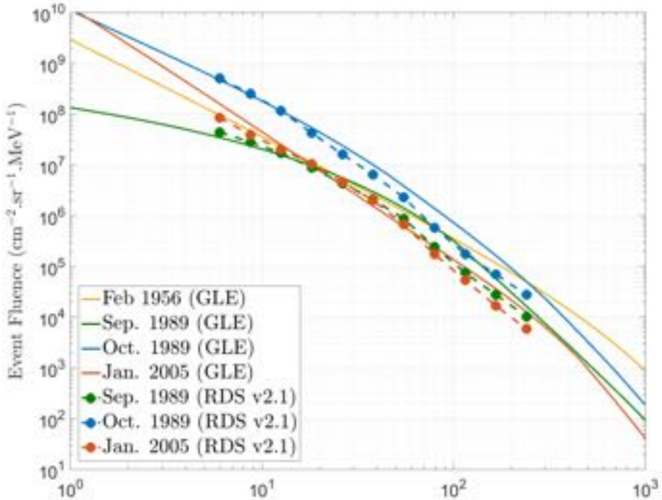


Proton comparisons at high energy



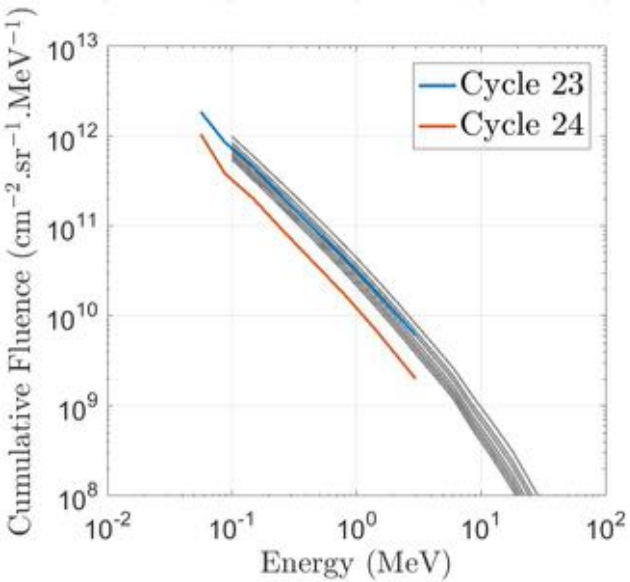
ronments place more
nergy part of spectrum

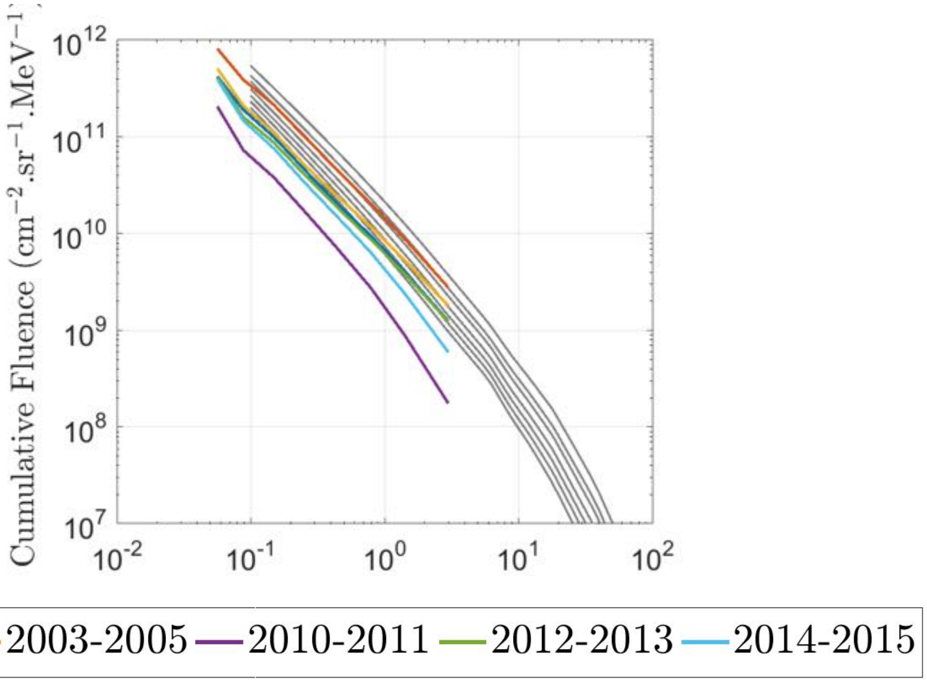
ylka & Dietrich and Raukunen
this in more detail (starting



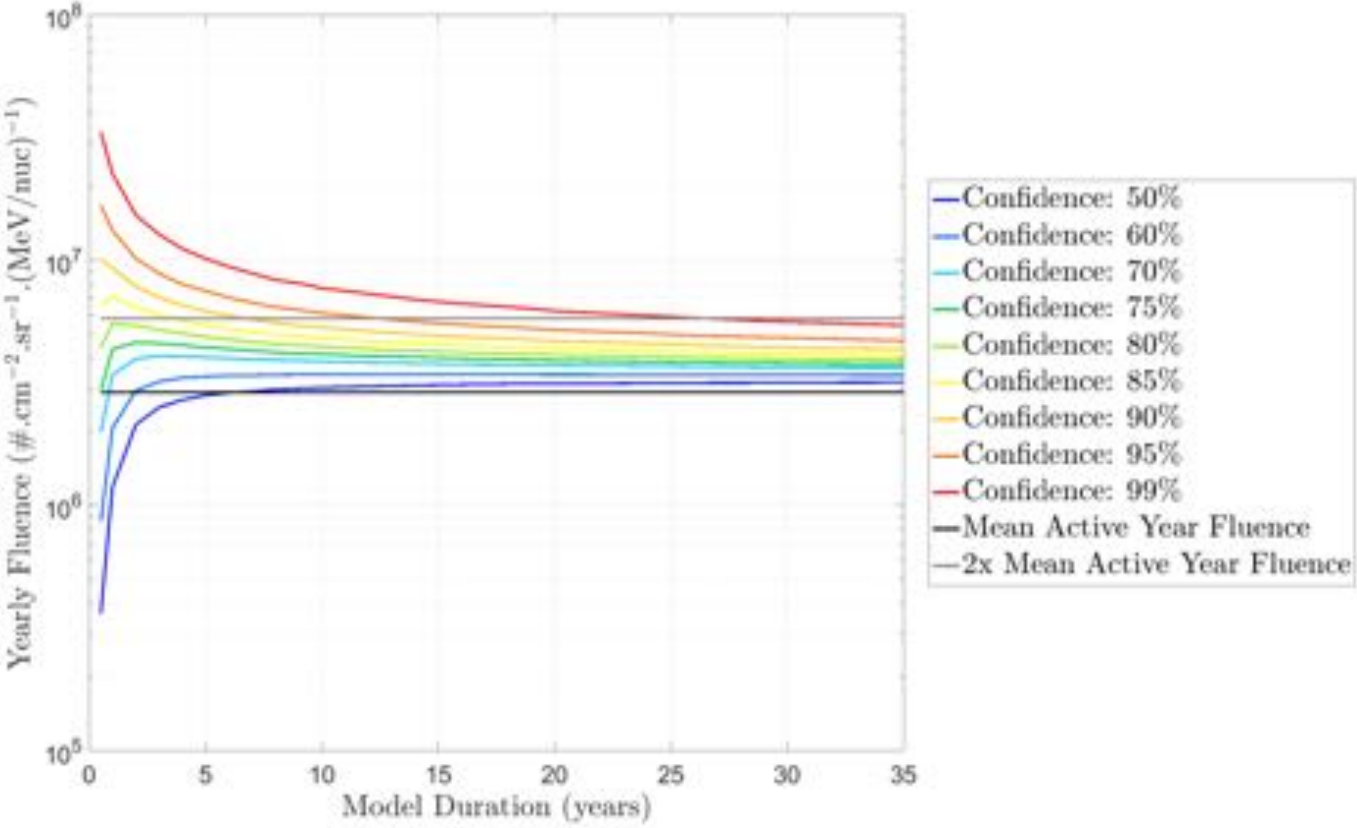
Proton comparisons to data at low energy

- ACE/EPAM data vs SAPPHIRE confidence 50%, 60%, 70,%, 80%, 90%, 95%, 99%
- Could be important for solar cell applications.

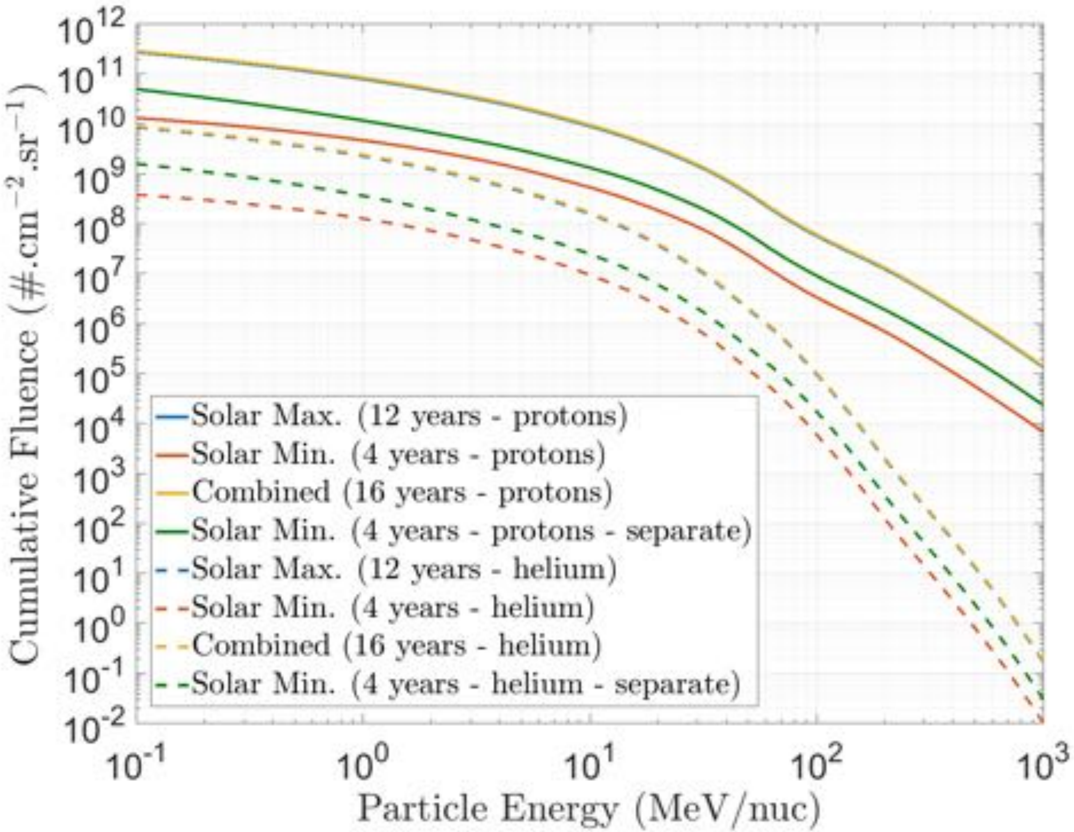




Yearly 35 MeV p+ Fluence from Cumulative Model



Solar Max – Solar Min combined Implementation



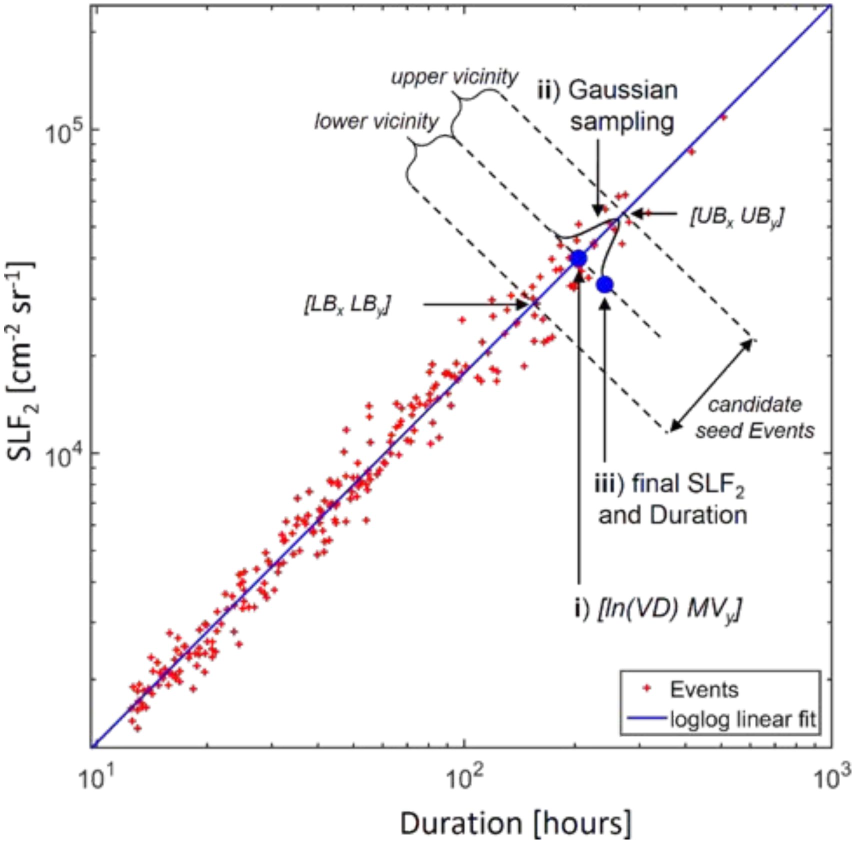
Next Generation of SEP Models

- **Motivation**
  - Combine SEP outputs with RB outputs
  - Produce flux time series not just cumulative fluence or SPE fluence or peak flux
- **Approaches**
  - Use a virtual timelines method but assign each event a flux profile
  - Requires seeding and modification of events from our RDS
- **End Game**
  - Transform both time series into an effect and sum
  - Find some parameter to drive both models (perhaps a dream?)

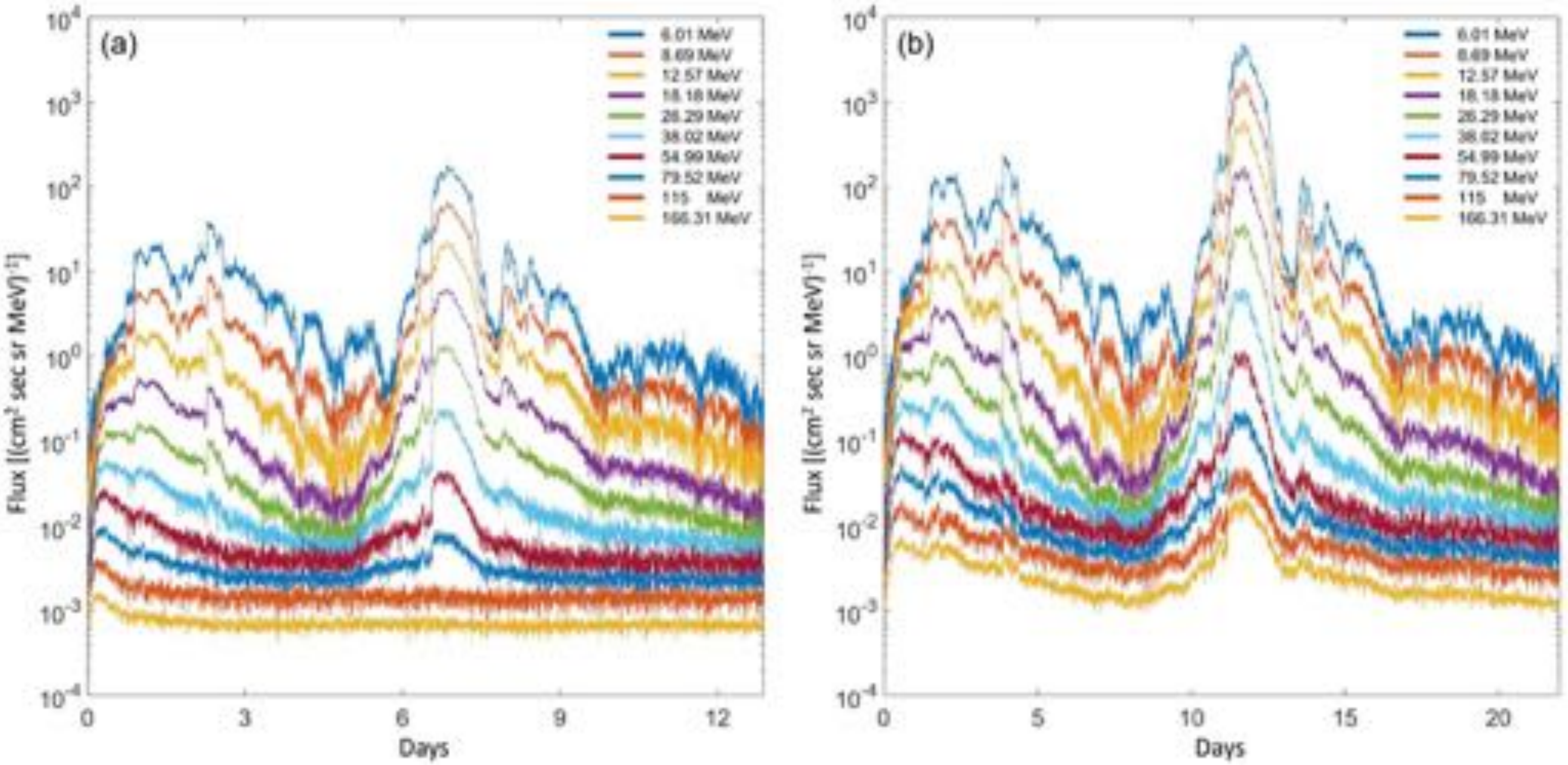
❖ Work by IASA & SPARC in Greece (I. Sandberg, Sigiava Giamini et al.)

The Statistical Basis

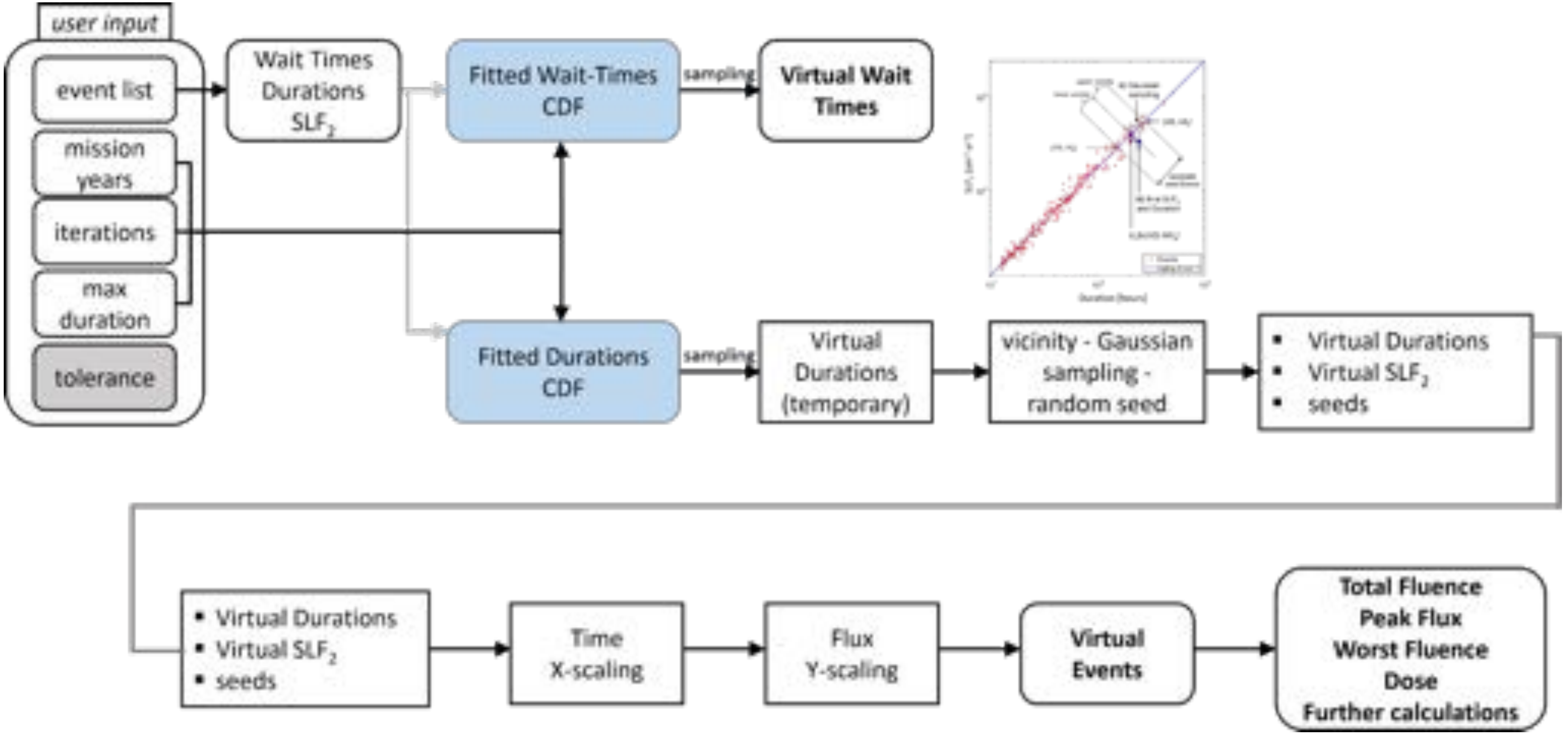
- Find a parameter related to flux to make a regression with duration (done)
- Sample waiting time
- Randomly sample duration or flux-type parameter
  - Find corresponding second parameter
  - Select random close by event to use as a seed
  - Build virtual event
- Repeat a gazillion times (>100,000 years)



Example modified SPE

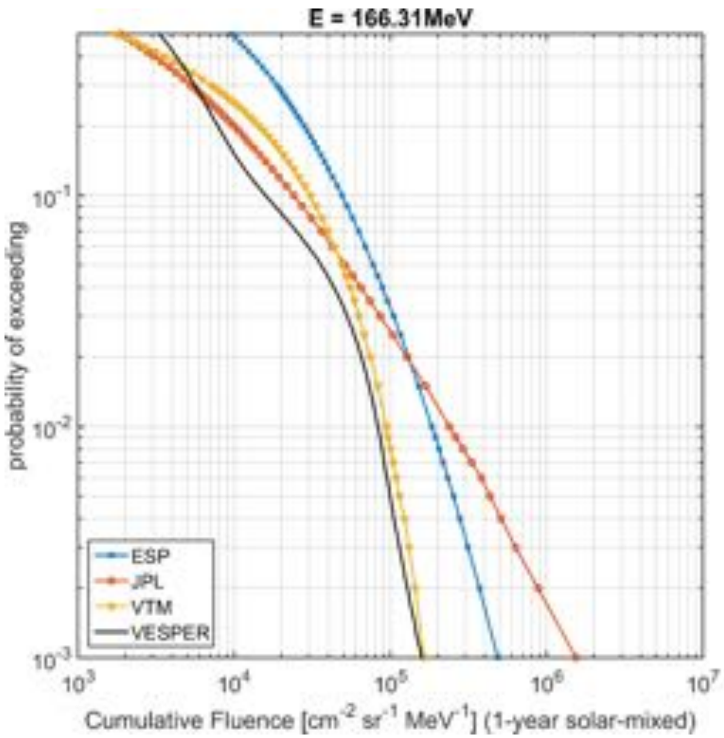


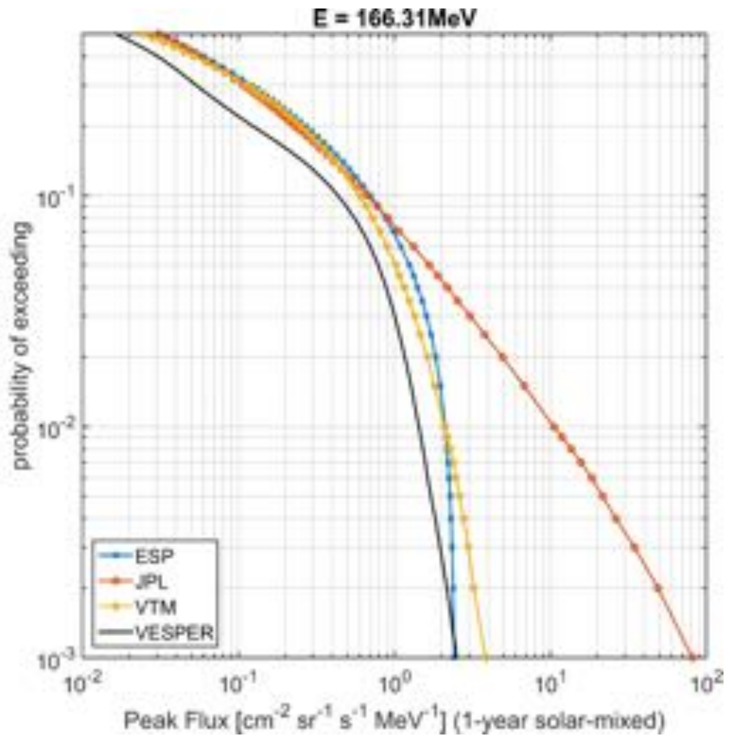
System Logical Approach



Some Preliminary Comparisons

- Good agreement at low energy (especially with SAPPHIRE)
- Some apparent under-estimation of peak fluxes and higher energy fluences





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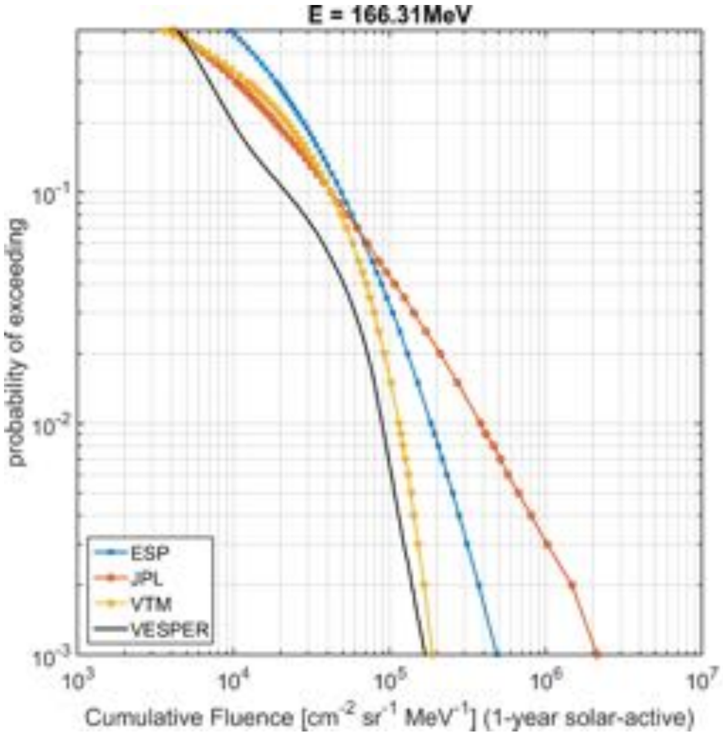
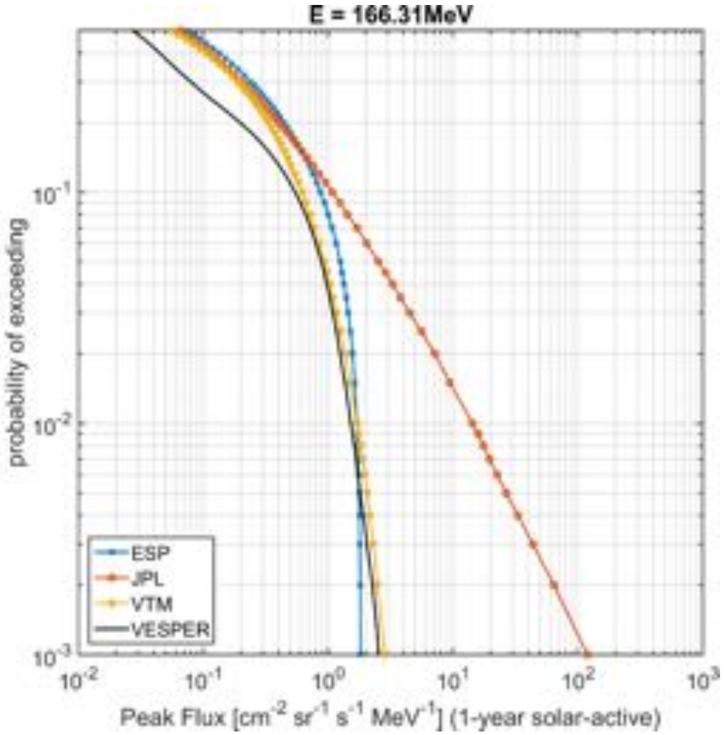
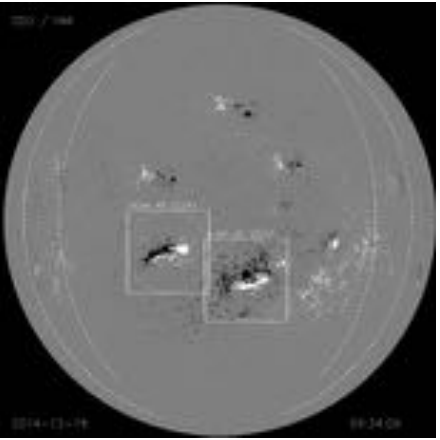
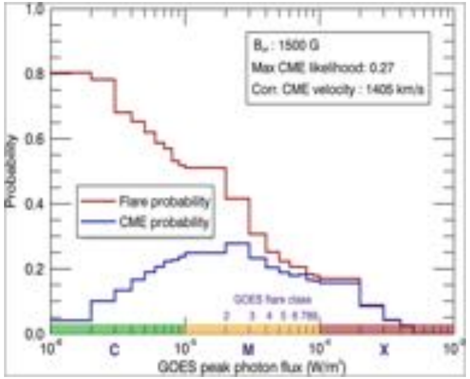
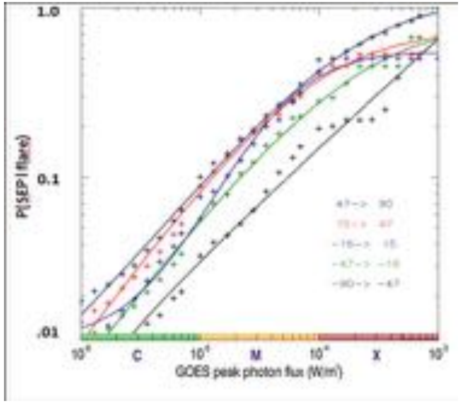


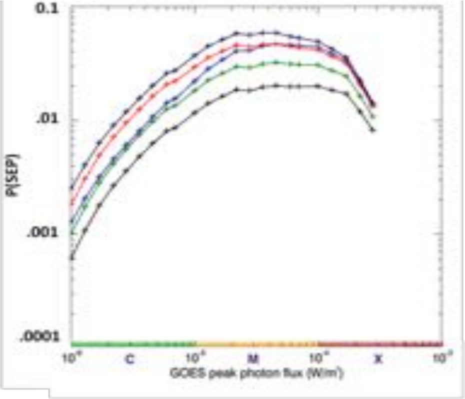


SEP Forecasting (for ESA SSA application)

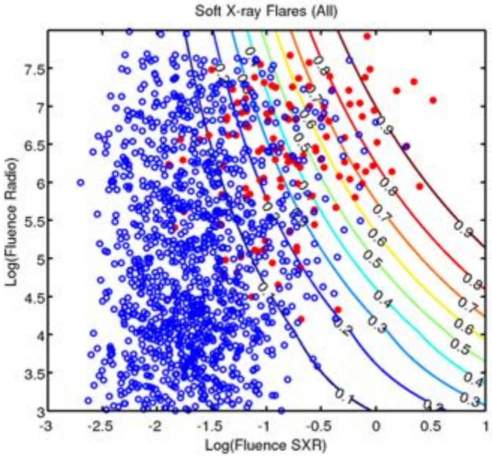








- New Activity to develop SEP Advanced Warning System
- Evolution of FORSPEF, see:
  - Anastasiadis et al., Solar Phy. 2017
  - Papaioannou et al., Jour. SWSC, 2016)
- More system based, leveraging the RDS, a load more data.



Today's SPE!

Concluding Remarks

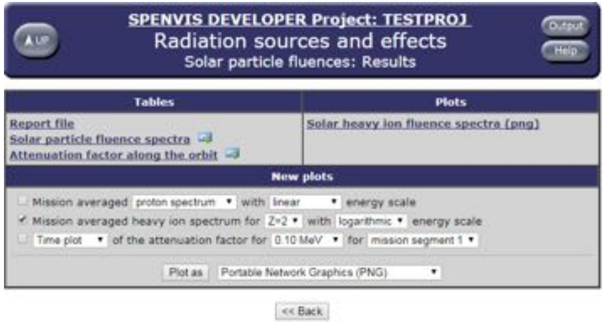
- SAPPHIRE model development is complete
  - Updated solar proton model (JSWSC, submitted)
  - New solar helium model (IEEE, Jan 2018)
  - New abundance ratios for solar heavy ions
- Outputs/implementation instructions on request
  - On SPENVIS in 2017 & OMERE in 2018
- Underlying Data (RDS) is already available at:

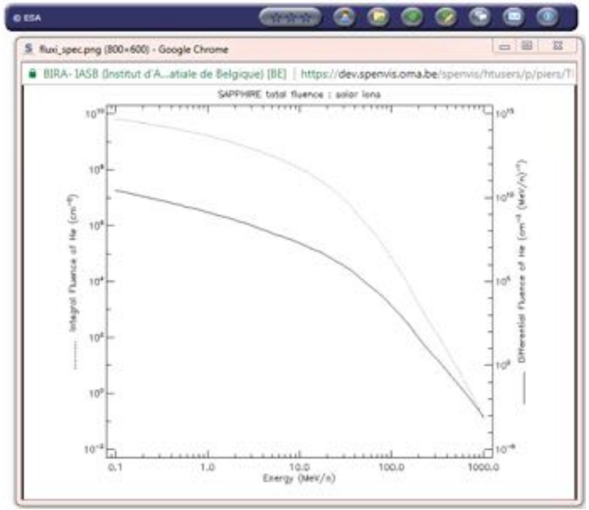
http://test.sepem.eu/help/SEPEM_RDS_v2-01.zip

- And now viewable at:

https://spitfire.estec.esa.int/ODI/dplot_sepem.html

- Next-gen and forecasting on the horizon

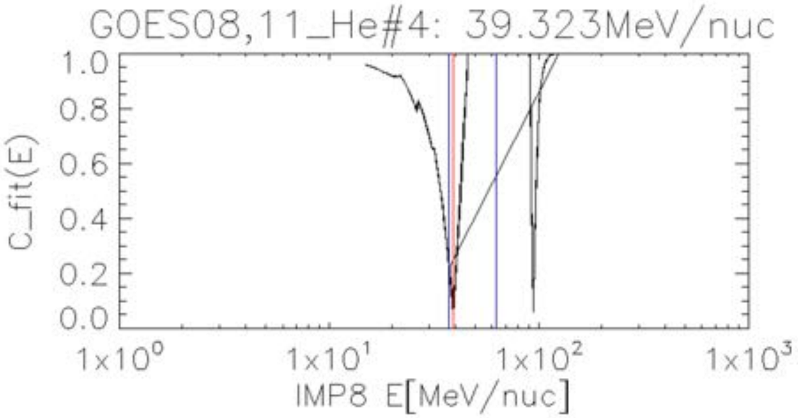


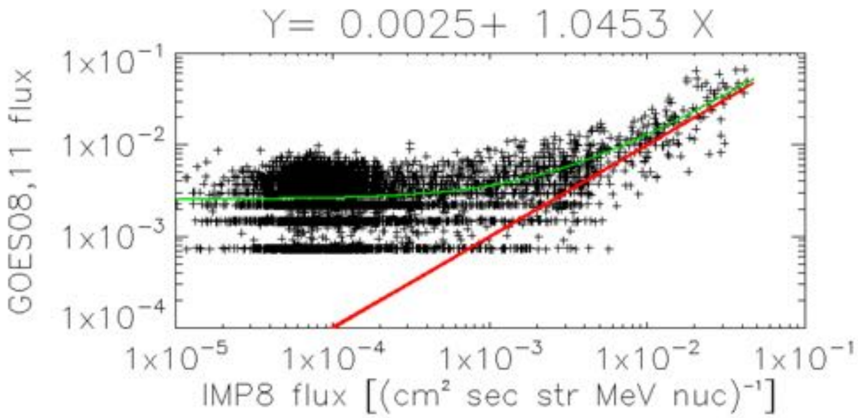


Thank you for your attention!

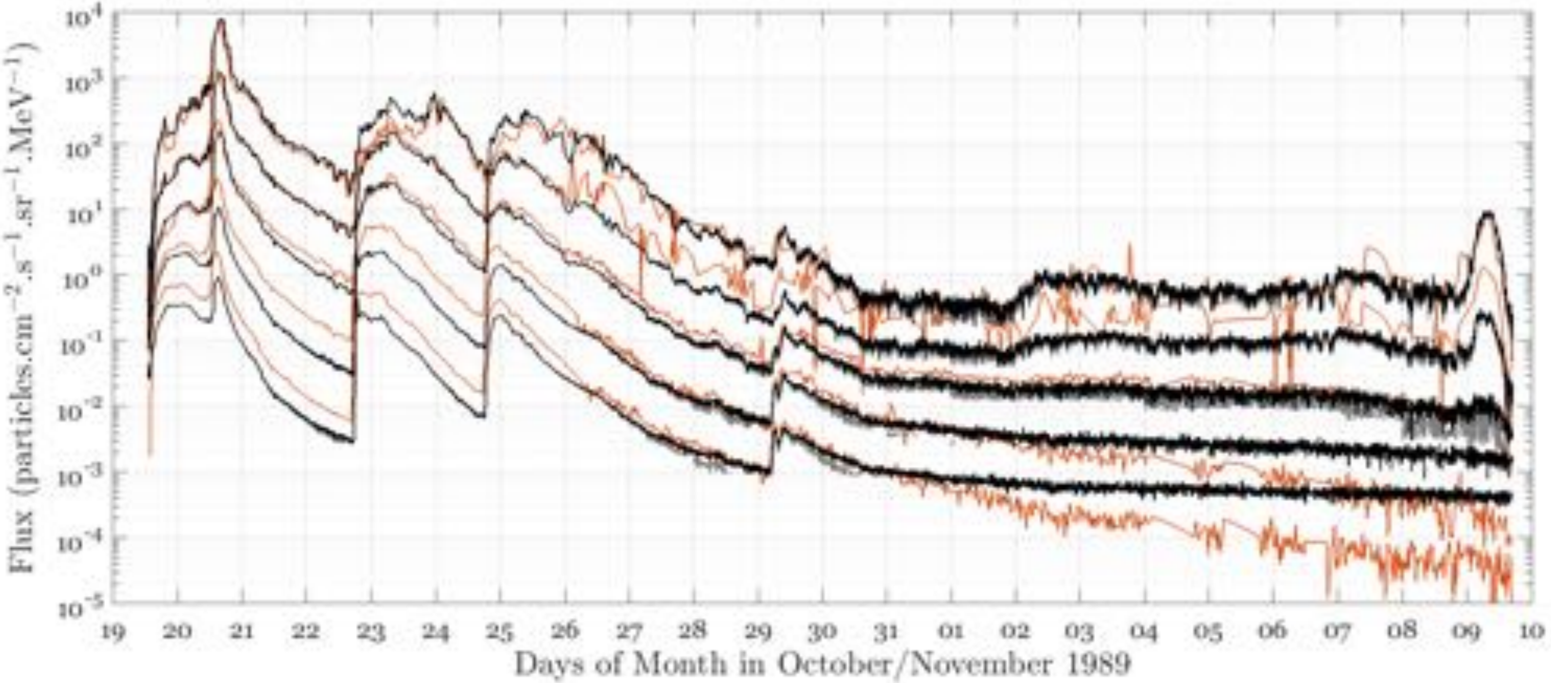
Back-Up Slides

Data Processing – Cross-Calibration

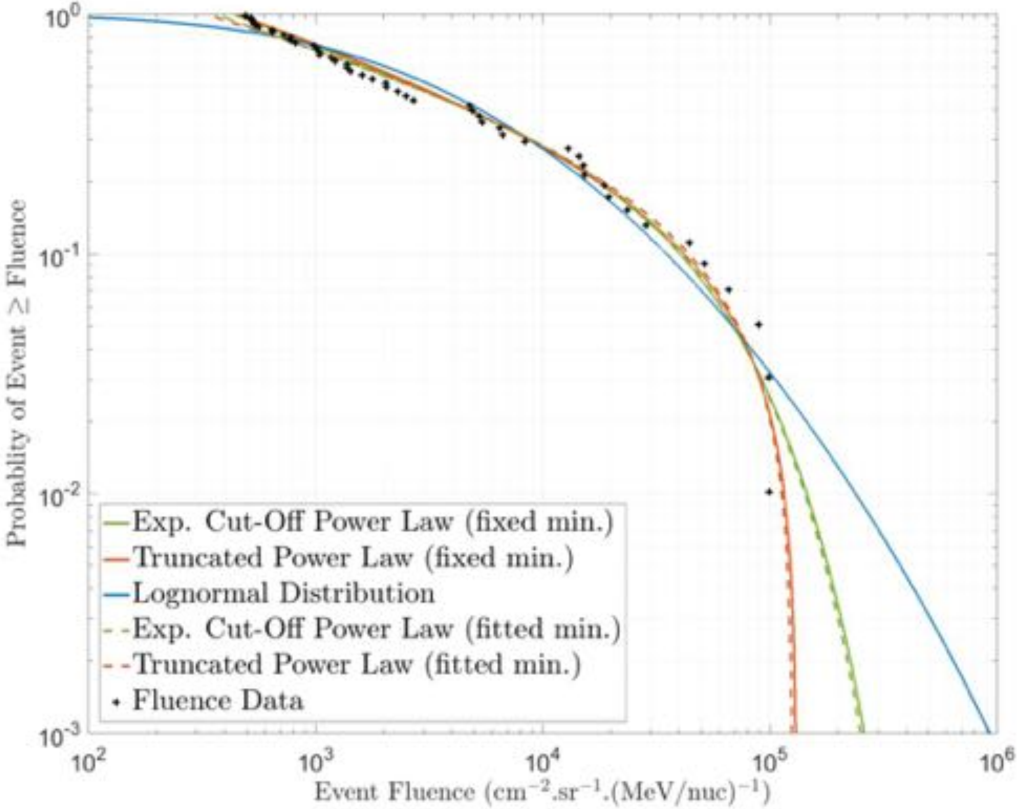




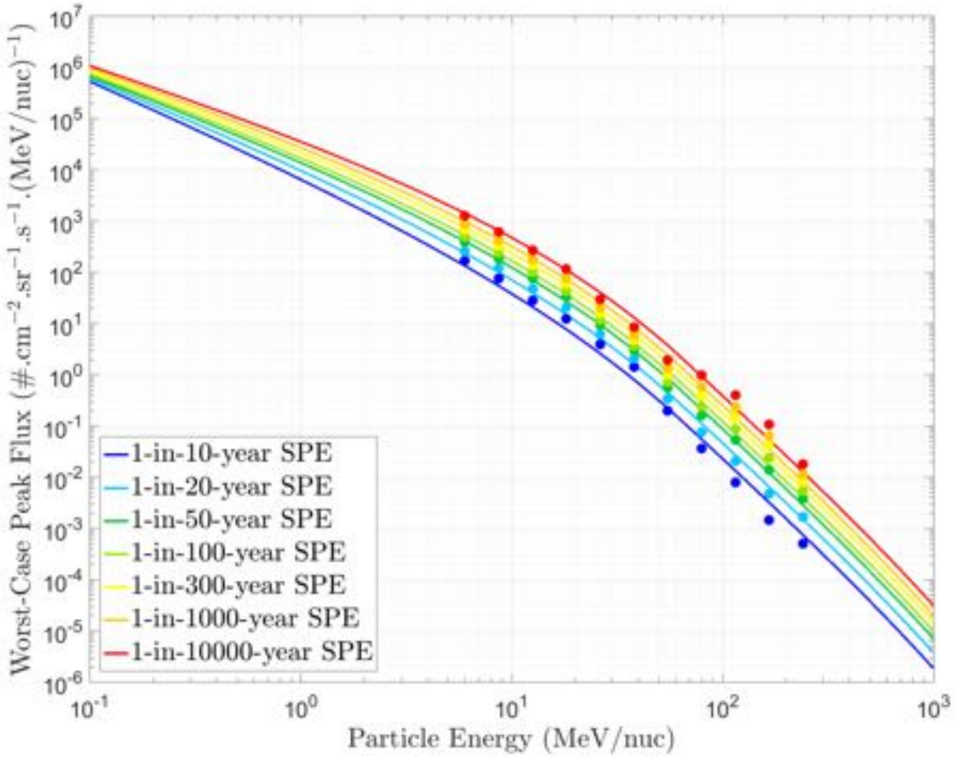
Comparison of RDSv2.1 to PSYCHIC IDS



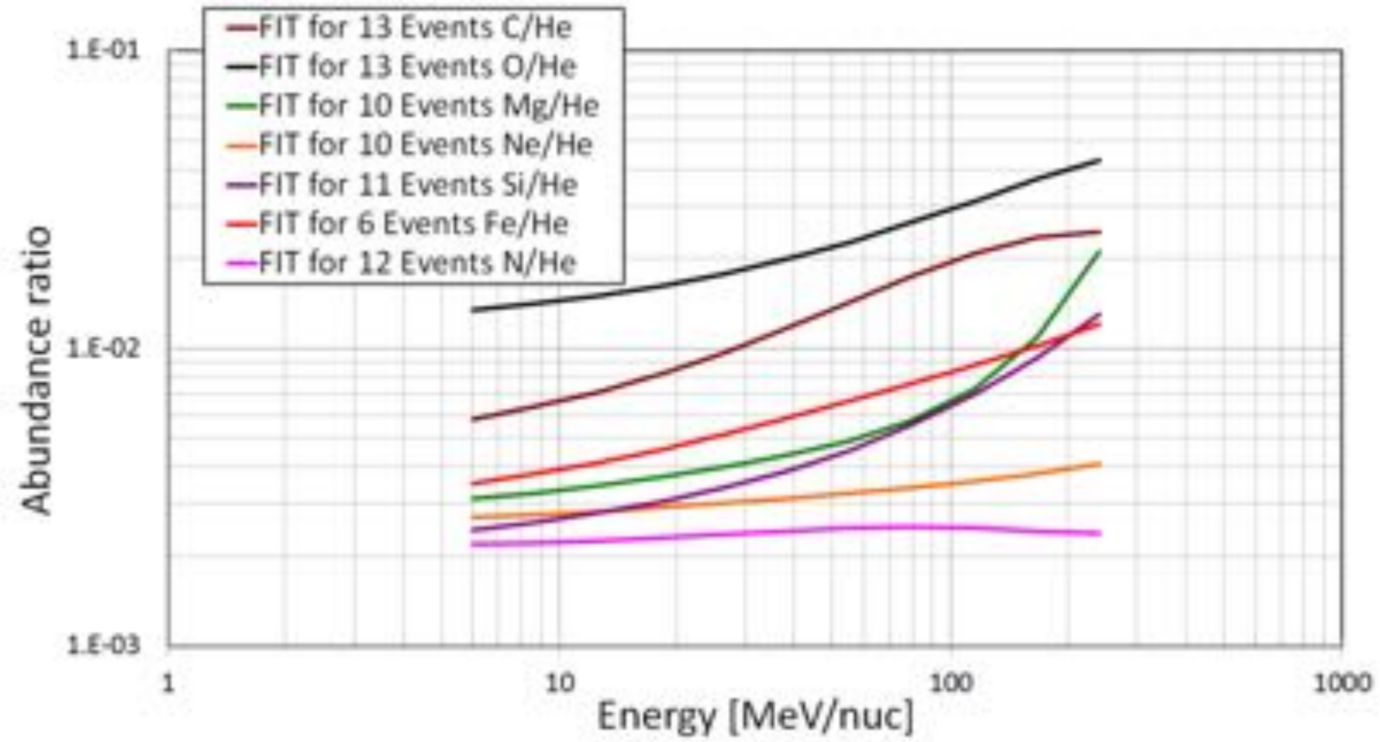
Example Probability Distribution Fit



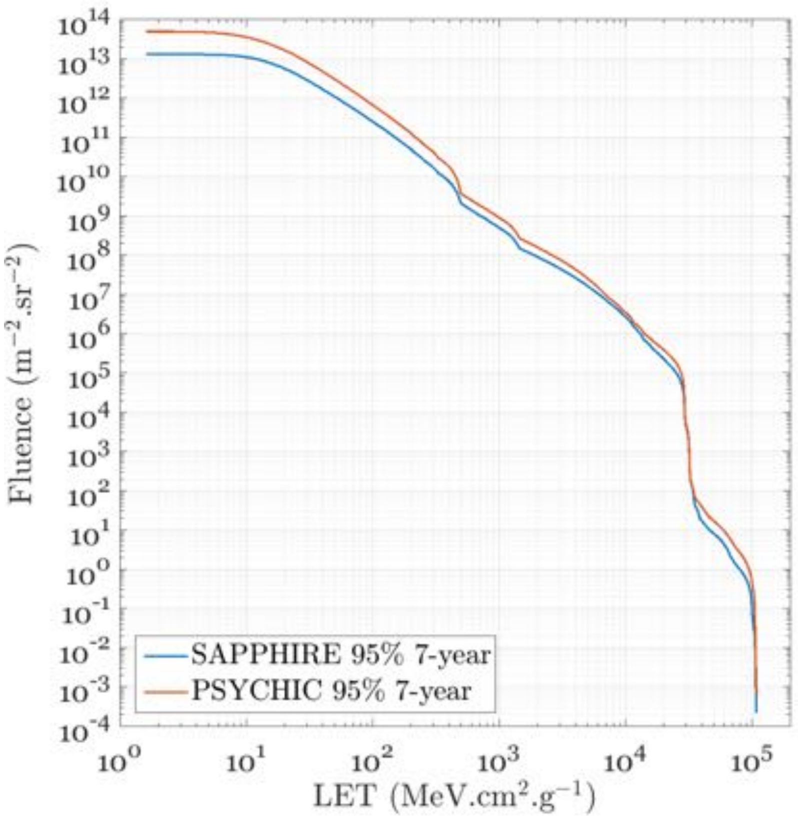
Example Energy Extrapolation



Abundances for 7 elements



Cumulative Fluence as a function of LET



Solar Array Degradation